IST-002057 **PalCom**

Palpable Computing:

A new perspective on Ambient Computing

Deliverable 51 (2.13.3)

Fieldwork: Documentation of work analysis, participatory design and evaluation of prototypes

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RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Integrated Project

Information Society Technologies

1 Table of Contents

2 Executive Summary

This deliverable presents:

1. 16 papers from the PalCom project that have been written since the last review in March 2007
2. 1 paper (5.1) that has been substantially revised since its inclusion in the previous deliverable D.45
3. As an indication of future continuing publication and dissemination, three accepted workshop proposals and two book proposals

These report and reflect progress in the fieldwork, participatory design and evaluation of the following prototypes (in Workpackage order):

- the SiteTracker in landscape architecture
- BlueBio and Overview prototypes for major incident support
- the Memory Stone, to support women and medical professionals in pregnancy
- rehabilitation from hand surgery
- the Incubator for premature intensive care
- Active Surface tiles for physical and cognitive rehabilitation
- the RASCAL prototype for maintaining connectivity in transient locations

In one case (11.1) the paper reflects more generally on the evolving methods for ethnography and interdisciplinarity represented in the project.

An introduction discusses the relationship of fieldwork, participatory design and evaluation to the Conceptual Framework and Palpable Open Architecture, summarises the activities in each domain, and concludes by identifying the distinctive bearing of each prototype on the project objectives. It is revised from the introduction to the previous deliverable D.45 in order to maintain a context for the prototypes while identifying new developments.

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4 Introduction, Summary and Conclusions

The main objectives of fieldwork, participatory design and evaluation in the PalCom project can be summarised as being:

- To identify domains and work practices that are good candidates to benefit from palpable computing.
- To use knowledge of those domains and practices to generate visions for palpable applications.
- As prototypes are brought into use, to identify how needs for palpability actually manifest themselves and how well they are met. Through this, to refine the understanding of palpability in the Conceptual Framework.
- To identify further requirements for palpable applications and for the palpable open architecture, and to contribute to their participatory design.
- To investigate how work practices change as they incorporate palpable technologies. Through this, to contribute instructive use cases to the Toolbox.

4.1 Relationship to the Conceptual Framework and the PalCom open architecture

As described in the PalCom Vision, pervasive computing has taken computing beyond comprehensive systems into a multitude of devices and environments. In some sense this makes the computer disappear and it enables ‘bricolage’ of disparate elements. However, people find it hard to realise the potential of pervasive computing. Which devices, services or resources are the best ones to use in a given situation? How to address breakdown? What to do when surrounded by potentially thousands of services and devices one could use? What when safety or privacy matters? Ubiquitous computing and a high degree of interoperability are worth little if people are unaware of the possibilities inherent in them, or unable to comprehend and realize them.

To engage pervasive computing technologies effectively and creatively, people need to be able to notice and make sense of actual and potential computational processes, states, affordances and dependencies. They need to be able to do so in ways that are appropriate for their specific situation, their level of computer ‘literacy’ and interest. For us, an important element of what is needed is captured by the word ‘palpable’, especially in its meaning of ‘plainly observable’, ‘noticeable, manifest, obvious, clear’.

To achieve palpability we originally complemented the vision of ambient and ubiquitous computing in six areas or challenge pairs:

ambient computing	complemented with	**palpable computing**
invisibility		visibility
scalability		understandability
construction		de-construction
heterogeneity		coherence
change		stability
automation		user control and deference

Our work so far has shown that all these are indeed contributors supporting palpability. ‘Invisibility/visibility’ and ‘automation/user control’ have turned out to be pivotal with ‘construction/de-construction’, as captured in the ‘assembly’ concept, as the instrumental enabler, and ‘inspectability’ as the key quality that they support. It is an equal challenge to maintain understandability and inspectability when scaling up to large numbers of devices and services, as is the related problem of forging coherence from heterogeneous assemblies. Automation, for example in switching between available communication channels, is intended to maintain functional stability through change, but needs to do so in ways that are appropriate and inspectable in context.

This year, in conjunction with developments in the Open Architecture, we have supplemented the PalCom challenges with seven key overlapping ‘properties’: inspectability, assemblability, resilience, adaptability, resource awareness, experimentability and multiplicity. Not all – and arguably not any – of these are unique to PalCom; many systems, for example, address the issue of resilience. But all of them, we argue, apply in distinctive ways in the context of palpability, especially when taken together. *Inspectability* addresses the tension between information showing and information hiding. It recognises that both will be necessary for the same information under different circumstances, and provides the handles whereby both can be achieved. It recognises that things will go wrong and will need active and sometimes improvisational repair. It uses primarily the HGraph mechanism to optimise the structure of layers, and facilitate drilling down the layers. *Assemblability* recognises the importance of making and breaking diverse connections between devices and services, in the expectation of continued reformations. It recognises that making and managing connections will sometimes be done by software and sometimes by people. It calls for tools for making the structure and operations of elements and connections manifest in ways that are appropriate for software services and for different kinds of user. *Resilience* is to do with making ‘palpable substitutions’ when things go wrong. It recognises that the system’s and the user’s perspective on functional equivalence may not coincide, so that the degree of automatic substitution that is appropriate, and whether changes should be notified or made visible, will vary. Some services may be dedicated to providing the resilience of others. *Adaptability* is closely related, but is oriented to the normal, expected though often unpredictable dynamicity of ubiquitous and mobile systems in use. *Resource awareness* covers familiar issues to do with discovery, but also recognises that beyond simple presence and absence, the dynamic properties and operation of devices and services will sometimes need to be known and manipulated. *Experimentability* goes to the heart of palpability because it connects with people’s indigenous strategies for making the material world knowable: ‘prodding’ and ‘tinkering’ to reveal its properties and behaviour. Experimentation is part of the route from present-at-hand, through exploratory-to-hand, to ready-to-hand. *Multiplicity* emphasises the gregarious character of palpable systems: the environment is inherently open rather than well-defined, with a potentially large and diverse population of devices, services and actors, with much overlap and sharing of services.

These point to the fact that people make palpability in the course of their activities. Materials, environments, tools or technologies may be ready-to-hand, that is ‘invisible’ in focussing on the job at hand, because they work well and we are used to them. At the other end of the spectrum, they may become present-at-hand, that is ‘visible’, demanding the attention of our senses, for example because they fail to support the work we seek to accomplish. Thus palpability is not a property of materials, environments, tools or technologies in themselves. It arises and is negotiated in engagement with them.

Achieving palpability in engagement with computing systems is especially difficult, however, because they are highly complex and abstract, immaterial and outside people's perceptual range, unfamiliar, and 'powerful but dumb': systems can be immensely powerful, flexible, dynamic and interactive but they are inherently unaware; systems can sense but not make sense. This makes interaction between people and computers fragile and prone to 'misapprehensions' on both sides. Palpable computing seeks to break into these cycles by making sophisticated causal relations, responsibilities, processes, failures, successes, services, data structures, affordances, (in)compatibilities, functions, emergences, activities, traces, possibilities, system actions, relations, dependencies, communications, changes, etc. available to the senses (see the elaboration of the differences between human, conventional computing, and palpable computing approaches to interaction in the 'Palpability' deliverable D.53).

Because palpability arises in use, however, it cannot be very straightforwardly 'designed in' to the technologies. This means that an iterative and empirical approach is required in which, through fieldwork and participatory design, the technical means to allow palpability to emerge are devised, calibrated and tested in particular use settings, in the hope and expectation that practical solutions will generalise to many other settings.

The papers in this deliverable show why there is a great need for palpable computing in their respective domains of work. As one might expect from the interconnected character of the six palpability challenge pairs, each prototype domain has a bearing on most of them. However, each prototype also poses unique challenges and we exploit these to inform the design of application prototypes and architectural support that begin to materialize palpable ubiquitous computing. The distinctiveness of the prototypes in this regard is explained in section 4.10 below. By focusing on the specifics of each particular use domain, generic functionalities can be addressed to a degree of depth that makes them relevant across different use situations.

A key focus is on the development of the palpable open architecture, sometimes directly and sometimes as mediated through the application prototype developers. The characteristics of this relationship are elaborated in the paper 'Bottom-up, top-down? Connecting software architecture design with use', in the previous Conceptual Framework deliverable D.37. Fieldwork has also made a contribution to the Open Architecture through the studies of 'developers' palpability'.

In the following sections of this chapter we summarise the fieldwork, participatory design and evaluation activities that have taken place with each of the prototypes, presented in Workpackage order. Further details are provided later in the report in the papers collected under each prototype area. Conclusions regarding the progress of the project are drawn in section 4.8.

PLEASE NOTE that the papers, published or intended for publication, that are collected here describe the status of work at varying points of time, some going back to earlier prototypes, some to very recent iterations. To gain an up-to-date sense of the current state of the application prototypes, the conceptual framework and the PalCom open architecture, please see deliverables D.50, D.53 and D.54.

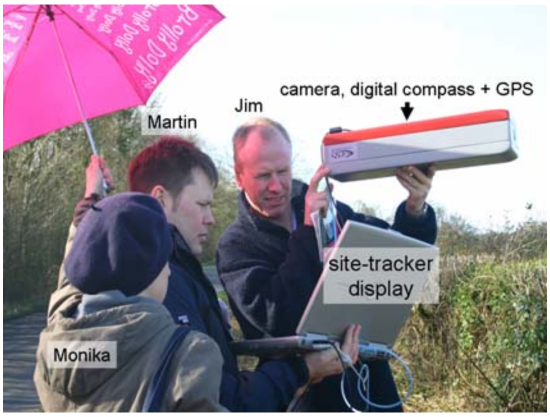
4.2 On Site

The work of landscape architects was the domain focus of a previous IST FET project, WorkSPACE (see Deliverable 45, paper 5.4). It analysed a range of practical difficulties that landscape architects encounter and devised a number of protoypes to address these, including the Topos 3D spatial modelling software that has been further developed as a basis for the Major Incident Overview prototypes (see section 4.3 below).

Fieldwork within PalCom has focused on difficulties that landscape architects face when reconnoitring large sites for major developments, for example, undertaking a landscape visual impact assessment (LVIA) for a proposed windfarm (see this Deliverable, paper 5.1). This could involve investigating the impact of more than one hundred 140m high wind turbines over a study area of 80km x 80km. To do this, they need to locate prominent or significant viewpoints from which the development would be visible, and document its impact through assessment reports and photomontages of the viewpoint with the proposed development accurately superimposed. However, identifying these viewpoints can be very difficult to do over a large rolling terrain where the development does not yet exist, and fieldwork revealed how days at a time can be taken up driving to and fro trying to achieve this.

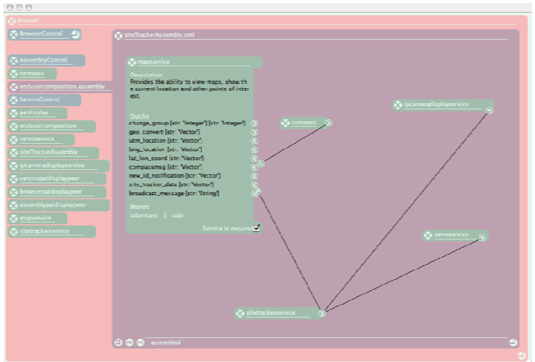
Landscape architects already use a variety of technologies, including PDAs, digital cameras, GPS, compasses, modelling, writing and visualization software, and more. However, at present, many of these are stand-alone, encapsulated devices. There is very little interoperability. Ubiquitous computing opens up the potential to create synergy by putting these technologies together in different ways, and by adding others into such ‘assemblies’ designed to suit people’s shifting goals. The SiteTracker prototypes emerged from a series of fieldstorms and participatory design workshops to address this opportunity. They involve variable combinations of devices such as video and still cameras, GPS, digital compass, stepper motors, 3D spatial software containing a model of the terrain and the proposed development, and palpable services to compose, decompose and inspect the resulting assemblies of devices and services. These would be used, for example, to mount a video camera on a car which would constantly point towards the centre of a proposed development, with a marker showing the centre of the development superimposed on the live video stream; or to take high quality still photographs with their position and orientation registered and shown on the 3D model.

Three iterations of the SiteTracker have been realised so far, and a fourth is in development (see paper 5.1). The first iteration, a proof of concept, combined devices in relatively large format and manipulated by hand, when on foot (below left) or in the car (below right).



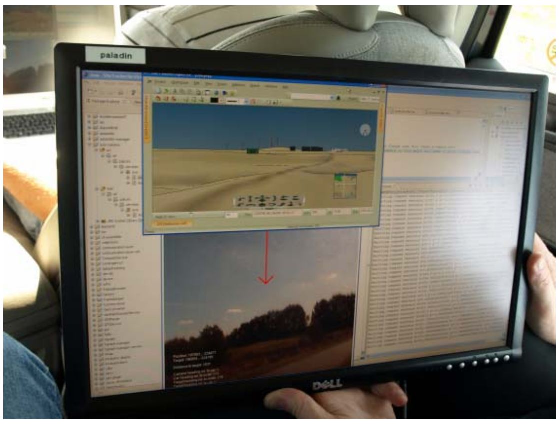
Lessons learned from the field trials included the need: to keep a recording of the SiteTracker video for the landscape architect user to study later; for a map view showing the camera’s field of view and orientation; to control camera direction manually as well as automatically; to be able to interrogate the level of accuracy; to be able to notice and address malfunctions; to be able to dis-assemble and re-assemble parts of the SiteTracker with other components, for example a high quality digital still camera, and otherwise to support emergent and unanticipated use.

The second iteration (see below left, as demonstrated at the 2006 IST event) provided a combination of: an IP camera, a Bluetooth enabled digital compass, a Bluetooth enabled GPS, a computer and display, a 3D model of the landscape and the proposed development, a stepper motor, a 'ServoService' that controls the motor and thus turns the camera, a 'MapService' showing the position field-of-view and orientation of the camera and points of interest, and a 'SiteTrackerService' to show the location of a proposed development. It also provided an Assembly Browser, showing which devices and services are in the assembly and their current status, expandable to show what kinds of input/output those services need/provide (below right).



Lessons learned from trials with the second iteration SiteTracker included: that the digital compass is too sensitive to the proximity of metal, as in a car, and to movement, and that when its battery is low it generates inaccurate readings without warning; that the video image, especially of distant views, is sensitive to very small degrees of tilt, either from the elevation mechanism or from the movement of the car; that the power consumption of the camera posed problems for wireless operation; but that the MapService view combined with the live video feed greatly improved understandability, and that the Assembly Browser proved to be a very effective means of inspecting the assembly, of looking 'under-the-hood' (see paper 5.3).

For the third iteration, realised this year, a damped cardanic (gimballed) suspension has been used to mount the camera and motor to the car roof (see below). It has been successfully tested in fieldwork trials on fictitious development projects in the countryside near Aarhus, with the cardanic suspension providing adequate stability even when the car is moving.

The fourth iteration SiteTracker, in development, seeks to replace the marking of the points of interest, superimposed on the video feed, with blue-screen techniques for inserting a model of the parts of the point of interest one can actually see (if any). This is implemented by integrating the SiteTracker with the Topos spatial modelling software (illustrated in a 'mock-up' below). This is ready for user trials, but was held up at the last attempt by technical problems with the digital compass. Experience with the SiteTracker has been written up in a revised version of the 'Mapping, Tracking and Interrogating' paper (this deliverable, paper 5.1), and this will be further revised when the fourth iteration trials are completed.

The SiteTracker was among the first of the PalCom prototypes into the field, and thus one of the first to explore in practical terms the need for palpability: that is, the need to provide clear and comprehensible means to represent and connect devices and services in functional assemblies, to vary assemblies for different purposes, and to inspect their properties for better understanding or to make repairs. Hence this was the initial context for the development of the Eclipse and Assembly browsers, as part of the PalCom Open Architecture. The former is more oriented to use by program developers, while the latter is more oriented to use by application developers and end users.

The SiteTracker has also influenced, and taken advantage of, other PalCom mechanisms for providing resilience and adaptability in a dynamic environment, including a palpable Resource Manager, a Contingency Manager (see deliverable D.52 Open Architecture) and the RASCAL prototype (see section 4.7 below). It has been the basis for exploring means to integrate different kinds of existing devices, services and software into the PalCom communication protocol, for which we have identified three alternative strategies of 'wrapping' devices with a PalCom service, running a PalCom service locally on the device, or using gateway services (see Deliverable 45, paper 5.3, section 3.1). The SiteTracker is now used in the Major Incident Overview prototypes (see next section).

4.3 Major Incident Support

At the project review in March 2006 it was decided to use the Major Incidents prototypes as a principal demonstrator for the PalCom project overall. It has therefore been the focus of particular effort.

A major incident, such as an airplane crash, a multiple road traffic accident, or a large chemical spill or explosion, is an inherently challenging environment. It happens without warning, is difficult to assess, requires the assembly of large-scale resources, and requires the cooperation of many disparate agencies and personnel, both local and remote, who may have no or only limited experience of working together, and who may themselves be placed in danger by the incident. There has been other research on devising IT-based support for major incidents, but this has mostly focussed on particular aspects – such as speech communication – or on particular emergency services. It has not considered the work as a totality of embodied conduct, involving and relating all participants with each other and with their tools and materials. And it has not considered the problems of 'palpability' that this gives rise to: of forging appropriate ad-hoc assemblies that are robust, flexible, comprehensible, and open to inspection.

4.3.1 Field studies

Our field studies have engaged the domain in a variety of ways (see this Deliverable papers 6.4 and 6.5): participating in induction and training courses and simulations for minor and major incidents; participating in specialised trauma team training courses; shadowing a wide range of personnel with responsibilities in incident response; observing videos of real major incidents and discussing them with the personnel who were involved; studying portions of Katrina and Rita emergency response on site; and observing a major unannounced simulation exercise and another major training exercise. These studies have drawn out key features of how members of the emergency services accomplish their work in major incidents.

A major incident is, initially, a site of great confusion. An early task of first attenders and emergency service managers is to produce order out of this confusion so that personnel can act effectively and safely. Those responsible need to try to make sense of what has happened, communicate this to others on site and at remote control centres, and devise appropriate plans and procedures. This is largely achieved collectively and through embodied conduct as personnel approach, circle and enter the incident site (see Deliverable D.45, paper 6.5).

Embodied conduct 'performs' a great deal of sense-making and organising activity, not only for those immediately involved but also, since they are plainly visible, for other personnel on site: it is 'broadcast communication'. This is particularly useful in a situation where the noise and chaos of the accident site makes sharing information difficult for the different agencies, a problem compounded by the fragmented nature of radio communication. An example would be the frequent formation of 'ecological huddles', where medical, police, rescue and fire brigade managers share and review information and make decisions. Ubiquitous computing devices can allow people to exploit the broadcast information that embodied conduct and the movement of equipment provides, through tracking, mapping and visualisation technologies. Paper D.45-6.5 demonstrates how such, potentially vast, assemblies of devices and services need palpability and how this can be realized.

Another issue concerns the use of biomonitors (see Deliverable D.45 paper 6.2). Where circumstances permit, doctors and paramedics routinely use biomonitors to assess the condition of people with injuries, most frequently to provide pulse, electrocardiogram (ECG) and blood oxygen saturation readings. They are valuable for triage, for diagnosis, for monitoring for deterioration, and for alerting receiving hospitals about the condition of inbound patients. The current standard 'LifePak 12' biosensors are wired and their use is severely hampered by the fact that data can only be seen by those who are immediately next to the display, which again has to be next to the patient. A patient wired up to biomonitors cannot move without help. A patient is moved many times throughout an incident, e.g. from the ground → temporary triage stretcher → ambulance stretcher → emergency room table → hospital bed → scanner → hospital bed. Thus biomonitoring, with all the required wires and displays in place, can hamper examination, treatment and relocation of the patient.

Understandably, then, biosensors are rarely used in major incidents, even though this represents a diminution of standard best practice for assessment. Moreover, there is often not enough biomedical equipment, and even if there is, it is often too difficult to transport. There is a limited amount of time to place biosensors on victims, and there are not enough professionals at the incident site to monitor and make sense of all the collected biomedical data – because the displays can only be located right beside the victims. Thus in major incidents sensors are only used for the most severely injured victims. Similarly, due to pressure of time and the priority given to immediate treatment, the incident card which should be tied to victims to identify them and be kept continuously up to date, and the triage card categorising the victim's condition, are rarely used.

4.3.2 Prototype design priorities

In analysing the field studies, the next stage was to focus down on a number of key challenges that encapsulate the difficulties experienced in trying to cope with major incidents, and that offer starting points for design (see Deliverable D.45 paper 6.1). These can be summarised as follows:

	Challenge	Design Response
1	Equipment is often tied to victims	Wireless medical equipment
2	Identification of victims is difficult and error-prone	Credible patient identification with minimal administrative effort
3	Situational overviews are very incomplete and mainly in the heads of the involved professionals	Dynamic support for situational overview
4	Equipment and systems change with every situation and even as specific situations unfold	Embrace change, be resilient to change in available resources, e.g. through use of assemblies
5	Equipment and systems vary considerably with respect to reliability and trustworthiness	Understandable reliability and trustworthiness, through inspection and recovery
6	Suitability and immediate usability determines what equipment and systems are actually used	Familiarity, e.g. though suitability for everyday as well as major incident use; ease of use

The first three challenges point to opportunities for application prototype design. The last three challenges point to the design of architectural support that will allow people to make the computational states, processes and affordances involved palpable.

4.3.3 Prototype evaluation and participatory design

On the basis of this preparatory work, a 'Future Laboratory' was staged at an emergency services dedicated training ground in Aarhus, involving 14 researchers, 10 pre-hospital emergency service professionals, 3 'victims', and a range of initial prototypes (see this Deliverable, papers 6.4 and 6.5). A traffic accident was staged in which two cars have crashed.

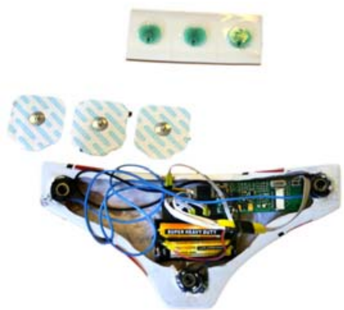
The prototypes deployed in experimental use during the ‘emergency response’ to this accident include connectivity, constituted in this case by a wireless network; wireless biomonitors measuring ECG; base stations relaying biomonitor signals into the network; wearable displays, simulated by portable tablet PCs; a remote-control overview video camera, simulated by a researcher manipulating a webcam; and a high resolution still camera with network connectivity. Mobile phones and radios were also available. These were used to explore a number of scenes, including forming an initial assessment of the victims, approaching victims in dangerous situations, collecting and displaying information for an overview, freeing the trapped victim with the doctor unable to be present, awareness of the deterioration of one of the victims, technical breakdowns, handover of victims, and communication with the Acute Medical Coordination Centre (AMC).

The prototypes demonstrated their usefulness, despite the artificial constraints. For example, the (remote) AMC doctor used the overview camera not only to gain a better sense of the condition of the victims and their requirements for treatment, but also to observe the on-site doctor’s activities and so judge the least disruptive time to contact him by mobile phone for information. Many valuable lessons about the requirements for the prototypes and the open architecture were learned, for example, the physical design of the biomonitors so that they will be easy to place and will perform reliably, and will not cause discomfort to patients; the need for at-a-glance feedback from assemblies to show that they have been established and are (still) working; that remote staff must be able to inspect and, if necessary, repair assemblies, as on-site staff will not have time; and the need for a clear mechanism to establish victim identity and link it to location, biomonitor data and communication channels.

4.3.4 The biomonitoring and identification system prototypes

A new generation of prototypes has been developed, on the basis of these and other findings. The current wireless and mobile biomonitoring system, ‘BlueBio’, is described in some detail in Deliverable D.45 paper 6.3. This is intended not only to enable wireless biomonitoring for medical assessment but also to address the issues of identification and categorisation of victims. The design framework for BlueBio considers these issues in relation to the conceptual framework challenge pairs of scalability/ understandability – e.g. appropriate for everyday use for regular incidents as well as in large numbers for major incidents; change/stability – e.g. continuity of monitoring through all stages and places between incident site and hospital; and automation/user control – e.g. the ability for medics to select which data they see, and in what degree of detail, while automatic recording, transmission and monitoring for victims’ deterioration continues in the background.

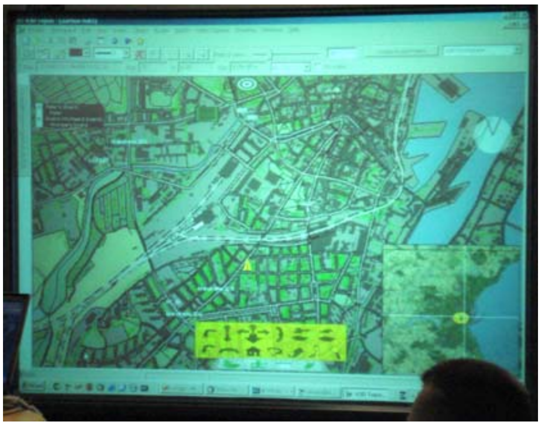
The degree of development of a designed artefact can be considered in two dimensions: the extent of its functional development – what it will do – and the extent of its physical or presentational development – its ‘production values’. The BlueBio prototypes have been quite highly developed on both dimensions because their physical qualities – such as ease and speed of deployment on an injured person, robustness, hygiene and visibility – are central to their eventual practicability and the willingness of medical staff to adopt them for everyday use, so attaining the necessary familiarity. In an integrated procedure, the medic activates the biomonitor (below left), with its wireless sensors (below centre), by tearing a self-adhesive identification strip from its back. This strip contains an RFID tag and is applied to the victim’s wrist, similarly to how a flight label is applied to a suitcase at check-in, while the biomonitor is placed on the victim’s chest (below right). The biomonitor distributes its signals through mobile base-stations by Bluetooth, and also directly if a display (e.g. PDA) with a RFID reader is used to read the identity strip. Since the last review the prototype has been fully integrated into the PalCom service framework. It has been implemented and evaluated in future workshops. A positioning unit prototype, to be integrated with the biomonitor, uses triangulation to give position with 2-4m accuracy independently of GPS. This has been constructed but not yet evaluated with end users. The biomonitor research area is very promising, and it is intended to seek resources to continue it.

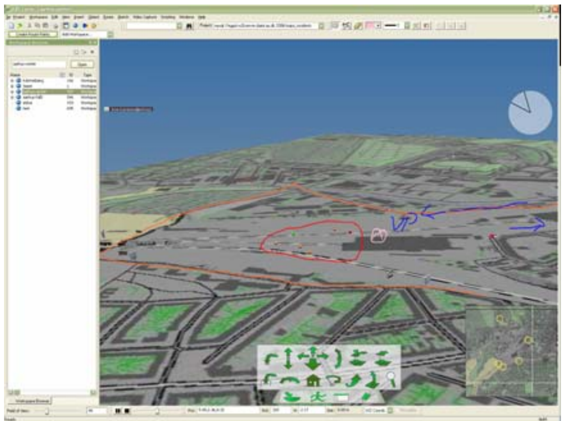


The present state of the biomonitoring system prototypes is illustrated and briefly described in the Prototypes deliverable D.50, section 5.2.

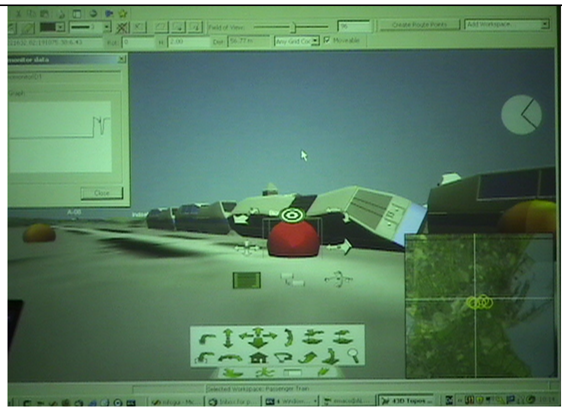
4.3.5 Overview prototypes

The Major Incident Overview (MIO) prototype and its use are described in this Deliverable, papers 6.1, 6.2, 6.3 and 6.6. It is an assembly of potentially thousands of tracking, mapping and monitoring devices, that, because it runs on (prototype parts of) the PalCom open architecture, supports people in noticing, inspecting and interrogating their status, processes and affordances. As enabling technology it uses proprietary 3D visualisation software, 43D ApS *Topos*, initially developed in a preceding IST FET project, WorkSPACE (see Deliverable D.45, paper 5.4). This is being developed in PalCom for major incident support. It consists of a 3D environment containing a digital terrain model of the relevant area overlaid with roadmaps, aerial photography, GIS information (emergency routes, location of fire hydrants, location of dangerous industries, etc.) depending on what is available for that area. The terrain can be represented in a variety of ways, e.g. in bird's-eye (below left) or 3D (below right) modes.

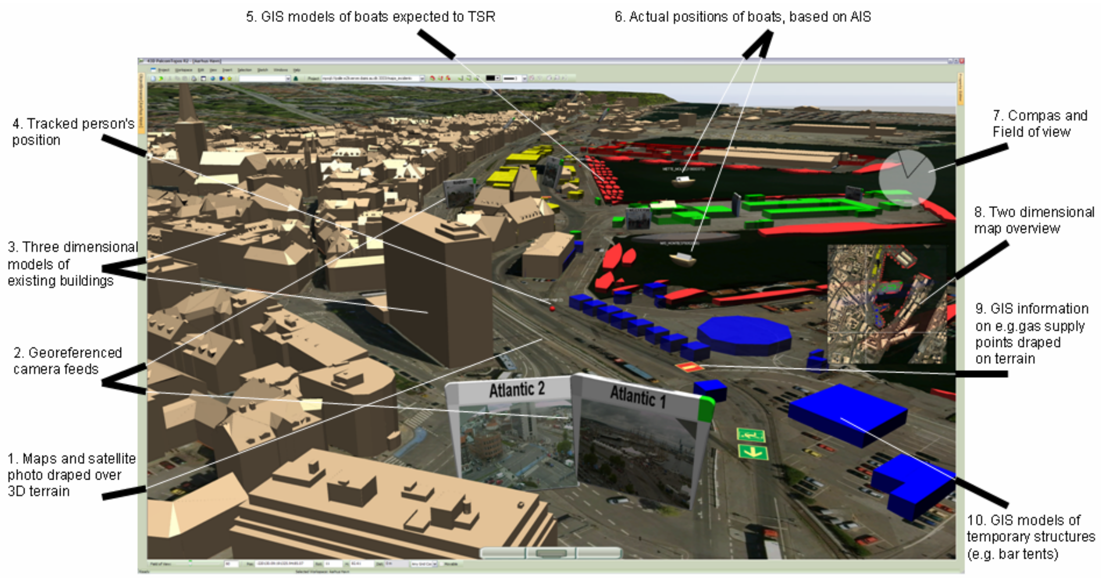




The prototype supports freehand drawing on the 3D terrain, inclusion of pictures or other documents, inclusion of 3D objects (e.g. buildings, vehicles, representations of people), and free manipulation of all these. The prototype supports collaboration via shared access to the incident workspaces from a variety of locations, and supports localised views and tools for manipulation. This means that the dynamic location of all tracked ‘objects’ (people and materials) can be displayed and made available to all relevant staff, both locally and remotely: for example, emergency service personnel, vehicles and equipment (below left), and (through the placing of BlueBio systems) victims and their biomonitor data (below right). To avoid excessive detail and confusion, objects can be collected in sub-workspaces and viewed in total or selectively as required, e.g. collections targeted at fire, medical and police users.



The MIO prototype augments collaboration done in and through talk with support for ‘stretching’ the materiality and scenic intelligibility of human and material behaviour. It constitutes a kind of media space, but one with rich connections between the digital and physical worlds, where the setting itself is the primary source of information: a ‘physical information space’ (see this deliverable, paper 6.6). A lot of relevant information is a visual byproduct of doing the job, so that video overview is a highly efficient means of capturing it. So, for example, it could be observed from the overview that lead staff from different services have gathered in a putative ‘huddle’, which remote coordinators might ‘join’. More deliberate communication is equally possible, such as taking a photograph which immediately becomes available, correctly located, in the overview. A range of scenarios of use are explored in Deliverable D.45, paper 6.6, including what happens when the alarm goes off, creating the initial organisation of the incident site, finding and treating victims, using the common workspace as a resource, and avoiding chaos and information overload.



The main focus of fieldwork since the March 2007 review has been the trial of MIO at the Tall Ships Race held in Aarhus on 5-8 July 2007. A total of 800,000 people attended a wide range of events in the harbour area, and MIO was installed in the harbourside control room. A 3D model of this area was draped with aerial photographs and 3D models of the buildings. The model also contained a variety of active objects and information, as illustrated above.

Experience of the Tall Ships Race and its significance regarding the key issues of the project are described at some length in Sections 3 and 5 of the 'Palpability' Deliverable, D.53. The prototype is also described in Deliverables 48, 50 and 52. We will therefore not repeat these accounts here, but rather summarise some key outcomes, from a user perspective.

- The PalCom technology was surprisingly reliable. Developers were on hand to attend to any problems, but it seemed plausible that eventually even as complex a setup as this could be maintained in operation with the kinds of technical support already found in most organisations.
- Aided by this, the fire and police staff gained considerable fluency in using the systems: they progressed from being present-at-hand, through exploratory-to-hand, to ready-to-hand for them.
- The systems did, overall, provide the palpability in use that was hoped for. Up to 40 devices and 100 PalCom services could be actively participating in the prototype, with dynamic changes in these populations, but the assemblies coped as intended and the overview kept running and remained comprehensible, conveying relevant status information.
- Nevertheless many lessons were learned about how palpability could be improved, so that operationally relevant matters that are at present inspectable for the technicians, could be made available and comprehensible to end users with straightforward modifications, thanks to the design philosophy of the Open Architecture. Some of these are explored in this Deliverable, paper 6.1.
- The prototype was really useful. The police and fire service staff, both at the time and in their subsequent official evaluation, regarded it as a dramatic improvement in the support available to them.

The present state of the overview prototypes is illustrated and described in the Prototypes deliverable D.50, section 5.3. It is intended to pursue the development of MIO extensively, both from research and product points of view.

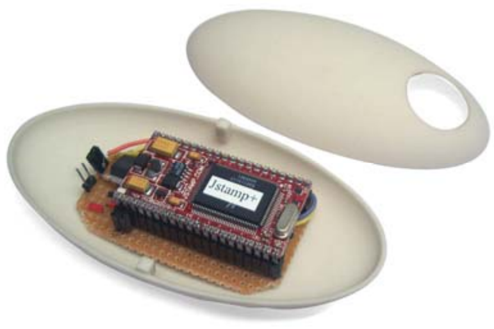
4.4 Pregnancy and Maternity

In the course of a pregnancy, the pregnant woman and sometimes members of her family come into contact with a wide range of health professionals. These usually require information from her, and often provide information to her, sometimes in the form of artefacts such as ultrasound scan images. Where there is an increased risk of complications, these encounters multiply. Many women and their families are keen to discover as much as they can about their pregnancy and what to expect, and are keen to keep records and mementos of their experience. However, these encounters can sometimes be frustrating. Communication between different health agencies can be deficient, so that pregnant women are repeatedly asked to provide the same information, and treatment may suffer where relevant information is available in health records but is not communicated. Information provided can be inadequate, or in an inappropriate form, or inconsistent, or overwhelming. There seems to be both scope and need for systems of support that will provide a more integrated, effective and pleasurable experience of health service and other encounters in pregnancy.

We investigated these possibilities using a range of fieldwork and participatory design methods (see D.45 paper 7.2). We undertook ethnographic observations in Skejby Hospital, Aarhus, and shadowed and then interviewed pregnant women, midwives and general practitioners. We looked at the special needs of pregnant women with diabetes. We used Dilemma Games and Artefacts as Triggers to prompt design, and a Future Laboratory to develop prototypes.

A key finding from the fieldwork was the great variation in the circumstances and preferences of pregnant women and in their trajectories of contact with the health service, and hence in the kinds of support they would want and need from a system. To refine this understanding of what the stone should do, a focus group and interviews were carried out with 11 pregnant women and four fathers to be (see D.45 paper 7.1). Their ideas were later discussed with health professionals. It turned out that an enormous range of features and information was wished for by at least some of those asked. This included detailed stages in the development of the fœtus, changes in the condition of the mother, including storing photographs and keeping a diary of the baby's activities, advice on life style such as diet and exercise, details about the birth process, pain relief and what can go wrong, detailed contact information, look-up tools such as a thesaurus of medical terms, and much else. They also wanted documentation, sometimes including audio and video records, of all their examinations and consultations, legal financial and welfare information, and recommendations on what to do when returning home with the baby.

The design solution proposed 'augmenting' the pregnant woman with a network-enabled, modular, configurable digital artefact for holding and communicating information. Called 'the Stone', this was initially realised in a PDA, but the concept was that it should be an attractive artefact that could act as a congenial focus for the integration of experience in pregnancy, and so it later evolved literally into an organically shaped stone, the MStone, with a single button, as illustrated below.



A range of horizontal prototypes was implemented with the initial PDA version, including:

- A Java program used by midwives, hospital doctors and general practitioners to see information about the pregnant woman, enter new data, and send pictures to a TV, giving the impression that data is saved in a database and is shared by all users on the general PregnAid system. This was done to investigate how health care providers imagined the data should be used by other health care providers and how their communication with the pregnant woman could change, when they could download data to her stone and vice versa. A later prototype added a web GUI for accessing data from electronic patient records.

- A prototype showing how data could be synchronized between the PDA and a laptop without loss of information. The data was annotated with a signature, showing who created the data and when, reinforcing user confidence.
- A GUI enabling the user (midwife, doctor) to access and save data in a storage component, annotated with signature and date. This prototype was designed to give the users the kind of GUI they wanted and show them how annotated data could give the same sense of safety that paper used to give them.
- A proof-of-concept technical prototype with a GUI enabling the user to transfer data to and from a BlueTooth radio (playing the role of a stone), demonstrating wireless communication for users.

The current Memory Stone (MStone) version of the prototype is a small handheld device, mostly intended for storing and communicating information. It consists of an embedded computer, a flash memory and a bluetooth radio – see section 6.2.2 of the final Prototypes Deliverable D.50. The horizontal PDA prototypes have migrated or are in the process of migrating to the MStone.

MStone information is accessed through an assembly with another device, e.g audio could be streamed from the MStone to a MP3 player or images from a digital camera could be stored on the MStone. In these simple examples the MStone could be used similarly to a USB-memory (although wireless). However, what makes MStone unique is the MStone hardware and software built on the PalCom architecture. The PalCom architecture makes it possible to personalize and integrate new services on the MStone in radically new formats. For example, a user could define an assembly that integrates the information stored on a PC with information stored on the MStone to be presented on an external display, as illustrated below.

To make these kinds of assemblies easy to use we designed a new simplified model for interaction where the MStone only has a single physical button as its entire interface. The MStone has neither a display nor any other graphical user-interface except a small inbuilt light-emitting diode and buzzer. Various assemblies are instead activated with a simple click and the user interaction is handled through an external device that renders the information stored in the MStone, e.g. at a clinic visit (below left) or to show images to a friend (below right). This can be seen as an 'extreme' PalCom interaction device that can only function in an assembly.

In paper 7.1 in this Deliverable, the experiences of pregnant women, their partners and families, and the various healthcare professionals with whom they come into contact are analysed in terms of *interaction ecologies*. The people, the artefacts in play, and the knowledge and information are all understood as participants or actants, interacting in fluid combinations that adapt or respond to the demands of the situations at hand. This provides an additional perspective through which palpability can be understood, with the technical means of assemblability, inspectability, experimentability, resource awareness, etc. engaging as facilitators or 'lubricants' to optimise the interaction ecology.

At the end of Year 3 of the project the decision was made to concentrate resources for the prototypes, and so not to undertake further fieldwork regarding pregnancy and maternity. The main effort in Year 4 has therefore been directed towards the Palcom toolbox, and within that especially to the Storage component. Two new prototypes have also been developed – see section 6.2.2 of the final Prototypes Deliverable D.50. The first prototype is built using a Jstamp CPU and Bluetooth radio, and for this some effort has been given to the industrial design to more clearly demonstrate the potential form factors for such a device (below, left). The second prototype is based upon the SunSpot technology (below, right), and embeds more computing resources as well as several additional sensors. In the former case most of the work in WP9 has been directed towards building software so this device can be fully integrated into the PalCom architecture. The result is that we now have a platform that could demonstrate the Stone as a general palpable interaction device.

4.5 Surgical Rehabilitation

Malmö University Hospital provides a specialist hand surgery clinic that services a large region (see D.45 paper 8.1). The hands play an essential part in people's lives and injuries can be traumatic, life-changing events. Quite apart from the pain, patients often struggle to understand the complexity of their injuries and the healing process, and it can be extremely difficult to come to terms with the necessarily slow process of recovery, and possibly radical and lasting effects on their everyday life. The stress of the new situation means that it is difficult to take in information. Yet it is crucial for the success of rehabilitation that patients take charge of their recovery processes. The necessity of understanding the recovery process includes the patient's surrounding social network such as family and employers. It can be quite a challenge for them to accept that after several months it is still not possible for the injured person to perform tasks that they used to. According to the staff, there is a noticeable difference in success between patients with a supportive network and those who are alone or have difficulties in accepting their functional impairments. Moreover, it is a challenge for the staff to understand the patients' possibility to adhere to rehabilitation. For example, fine-grained movements of the hand used in work tasks can be difficult to understand from verbal reports.

We have sought to contribute palpable technologies to support surgical rehabilitation, and to do so through pursuing the design ideal of explicit interaction (see D.45 paper 8.3). This refers to interaction techniques that are designed to make actions and intentions visible, understandable and accountable – or, in other words, palpable. Explicit interaction can be considered at three levels of analysis. First is a *usability* level which is to do with the affordances or product semantics of an artefact, such as the way that the shape of a bowl invites the placing of objects in it. Second is a *materialization* level, which is to do with giving a physical form to something, such as a digital signal or process, which would not otherwise have one, as in the extensive work on tangible user interfaces. Third is a *social performance* level, which is to do with the ways that interaction enters accountably into social practice: for example, that I am rarely interrupted by colleagues when I am holding a phone to my head.

We have pursued these objectives through a participatory design process with four main phases:

- participant observation of physiotherapists and occupational therapists in sessions with patients
- joint concept development workshops with rehabilitation staff and patients
- developing a moderate-fidelity prototype of one of the most promising ideas
- participatory assessment through envisionment exercises and qualitative reflection

On the basis of the fieldwork and the workshops, the design concept formed for the prototypes was that of collaborative articulation, achieved through short-lived assemblies. Collaborative articulation means that the patient and the medical staff engage jointly in articulating information and knowledge pertinent to the rehabilitation. We have sought to understand this through the ways in which human and non-human actants align with each other in a chain of 'circulating references'– for example, the 'metamporphing' of artefacts and references between the anatomical poster, representing the abstract 'idea of the hand', the X-ray representing the invisible particular hand, and the status sheet which is the 'processed hand' (see paper $, this deliverable). The ethnographic approach addresses how the dysfunctionality of the hand is *performed* rather than simply described, tries to capture the specific *doings* of hand surgery, and attends to the life-world of the patient in the round.

The principal means chosen for this was video production, so extending the field of alignments to the 'video hand'. The assemblies are short-lived because an ecology of devices is envisioned around a central ever-present device – in this case a mobile phone or PDA with a video camera – that is augmented by other devices as needed for particular tasks and situations. Relevant situations in this context could include:

1. Patient makes an audio annotation when his hand starts swelling unexpectedly and reviews this on the way to the clinic as a reminder to raise it in the consultation.
2. Physiotherapist and patient together make a brief video at the end of a consultation detailing how next week's exercises should be done. Patient views this twice during the first day, then views it again in the evening with his wife and kids so they understand what he needs to do and why.
3. Patient records a video illustrating how he manages to tie his shoelaces with one hand, and brings it to the work training group to share with other patients, and for inclusion in the clinic repository of clever rehab ideas.
4. Patient gets colleague to record him during a workplace visit as he tries to perform the motions of his former job. He takes this to the occupational therapist so they can refine appropriate training and consider what elements of the work tasks might need to be changed.

The main components of the prototype, as illustrated below, are:

- A custom-built recording station containing an RFID reader, for wireless interaction based on proximity. Physically, it has the form of a bowl for situations such as media sharing, as in 2 and 3 above.
- PDAs with WLAN connectivity and passive RFID tags.
- A digital video camera mounted on a desk lamp.
- Resource manager software, currently running on a PC, which manages the short-lived assembly and its interactions. Corresponding software also runs on the PDAs.

In use, when they agree to record a short video of next week's exercises, the therapist puts his PDA in the recording station, and the PDA's display changes to show a video feed of the desk. When the patient also places his PDA in the recording station it does the same, and pressing a button on the PDA initiates recording. When they are finished, the patient takes his PDA out of the station and the recording is clearly shown as a file handle for later playback.

This design satisfies the objectives of palpable explicit interaction in various ways. In terms of usability, the affordances that are provided include the shape of the recording station (above right), the PDA showing the video stream when it is placed in the station, and the camera mounted on the desk lamp, suggesting its view can be adjusted by adjusting the lamp and seeing where its light falls. In terms of materialization, everyday experiences are captured, and volatile digital media are turned into articulated material for shared rehabilitation work. In terms of social performance, placing the PDA in the recording station signifies a change of pace and character of the consultation, and puts the patient in equal control of the recording, so shifting from a situation of 'compliance' to one of 'concordance' (see paper 8.1, this deliverable). Both partners can relate to a risutalistic series of actions that reflect a change of rhythm in the consultation. The collaborative nature of the interactions enforces – makes palpable – the shared and negotiated nature of the decision about when and what to record. The two phones in the recording station provide an at-a-glance readability for other users of the consulting suite of what is going on so that they can, for example, be expected for the time being not to interrupt and to keep noise down. The distinctive design philosophy in this prototype is to provide as much palpability as possible through its normal, visible and physical operation, without the need for parallel 'palpability mechanisms'.

In the period since the last review in March 2007, these analyses have been developed and written up, and formal usability evaluations were carried out with staff and patients with good results. There has also been a focus on two other aspects that have general application across the project: proximity-based interaction, and palpable contingency handling. In articulating virtual representations with physical artefacts, proximity-based interaction is a way of underpinning the palpability of actions and supporting the user in understanding how computational resources are intertwined with physical space. A vocabulary has been developed and implemented for handovers in near-field communication, for a proximity service in the PalCom architecture. Proximity has also played a role in resource management and contingency handling. The model is a hybrid one, which seeks to combine a minimal but effective level of autonomic self-healing with an element of human intervention, for example when there is a breakdown such as loss of power in the master device (PDA) controlling a remote display.

The development of the Surgical Rehabilitation prototypes took its offspring in field studies at the clinic and the design of the first prototype, inspired by those studies. In relation to how patients move between different situations a need for representations of rehab related material arise that can be explored in a variety of ways. The way she relates to her rehabilitation differs much depending on the situation at hand. Talking to staff at the clinic, talking to employers, talking to family or trying to grasp the situation on her own are situations with each their focus and specific ways to deal with the rehab material. This seems to call for a persistent yet flexible way of holding on to and accessing digital material pertaining to ones individual process of rehabilitation. For this means we designed the CARE paper and the Mouse++.

A CARE paper is a physical piece of paper that allows the patient and caregiver to place and hold on to regular handwritten or typed notes alongside links to multimedia snippets and web sites. In this way, a CARE paper provides a physical space for collaboration where a mix of digital and physical media can be used for the articulations used in the patient-caregiver understanding of the current state of the rehabilitation process. By integrating the use of paper documents with the use of digital media the CARE paper tried to combine the dynamic and flexible nature of digital media with the qualities of persistence and tangibility inherent to paper.

The Mouse++ demonstrates a feasible technology path and helped us to define what actual interaction with a CARE paper could/should be like. Mouse++ enables you to discover links on the paper, retrieve media attached to these links and create new links, but also serves as an ordinary mouse for GUI-style interaction with a desktop computer. With the CARE paper and with electronically augmented paper in general we meant to enhance and enrich our use of paper documents as well as our use of digital media in the meeting between the two. We prefer to use the term ‘Augmentable’ rather than ‘Augmented’ paper documents when describing the key properties of our CARE paper. This is to emphasize that we aim for a dynamic user controlled, and continually ongoing process of augmentation rather than a static pre-augmented configuration produced at the time of design. We believe this corresponds directly with the notion of collaborative articulation as a process guided by the particularities of the situation - a process that will bring the CARE paper into use in ways that are beyond the control and anticipation of us as designers.

While not being subject for further development the prototype raised the interest among staff at the clinic for developing placeholders and a platform for storing and accessing media produced on the fly by patients away from the clinic or staff during consultations, a work currently being negotiated. Furthermore the prototype stressed the act of collaboratively articulating the situation at hand through jointly using shared interfaces. It was also the starting point for exploring issues of connectivity between devices engaged in media production and reviewing.

The present state of the Surgical Rehabilitation prototypes is illustrated and briefly described in the Prototypes deliverable D.50, section 7.

4.6 Care Community

4.6.1 Neonatal intensive care

Extensive fieldwork and participatory design has been carried out at the Neonatal Intensive Care Unit (NICU) at the ‘Le Scotte’ hospital in Siena. This has identified a number of difficulties that arise in the intensive care of often very premature babies, which may be amenable to support from palpable computing assemblies. Various prototypes have been developed to address these needs and to test the palpable architecture and services (see this deliverable papers 9.1 – 9.5).

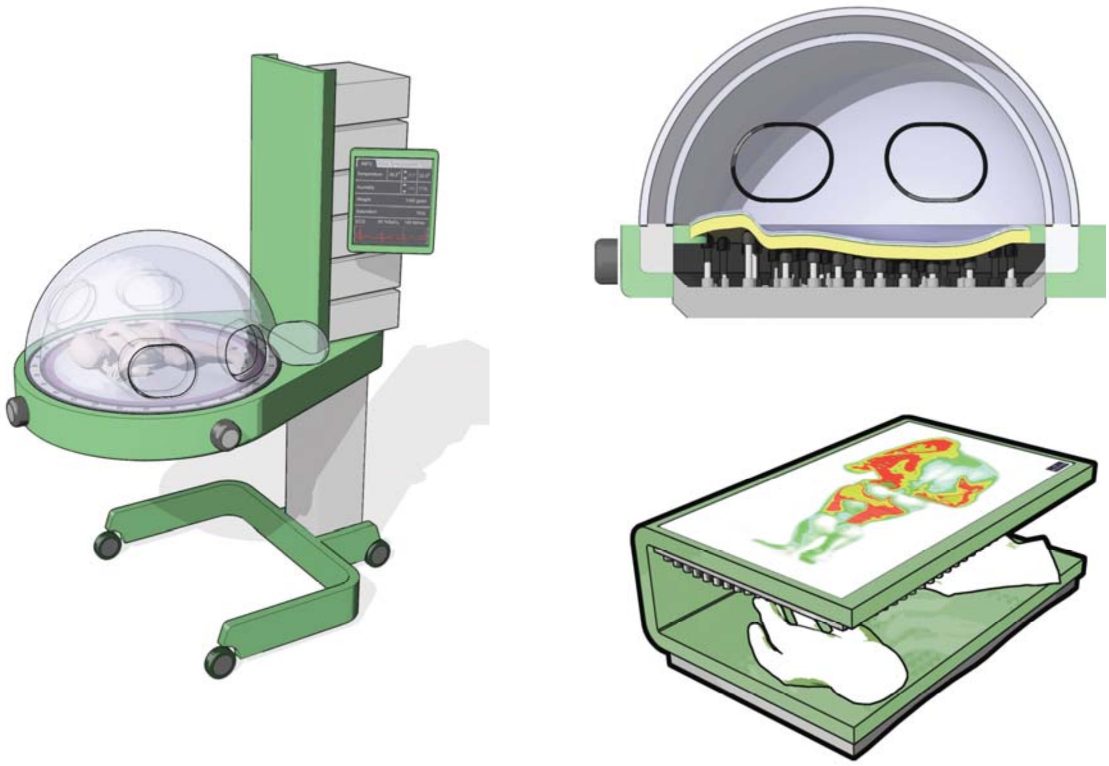
On admission to the NICU, usually as an emergency, the premature newborns usually require complex medications, umbilical tubes and intubations. They also need continuous monitoring – typically of heart rate, oxygen saturation, respiratory and blood pressure – to prevent critical reactions and to try to anticipate emergencies. These activities centre on the incubator, which provides the controlled environment necessary for the baby’s survival (below left), and also detects temperature, humidity and weight. The incubator is functionally extended by attaching or removing a range of surrounding equipment, such as the skin saturation, heart rate and ventilating equipment shown below right. The mattress of the incubator and soft materials are also configured to provide necessary physical support for the premature baby’s body.

Discussions and workshops with neonatologists and other medical staff identified several aspects of the present environment that are less than ideal:

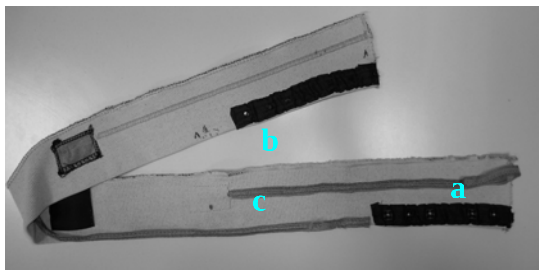
- the wires and tubes can be very painful and irritating for the premature baby
- these, together with the surrounding equipment, can make it difficult to move the baby or carry out medical procedures, and hamper contact between mother and baby
- the incubator must be opened for various procedures, disturbing the controlled environment
- some sensors are limited, e.g. only measuring the baby's temperature on one point of the body, or can only provide a warning when the situation has already deteriorated rather far, e.g. SpO2 oxygen saturation to warn of breathing difficulties
- the physical support for the baby's body is not very subtle, risking postural damage, pain, and pressure sores

The first incubator prototype, developed in collaboration between Siena, Aarhus School of Architecture and Aarhus University, was conceived as a 'dome' (see below), invoking the 'waterlilly' metaphor, and was designed as an autonomous system that does not need to be connected to other external devices like ventilators or phototherapy lamps as is the case today. As a modular system, the various units of equipment needed for treatment, and their displays, are plugged into a rack on the back of the incubator (below left). The baby can be moved within the dome assembly, preserving optimal conditions. The incubator bed swivels and this, together with the multiple openings, gives maximum access for treatment with mimum disturbance to the baby.

The baby lies on a mattress with a special material containing body pressure biosensors for detecting the loaded areas of the baby's body on the mattress surface (below right). In order to avoid pressure sores and similar problems a fine grained modular system allows the medical staff to manipulate and change the position of the baby's body without opening the incubator, using a pin art-like system whose elements can be moved up and down directly or remotely.



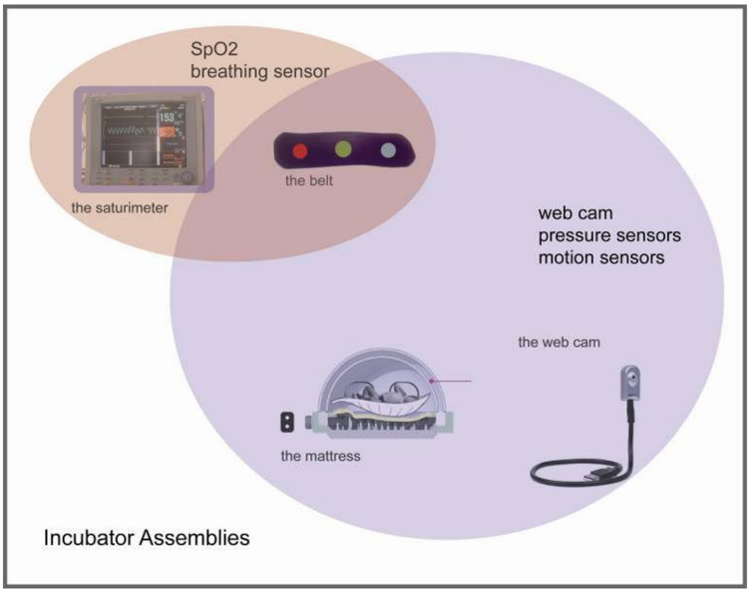
When the baby is placed in the incubator, a small wireless biosensor belt is applied between the baby's chest and abdomen, with embedded sensors and transducers for heart rate, respiratory rate, body movement and temperature. It communicates by Bluetooth with a base station with network access. Following evaluations there has been substantial development of the belt prototype this year regarding both its physical properties and the embedding of sophisticated sensors (illustrated below).



Biosensor belt prototype: respiratory sensor (a), electrode for ECG (b), pocket for accelerometer/temperature sensor (c)

Some of the most significant features of the prototypes take shape through the assembly and interaction of different elements and services, composed and decomposed using the assembly browser and framework described in section 4.2. For example, EEG + video streaming of the baby can provide monitoring of neurological development and of convulsions and spasms. Different assemblies can co-exist in parallel, sharing some of their elements, as illustrated below, and can combine palpable and non-palpable elements. This may provide new and greatly improved services, not only more convenient and less intrusive ones. For example, if CO_2 and sound biosensors are applied to the tube connector of a ventilator, staff may get an early alert to breathing anomalies or obstruction in the ventilator, making it possible to intervene before the SpO2 value significantly decreases, and to avoid painful preventive and inappropriate aspirations.

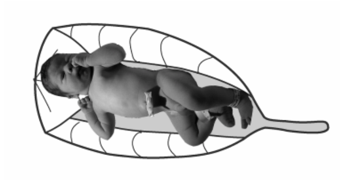
The creation and manipulation of assemblies aims to provide that each part of the assembly is easy to understand on the logical level (what can be done with this, what can it go together with and for what purpose), on the functional level (how to use it), and on the physical level (it must be possible to see what fits together and to actually build/rebuild). Consequently, the assembled systems should support the continuous attribution and negotiation of meaning through interaction.

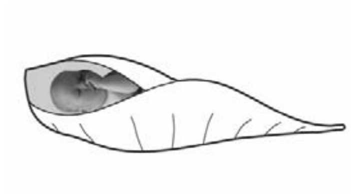


This first prototype appeared to offer a very elegant and well-concieved solution to clearly identified problems with existing incubators. It was arrived at using thorough participatory design methods, closely involving neonatologists, nurses and therapists through: user workshops and activitiy modelling, sessions reviewing ethnographic data, bricolage workshops aimed at the practical integration of activities and prototypes, a travelling architects' workshop, and future laboratories. Different scenarios of use were also developed, addressing initial activities at the neonatal island, regular daily care, assembling services, and dealing with emergencies.

However, when subjected to expert evaluation by the founder of the NIDCAP (Newborn Individualised Developmental Care and Assessment Program) approach, it was strongly criticised because – despite its functional efficacy – it retained a traditional approach to the incubator space which did not provide enough of the interaction and contact which NIDCAP regards as important for neo-natal development (see this deliverable, papers 9.4 and 9.5). This prompted a major evolution of method in this year's work. The developing field of the 'aesthetics of interaction' suggests ways of complementing functional requirements with a 'soft set' of requirements. In this case, this speaks to such aspects as filtering the light, the ability to freely open or close the incubator, perceptible output of the child's condition and well-being, and the variable granularity of visibility of the technology. Soft qualities also prompt reformulation of some of the functional requirements.

This has led to new mattress prototype proposals, employing this time the metaphor of the leaf rather than the lillypad (illustrated below). The softness and thickness of the polyuretanic gell material and its metamorphic possibilities are critical for this design. The inner surface contains pressure and other sensors, while the outer surface makes the sensor readings palpable through LEDs with varying pattern and intensity.





Neonatal intensive care is obviously a safety critical domain and this imposes particular requirements and constraints on the evaluation of the prototypes. These have to undergo all the rigours of medical ethics and experimental design approval procedures, and much time and effort has gone into preparing for these this year. A proposal for a study involving at least 20 newborn patients is currently under consideration.

Further ethnographic analysis of some of the detailed practices of neo-natal intensive care is given in the draft paper 9.6 in this deliverable.

The present state of the Incubator prototypes is illustrated and briefly described in the Prototypes deliverable D.50, section 8.2.

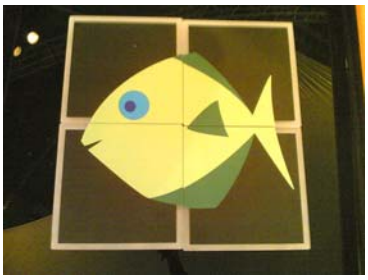
4.6.2 Active Surfaces

Therapists working in cognitive and physical rehabilitation have to define a specific program and ad hoc interventions that are adapted to individual patients' needs. In many cases (e.g. Hanart Syndrome, Moebius Syndrome, Angelman Syndrome) there is no agreement on a standard therapeutic protocol, so the work of the therapist is mainly characterized by creativity in designing both engaging activities and suitable tools. These activities sometimes take place in swimming pools, where the quality of the water creates a safe and calming context where people with such disabilities can move autonomously, which they cannot do elsewhere, and with less pain and discomfort. Water is a great 'equalizer' for disabled people who find that their movements are easier and less different from those of others. The water offers new opportunities, such as the combination of cognitive and physical rehabilitation which, taken separately, tend to be both boring and tiring for disabled children. This environment poses particular challenges, however, and 'Active Surfaces' is the concept developed for prototypes to support rehabilitation practitioners in providing physical-functional and cognitive rehabilitation treatments in a swimming pool setting (see Deliverable D.45, paper 9.2).

The concept involves using tiles with perceptible properties, such as colours, letters and parts of a picture, and that can provide feedback through light or sound. These are used as components in game-like sequences of activities for rehabilitation. The tiles should 'know' when they are being used in accordance with the designed activity and provide appropriate feedback. Different possibilities for their use were devised in workshop and brainstorm sessions with therapists from the Rehabilitation Unit at 'Le Scotte' hospital in Siena, and tested using 'Wizard of Oz' techniques with disabled children at the public swimming pool. Following these it was decided to focus on floating tiles for the early prototypes. In parallel, a Java prototype, PoolSim, was developed in order to simulate the properties of tiles in the pool, devise appropriate games with the therapists, and investigate issues such as graceful degradation and dynamic communication.

A step-wise approach was adopted to transform the concept into early mock-ups and then into working prototypes. In this sense, traditional Participatory Design and eXtreme Programming methods have been integrated in the development phase, fostering a creative process with the stakeholders. A number of low-fi prototypes were developed to verify different assumptions, potential design solutions, and integration with the swimming pool setting. This work has resulted in more mature prototypes that have been assessed by the stakeholders along the evaluation process. Users have been able to comment on functionality and look-and-feel, and have been able to use ‘semi-working’ prototypes in a way that is not possible in the traditional Wizard of Oz approach. In fact, some of the prototypes turned out to be easier to develop than setting up the Wizard of Oz sessions. Eventually two more advanced prototypes where developed in parallel. The first had limited functionalities, but worked sufficiently to be more easily adapted as new user requirements emerged. The second was closer to a hi-fi prototype built on the final target platform. The latter is now under development and meets the specific requirements regarding execution speed and flexibility that are needed in the final system. Siena has cooperated with Aarhus School of Architecture on the physical prototypes and with Lund and Aarhus Universities on the protype software.

The Active Surface components are ‘normal’ tiles, an ‘assembler’ tile, and an assembly browser and framework. ‘Normal’ tiles measure 30 x 30 cm, they float, and they can have different graphics or textures applied to their top surface (see below). Tiles contain a UNC20 microprocessor running the PalVM and they communicate horizontally on their four sides using infrared.

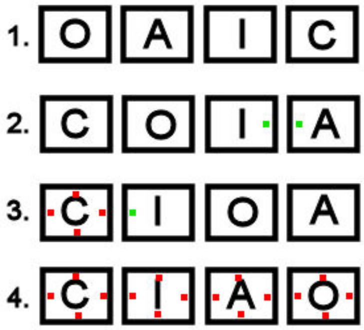

The assembler tile is a ‘privileged’ tile that is used by therapists to program the other tiles. The rules and feedback responses of the particular game are downloaded to the assembler tile from the assembly browser. The normal tiles are aligned in their game solution positions, and the assembler tile is then applied to them, effecting ‘programming by example’. The tiles themselves once assembled constitute a network of physical and software objects that communicate and exchange data and are able to recognize their relative positions and respond appropriately.

This year has seen the development of different services – puzzle service, connectivity service, LED service and coordination service – targeted at the PalVM running on the tiles. The Assembler tile also contains a Configure service. These developments have been trialled and evaluated with users.

In the example below the tiles’ states are described through the use of a “happiness” metaphor (see deliverable D.45, paper 9.4). These terms are used with specific meanings in the scenario and in the code development. We consider different states of happiness (satisfaction of conditions) for the position and orientation of the tiles in the assembly:

- SideHappiness means that a tile realizes that it is correctly connected on a particular side. On the side(s) that are Happy the tile provides the users with HappySide feedback. If all its sides are correctly aligned, LocalHappiness is achieved.

- LocalHappiness means the tile is properly connected to the others and it has on each side the tiles it was looking for. It is in the right position and it is correctly orientated in the assembly
- AllHappiness means all the tiles satisfy the LocalHappiness and, knowing that all the others are sending that feedback, they realize a global happiness, satisfaction of the activity game.



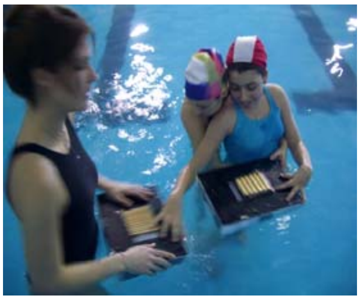
Row 1: No happiness

Row 2: HappySide for ‘I’ and ‘A’ between ‘I’ and ‘A’ sides (Green feedback on HappySides)

Row 3: ‘C’ is LocalHappy (Red feedback) and ‘I’ has one HappySide (Green feedback)

Row 4: All tiles are LocalHappy, this gives complete Allhappiness within the system

The therapist can start the game by simply throwing the tiles into the pool for the patient to experiment with and respond to the feedback:



The Active Surfaces prototype presents a number of Palpable qualities and challenges. Apart from providing input to the architecture on how users perceive an assembly and how they can work with this assembly, the Active Surfaces challenge the architecture by requiring a small footprint since the UNC20 is a truly embedded system. Low bandwidth provides new challenges and requirements for the communication layer and protocol, regarding for example discovery services and broadcast messages that risk flooding the IR based system. The Active Surfaces represent a truly mobile and modular system where end user composition is a key point, addressed by different interaction modes and interfaces based upon the current user and the current needs. Different inspection strategies have to be supported in the Active Surfaces application since the tiles as such lack a rich input and output environment. Feedback from trials with were the basis for developments by Aarhus and Lund of a non-XML based protocol for palpable computing and communication, which goes beyond the Active Surfaces and has informed the development of components such as the generic PalCom Discovery service.

The present state of the Active Surfaces prototypes is illustrated and briefly described in the Prototypes deliverable D.50, section 8.1.

4.7 Transient Locations

Mobility is now a central aspect of everyday life with mobile users expecting to be always-best-connected wherever they are and whatever they are doing (see, this Deliverable, papers 10.1 and 10.2). This certainly applies to the PalCom prototypes, most of which assume mobile wireless connectivity between palpable devices and services and beyond. Communication environments are, however, still vulnerable to disruption in various ways. Equipment can fail and networks are subject to prevailing natural conditions. Even in normal operation, however, those attending a major incident, for example, may find network coverage is very patchy, or is overwhelmed by the unanticipated number and bandwidth of connections demanded.

The RASCAL (Resilience and Adaptivity Scenarios for Connectivity over Ad-hoc Links) prototype is designed to overcome these disruptions and maximise the chances of a message reaching its target. It is middleware software that resides between a user application and the underlying network communication interfaces. RASCAL uses software agent architecture and applies policies to the selection of media channels and related actions. A graphical user interface provides for inspection and currently can show the status of the network interfaces of its connected device, the other PalCom services discovered, the incoming and outgoing messages, etc., and it receives user input.

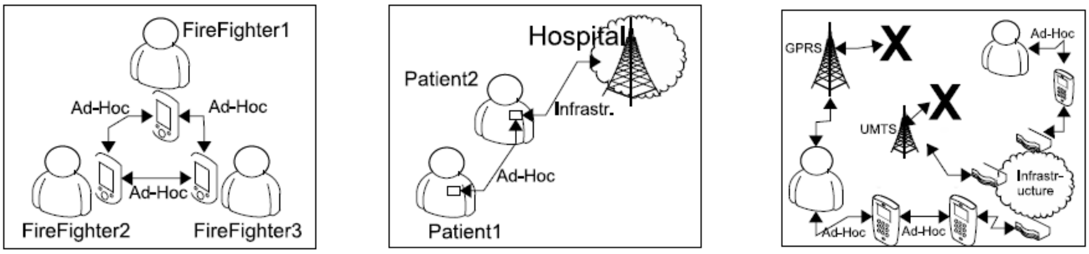
RASCAL provides resilience and adaptivity through continuous assessment of available resources. It provides network awareness by assessing the condition of all the available interfaces and services, and can also exchange load information with other RASCAL-enabled devices. It provides usage awareness by being able to apply a range of decisions, such as:

- contingency management, e.g. sending a message by two or more different routes to ensure it reaches its target
- content adaptation, e.g. sending only the audio channel from a video stream or reducing resolution to cope with congestion
- defered service, e.g. waiting for a high speed connection to send video data
- role management, e.g. providing an authorisation policy mechanism when distributing orders among a rescue team

RASCAL has autonomous capabilities that attempt, where appropriate, to shift the burden of tasks such as configuration, maintenance and fault management from users to the underling technology. Hence RASCAL is:

- self-configuring, since it adjusts its behaviour to environmental conditions
- self-optimising, taking decisions based on behavioural policies provided by the end user and network/service providers
- self-healing, automatically switching between underlying bearer technologies.

The initial RASCAL prototype was extended in order to take such autonomic decisions. It is now able to do so based on deployed PalCom services. The extended requirements were defined in collaboration with the Major Incidents prototypes through iterative, participatory design and experiments with end users, though the prototype is suitable for a very wide range of situations (see below).



(a) Major incident scenario. (b) Telemedicine scenario. (c) Recipient Pursuit.

RASCAL is now a core component of the PalCom Open Architecture, and is publicly available via the PalCom Open Source Repository. The present state of the RASCAL prototype is illustrated and briefly described in the Prototypes deliverable D.50, section 9. Further development work with RASCAL is expected.

4.8 Ethnography and Interdisciplinarity

Paper 11.1 reflects on the now considerable history of ethnographic studies of work practice and assesses their contribution to the design of real systems. It argues that this has been limited, because the great majority of these studies have in practice been disconnected from serious design effort and capability. This in effect – even if disavowed – reduces work analysis to requirements capture, and we should already know from theory that this is not viable. It argues that systems cannot attain ‘artficial sociality’, but might succeed in designing for palpability. The paper puts forward a pragmatic strategy for realising this, and argues that this is largely achieved in the PalCom project.

4.9 Workshop and book proposals

The ongoing publication and dissemination effort has, among other things, taken the form of various successful workshops at major conferences and also free-standing, and proposals for book-length coverage of some of the issues at the heart of PalCom. Some of these are represented in this section, and plans are still in development.

4.10 Conclusions

All the prototypes have a bearing on most of the palpability challenge pairs, invisibility – visibility, scalability – understandability, construction – de-construction, heterogeneity – coherence, change – stability, and automation – user control and deference; and on the seven key properties of inspectability, assemblability, resilience, adaptability, resource awareness, experimentability and multiplicity. This is to be expected since the challenges are themselves connected. They also make use, in some form, of most of the features of the palpable open architecture. However, each is distinctively well placed to have a bearing on one or two challenges and/or features in particular.

The SiteTracker prototype originated the assembly as a core component of the PalCom architecture and was the first to provide tools for constructing, deconstructing and reconstructing assemblies of devices and services, and for inspecting their operation. These have informed the work on end-user composition. They are still in development and evaluation, and have migrated to the Major Incidents prototypes.

The Major Incidents prototype has a distinctive focus on issues of scalability, as a PalCom-supported major incident could produce an unplanned and rapid confluence of a very large number of devices and services. Designing for scalability has both a technical aspect, as in providing for resilient and adaptable communication channels, and a use aspect, as in using 3D spatial representations or the direct proximity of devices to filter and handle complexity. Major Incidents has also focussed on strategies and techniques for incorporating non-PalCom legacy devices and services into the PalCom environment. It also has a distincitive approach to inspection since inspectability and repair of assemblies by remote support staff is a necessity.

The MStone has a distinctive focus on issues of visibility and invisibility and of composition, as it has a congenial but absolutely minimal interaction interface. This can be seen as an ‘extreme’ PalCom interaction and bridging device that, although having extensive functionality, can only function in an assembly.

Rehabilitation from hand surgery has a distinctive focus on autonomy versus user control in interaction, as its design philosophy is to achieve cooperative articulation through explicit and tangible interaction. This seeks to provide as much palpability as possible through normal, visible and physical operation, such as proximity and the mirroring of content, without the need for parallel ‘palpability mechanisms’. This is not just a matter of functional elegance, but supports different and more equal relationships of awareness and control. Surgical Rehabilitation has also provided the setting for prototyping contingency handling, which adjusts between autonomous self-healing and social negotiation depending on context.

The Incubator prototype has a distinctive approach to palpable service composition and inspection in its sensitive, safety-critical environment. It assembles overlapping services to provide redundancy, and also uses the combination and correlation of palpable services and devices to provide entirely new functionality, such as more timely and accurate alarms that avoid unnecessary interventions. The delicacy of the setting has also prompted the serious consideration of ‘soft properties’ of interaction, and corresponding ‘soft requirements’.

Active Surfaces challenge the architecture by requiring a small footprint since the UNC20 is a truly embedded system. Low bandwidth stresses the requirements for the communication layer and protocol, regarding for example discovery services and broadcast messages that risk flooding the IR based system. They represent a truly mobile and modular system where end user composition is a key point. They also require distinctive inspection strategies since the tiles lack a rich input and output environment.

The RASCAL transient locations prototype is explicitly targeted at maintaining stability and resilience through changes in available communication infrastructure, responding to contingencies in resources. It provides a basic underpinning technology needed by the majority of the prototypes, and by the majority of plausible candidate palpable environments.

In the course of the year most of the prototypes have completed their migration from earlier, ad hoc technical solutions to incorporating – and providing – the features of the palpable open architecture as these mature.

Overall, it may reasonably be claimed that the PalCom project has achieved a remarkable degree of interdisciplinary understanding and coherence, given that only a small core of its participating researchers came to the project with previous experience of this. We believe there are no areas of this complex project that do not see and welcome the value of all the others, however strange these may have seemed initially. This is reflected in the harmonious connections that are now strongly emerging between the Open Architecture, the diverse prototypes, and the evolving work practices of their intended users – mirroring the sympathetic conditions of their development within the project.

5 On Site

5.1 Mapping, Tracking, Interrogating: The PalCom SiteTracker

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Status: Draft (intended for submission after further revision)

Mapping, Tracking, Interrogating: The PalCom SiteTracker

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ABSTRACT

Building ubiquitous computing technologies to support the work of landscape architects addresses specialized but also important generic issues for ubiquitous computing. In this paper we describe prototypes that support landscape architects in creating assemblies of ubiquitous computing technologies for mapping, tracking and interrogating new landscape designs. The PalCom SiteTracker prototypes materialize and afford experimental immersion in a future where ubiquitous computing technologies are available for landscape architects. Based on experimental formative evaluation, we demonstrate the importance of being able to make ubiquitous computing palpable, that is noticeable, understandable and de-/composable. We illustrate the use of a prototype architecture for palpable ubiquitous computing in the design and experimental assembly/use of the prototypes.

Keywords
landscape architecture, mapping, tracking, interrogating, palpable computing, ubiquitous computing

1 INTRODUCTION

Landscape architecture is an inspiring and demanding application area for ubiquitous computing. Understanding and changing landscapes and cityscapes involves indoor and outdoor work, it requires mobility, in-situ observation, measurement, and precise objective as well as intersubjective judgments about the desirability of change. It requires an ability to visualize change (both for oneself and others), to weigh up large amounts of diverse information, and to enable others, including members of the public, to make sense of it. Landscape architects already use a variety of technologies, including PDAs, digital cameras, GPS, compasses, modeling, writing and visualization software, and more. However, at present, many of these are stand-alone, encapsulated devices with very little interoperability. Ubiquitous computing opens up the potential to create synergy by putting these technologies together in different ways, and by adding others into such 'assemblies' designed to suit people's shifting goals. In this paper we describe a series of 'Site Tracker' prototypes we have developed. They combine existing and future ubiquitous computing devices and services to support important aspects of the work of landscape architects on site. This is because we consider that the real possibilities and constraints for ubiquitous computing are best discovered through confrontation with real and serious, not general or imagined, contexts of use. In such contexts, useful systems will nearly always have a hybrid character rather than being ‘purely’ ubiquitous, and in what follows we describe the mixture of requirements that emerge from our field studies and prototype trials. The capacity to combine these aspects is necessary for ubiquitous computing to succeed. Although we focus on the development of a specific prototype within a specific application domain, the components, services and software architectural means developed have much wider and generic potential. We show how lessons learnt from experimental use have informed the design.

However, for us these prototypes are also a means to a more foundational end. Ubiquitous computing and a high degree of interoperability are worth little if people are unaware of the possibilities inherent in them, or unable to comprehend and realize them. Yet the tendency is for ubiquitous computing easily to become confusing since, if computing and communication power could be ‘anywhere’, it is intrinsically difficult to detect what devices and services are available, how they can be combined, what they can do, how they can be interacted with (Bellotti et al, 2002), when they are working correctly, and how to ‘fix’ them when they are not. The term we have coined for this is that we seek to support users in making computing – and especially ubiquitous computing – ‘palpable’, that is, noticeable, understandable, and de-/composable (Büscher et al. in preparation). A principal purpose of the present study is to discover what palpability entails in this context and how to provide it.

If ubiquitous computing is to be adopted on a larger scale, and if it is not to be confined to proprietary systems with a small number of participating devices and services, then it is necessary to provide an architecture, with minimum specifications of conformity or compatibility, that will accept, connect and support participating devices, services and infrastructures. This architecture must support palpability, and should also be palpable itself in the face it presents to the users and developers of ubiquitous applications.

We are involved in the design of an open architecture for palpable ubiquitous computing in a project called PalCom (Palpable Computing: A new perspective on ambient computing (PalCom External Report 50)). The project is also developing a number of palpable ubiquitous computing prototypes, including those reported in this paper, in order to establish and test the requirements for the open architecture. Our development work has, therefore, three strands:

- *Ubicomp Futures*: We envision and materialize enough of a future populated with application prototypes of ubicomp devices, services, and resources to allow end-users to experimentally explore how one could assemble them and, through this, participate in their design. This allows researchers and users – not only discursively but also practically – to explore what kinds of assemblies would be useful and how, when and where these would be created, changed or dissolved.
- *Informing the design of the open architecture:* The development work on these prototypes, as well as ongoing collaboration with end users, contributes to the specification of requirements for an open architecture that supports people in making ubiquitous computing palpable.
- *Testing prototype architectural features:* The PalCom SiteTracker and other application prototypes take advantage of prototypical architectural support for palpability, providing formative evaluation for the iterative architectural design process.

In this paper we describe the design of the PalCom SiteTracker (Part 2), discuss relevant aspects of the open architecture (Part 3) and report on evaluation through experimental use in landscape architecture. In Part 4 we discuss the importance of palpability and how our design supports people in making ubiquitous computing palpable.

2 MAPPING, TRACKING, INTERROGATING LANDSCAPES: OPPORTUNITIES FOR DESIGN

Apart from creatively designing new landscapes themselves, landscape architects are often asked to carry out landscape and visual impact assessment (LVIA). LVIA is a statutory part of all major urban or rural developments. It is designed to provide a professional assessment of the likely effects of new developments – a new building, airport runway, windfarm, etc. – on people's experience and views of the landscape. This is a highly skilled and often difficult job, not least because it combines scientific, exact judgment with intersubjective cultural aesthetic and experiential evaluation. The two key questions are (1) Is the proposed new development visible from prominent viewpoints within the study area? (2) Does visibility matter? Viewpoints might be tourist attractions, vantage points within nearby towns and villages, or key points on major roads. Observer height, weather, existing vegetation and buildings and, with long distance views, features like earth curvature, can affect visibility and must be taken into account. Colour, movement (e.g. of wind turbine blades), and materials can influence how much can be seen.

While the first question can be answered through objective measurements and calculations, the second requires a keen sense for cultural tastes, trends and sensibilities. Whether the visibility of a proposed windfarm, for example, will offend local, national and international (tourist) tastes depends on the exact landscape context, people's views about environmental issues, personal and political factors. More detail about the judgements involved in LVIA can be found in Büscher (2006). Most important for the purposes of this paper are the practical difficulties landscape architects encounter.

Figure **1** and the ethnographic detail below capture the two most troublesome problems of LVIA in practice: keeping track of the site of the proposed development and integrating information from different sources (maps, plans, photographs, computer models, positioning devices, the physical landscape).

> ***Excerpt from ethnographic study:*** *Within an unfamiliar 30x30km study area, landscape architect Lynda is to assess the impact of a proposed windfarm. As she drives to find important viewpoints, Lynda tries to keep track of the site with the help of a 'landmark' hill with masts on (Buttercup Hill). However, low cloud makes the masts invisible. Driving along a major road she finds a touristically significant view, and, believing Buttercup Hill and the site to be right ahead of her, she becomes deeply concerned. If this was the site, the proposed windfarm would dominate a sensitive and important view. Lynda drives up and down the same stretch of road, stopping and looking at maps, eventually getting out, walking. She works out that she was wrong. Buttercup Hill and the site are on her right and farther away. She takes photographs and saves GPS coordinates. As she approaches one last time in the car, she keeps looking right – thinking that there might be another important viewpoint further up the road. She stops to fill in a field survey form that describes the existing character of the landscape and the view captured in her*

photographs. At the holiday cottage where she is staying she uses computer modeling to gain a sense of what would be visible from these viewpoints. The next day has clear visibility – ideal to take photomontage pictures that show how existing vegetation would/would not screen the proposed windfarm.

Figure 1 In the frequently large, unfamiliar, undulating study areas that landscape architects encounter it can be difficult to keep track of where exactly a new development is proposed, let alone assess the impact of not (yet) existing structures on views and experiences.

This short exhibition of work practice poses interesting challenges and opportunities for designers of ubiquitous computing technologies. In a series of fieldstorms (idea generation grounded in ethnographic video data) and participatory design workshops with landscape architects, we explored them in some depth, developing and prioritizing a design agenda for our dual focus on application prototypes and architectural support for palpable ubiquitous computing.

One key idea is the ‘SiteTracker’: an ‘assembly’ that brings together some ‘first generation’ ubiquitous computing devices the landscape architects already use to do their work (e.g. car, laptop, GPS, video camera, and compass) and some to-be-designed devices and services to track positions (such as the centre point of a proposed windfarm) and support the landscape architects in integrating location information, real world experiential and visual information, and insights from computer modeling tools (Figure 2).

Figure 2 SiteTracker sketches created in fieldstorms and participatory design workshops.

To support landscape architects in keeping track of the location of a proposed new development, covering potentially very large study areas (often 80 km x 80 km) we envisage a video camera, mounted on a motor with 360˚ horizontal movement and around 45˚ tilt. This mobile camera should be placed on the roof of a car and – through computation of the changing relationships between dynamic location information (e.g. position and orientation of the car) and one or several fixed points (e.g. centre of wind farm) – could be instructed to always 'look' at the centre of interest while driving. Wireless connections serve to avoid twisting cables and to stream the live video to a display mounted on the dashboard of the car or integrated into a part of the windscreen. Ideally, one would be able to dynamically combine the information from the live video with computer models of the proposed development (e.g. by superimposing live images of the parts of the wind turbines that would actually be seen), in effect producing a live video-montage of the envisaged changes to the landscape (an idea sketched out in the static montage on the left of Figure 2, see also Figure 10). It should be possible to notify the level of accuracy of the montage, that is, to make accuracy 'palpable'.

In the sections below we now describe a series of SiteTracker prototypes intended to realize these ideas, specifying the lessons learnt from experimental use. Future work and general issues for the design of the SiteTracker are drawn out, but we also discuss implications for the design and implementation of ubiquitous computing at a more general level.

Iteration 1: First trials

The first physical iteration of the SiteTracker consisted of:

- a USB webcam
- a RS232 enabled digital compass
- a RS232 enabled GPS
- a laptop computer and display
- a 'SiteTrackerService', that is a software service interpreting the signals from the GPS and compass, computing orientation and distance to the point of interest, and pointing at specified locations in the live video feed from the camera
- a wooden casing

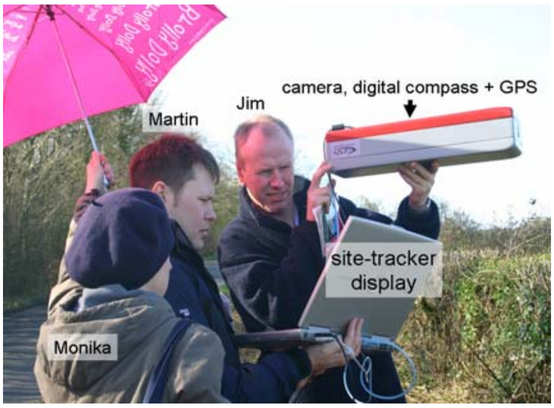

Figure 3 Landscape architects experiment with SiteTracker assembly, as ethnographers and developers observe.

Figure 4 Driving with the SiteTracker.

In Figure 3 Martin and Jim, two landscape architects, are experimenting with the SiteTracker in the English countryside. They have instructed one of the developers to enter the position of a (fictitious) windfarm. The SiteTracker is here used to look over the top of hedges. The indication of the centre of the windfarm and its distance on the live video is useful to work out whether existing vegetation would be likely to screen the development or not. Having keyed in a number of additional points, whose location and distance are also indicated on the video, helps make sense of where the development is in relation to these important landmarks. After this stationary experiment, the landscape architects take the SiteTracker for a drive (Figure 4), with Peter, one of the software developers, acting as the motor. The GPS is placed in the front window of the car and as they drive, Peter turns the camera to keep looking at the fictitious windfarm. In Figure 4 the windfarm is located to the left of the car and Peter has moved the camera to 'look' through the passenger window. As Jim drives, Martin uses the SiteTracker display (shown on the right in Figure 4) to gain a sense of how much of the windfarm would be visible. In a similar situation during a subsequent experiment in Scotland, Lynda (the landscape architect whose struggles initially inspired the design) is driving, while Jim and Martin try to evaluate the changing visibility of the fictitious proposed windfarm. The following exchange takes place:

Martin: *presumably this'll be fixed permanently looking forward?*

Lynda: *no it'll always look towards the windfarm*

Martin: *allright. mhm it's very disconcerting driving forward and …*

Jim: *seeing what you're seeing out of the side window*

((Jim who is acting as the motor for the camera had moved it to look at the proposed windfarm through the passenger window. He now turns it to look forward))

Jim: *I mean you could do that, which just proves that it [the proposed windfarm] is over there*

Martin: *I guess it probably needs to do both things, doesn't it?*

Jesper: *((a developer)) You can just remote control it.*

Being able to experimentally appropriate the SiteTracker into their work practice, the landscape architects practically explore how they might work with it, influencing the design of the technology, and simultaneously inventing new ways of working, as we describe below.

2.1.1 Lessons learnt

The objective of this first prototype was to assess whether it was possible to calculate the distance and direction to the point of interest, and whether we could meaningfully convey this information to the user. The trials showed that both were indeed possible, and we also became aware of a range of issues to address in future versions. The main lessons learnt during this round of experiments were:

- LVIA is usually carried out in teams. However, as our field study with Lynda shows, it can happen that large study areas have to be explored by an individual landscape architect alone. To facilitate individual LVIA, it should be possible to record the live SiteTracker video and examine it when stopped (it is dangerous to drive and try to monitor views at the same time). This means that sometimes a video recording medium and service must also be connected to the assembly.
- To understand what is seen in the video, it would be useful to also have a map-view with an indication of the camera's field of view and orientation, which are additional services required from the modeling software.
- It should be possible to manually remotely control the camera on the car roof (as well as controlling it automatically through tracking).
- Drivers and/or passengers might find it useful to take still pictures as they drive, so that sometimes the video would need to be supplemented or substituted with a higher quality still photography service.
- It would be useful to see not just the centre of the windfarm, but an indication of its extent (the leftmost/rightmost turbine visible from a specific point.)
- The landscape architects must be able to interrogate the levels of accuracy achieved to be able to determine the degree of certainty they can claim for their evaluation. This is needed to make the tools 'palpable' in relation to their professional requirements.
- The landscape architects must be able to notice and address malfunctions or failures. This is a complex assembly of devices, services and software, and in order to be inspectable and repairable its characteristics must be made palpable.
- The landscape architects would dis-assemble and re-assemble parts of the SiteTracker with other components, for example a high quality digital still camera to get out of the car and take photographs and index these with GPS coordinates. There is great potential for emergent, unanticipated use (Robinson, 1993). Users should be supported in noticing and making sense of the states, processes and affordances of the components involved.

2.2 Iteration 2: Proof of Concept

Based on the shared experience of experimental use, the next iteration of the prototype combined the following devices and services:

- an IP camera
- a Bluetooth enabled digital compass
- a Bluetooth enabled GPS

- a computer and display
- a 3D model of the landscape and the proposed windfarm
- a stepper motor
- a 'ServoService', that controls the motor and thus turns the camera
- a 'MapService', showing the position, field of view and orientation of the camera and points of interest.
- a 'SiteTrackerService', revised to show a line rather than a hand[1]

an Assembly Browser, showing which devices and services are in the assembly and their current status, expandable to show what kinds of input or output those services need or provide

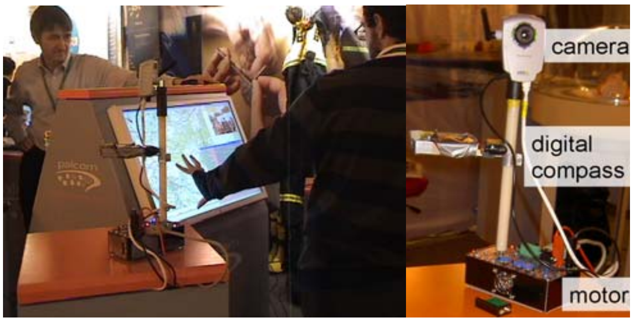

Figure 5 SiteTracker Iteration 2 demonstrated at IST.

Figure 5 shows part of Iteration 2 demonstrated at the European IST event 2006[2]. The location of the car (simulated due to the fact that the demonstrator is shown indoors) is tracked and displayed on the map with the help of the MapService. The MapService allows users to specify one or several key points, e.g. the centre of a windfarm. Combining these data with the information provided by the digital compass mounted on the roof of the car, the SiteTrackerService calculates where the camera should be 'looking'. It communicates this value to the ServoService, which turns the camera. The live video overlain with indication of the location of and distance to key points is shown at the top right corner of the large display mounted on the exhibition furniture. Below it, an Assembly Browser makes it possible to 'look under the hood' of this SiteTracker assembly and inspect the states, processes and affordances of its assembled services. A more detailed explanation of the Assembly Browser is found in section 3.3. The Iteration 2 SiteTracker prototypes were also brought to Edinburgh in Scotland and extensively tested and evaluated by the landscape architects at their premises (among others, Martin and Lynda from above). Furthermore, the SiteTracker was thoroughly discussed during the three days of the IST exhibition, with more than 400 visitors experiencing the prototype. The results of these evaluations are described below.

2.2.1 Lessons learnt

The objective of this second version of the SiteTracker was to evaluate a 'proof of concept' of the SiteTracker in its entirety, e.g. including the motor rotating the

[1] It is not forgotten that it would be useful for the landscape architects to see the extent of the windfarm rather than its centre point, but the ambition is to ultimately realise a better solution, as we discuss in Section 2.4 below.

[2] http://ec.europa.eu/information_society/istevent/2006/index_en.htm

camera, the MapService, and the Assembly Browser. The evaluation was directed towards both:

- technical constraints and possibilities, in that the setup is rather complex and involves a lot of hardware devices and software services interoperating; and
- possibilities for providing the user with suitable means to 'focus on the job' when that is appropriate, without being concerned with the assembly; but also to manipulate and inspect the complex assembly when that is necessary or desirable.

The lessons learnt and ideas generated around this iteration of the SiteTracker can be summarized as follows:

- The digital compass needs to be positioned relatively far from potential magnetic sources (e.g. the motor and camera) due to their interference with the compass readings.
- When the motor turns the compass gets shaken and for a period the readings are almost random, so we have to wait a period until the compass stabilizes until we may trust its readings again
- Experiments with tilting the camera showed that even a small (vertical) pitch will have a significant impact if one is looking at a point of interest 20 km away. Moreover, roads dip and rise in undulating terrain so the camera is rarely level.
- When the batteries in the compass began to run low, instead of stopping to work, the compass becomes untrustworthy and delivers unreliable readings. Either, we need to provide a more stable power supply, the compass could signal when power is running low, or we should detect in software that the compass is becoming unreliable. This last would take advantage of emergent properties of a palpable assembly.
- The camera we used needed power of a magnitude that forced us to provide it by wires. Wires to a camera that turns constantly will twist.
- The MapService showing point of interest, one's own location and orientation as well as field of view of the camera, combined with the live video feed, was found to be very valuable and understandable.
- The Assembly Browser proved to be a very effective means of inspecting the assembly, looking 'under-the-hood'.

As the prototype iterations proceed, the remaining difficulties are progressively less to do with ubiquity and palpability *per se*, and more to do with integrating with the practical rigours of a real working environment.

2.3 Iteration 3: Physical prototype

Iteration 3 of the SiteTracker has undergone extensive physical changes. First, we have mountede the rooftop part of the Sitetracker on a damped Cardanic (gimbaled) suspension (always level) to avoid the problem of the car not being level when driving. Secondly, we plan to replace the digital compass originally used to keep track of the orientation of the camera with a gyroscope (calibrated when starting out via GPS or digital compass) that is not affected by the metal and whose readings should be much more stable. Thirdly, we are experimenting with ways to power the camera via its mounting to the motor.

The physical prototype has been constructed and trialled with success using fictitious development projects in the countryside near Aarhus. The cardanic suspension provides adequate stability even when the car is moving. This version will be tested against both existing and planned wind farms together with the landscape architects in Scotland in the near future.

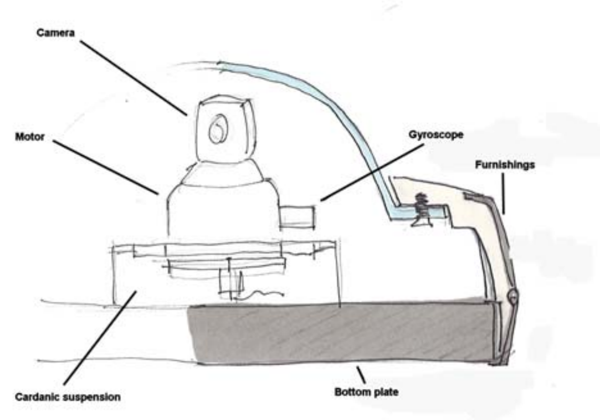

Figure 6 The SiteTracker mounted on top of a car.

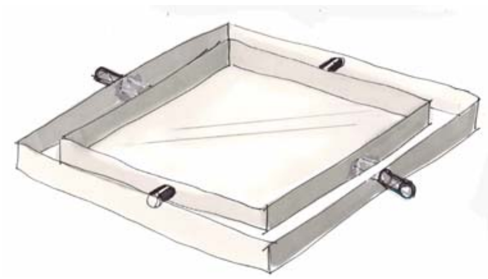

Figure 7 Sketch of a Cardanic suspension unit

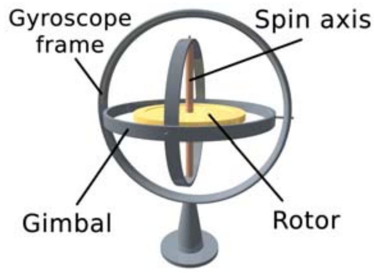

Figure 8 A diagram depicting the principles of 3D gyroscope

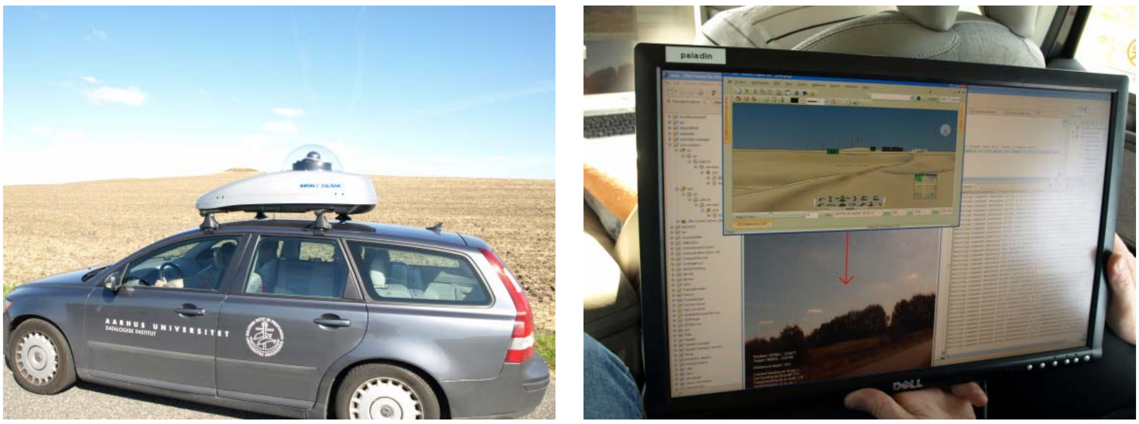

Figure 9: Cardanic suspension fitted to car, with resulting ouptut

2.4 Iteration 4: Pursuing the video-montage and augmenting the SiteTracker

The fourth iteration SiteTracker, in development, seeks to replace the marking of the points of interest, superimposed on the video feed, with blue-screen techniques for inserting a model of the parts of the point of interest one can actually see (if any). This is implemented by integrating the SiteTracker with the Topos spatial modelling software (illustrated in a ‘mock-up’ below). This is ready for user trials, but was held up at the last attempt by technical problems with the digital compass.

Figure 10: A sketch of the montage of live video of the existing landscape (without the proposed windfarm) and the parts of the model of the proposed windfarm that would be visible, updated as the landscape architects are driving.

In addition, the highly dynamic and ever changing environments encountered daily by landscape architects in their fieldwork have had profound implications on the notion of stability in relation to the active assembly of devices and services. From our experience with experimental use so far, we know that there will be a crucial demand for devices and services to be able to communicate across different networks, even if the environment is of a disruptive nature. By disruptive we refer to a physical location, or series of locations, that may be subject to intermittent or complete lack of a communication infrastructure. This Iteration should consequently allow users to utilize resource and contingency mechanisms to meet some of the above described challenges. We outline how this is achieved in section 3.1 below.

3 DESIGNING FOR PALPABILITY

The SiteTracker is envisaged not so much as a stable ‘product’ but as an assembly of ubiquitous computing devices that provides synergetic value. It supports the mapping, tracking and interrogation of landscape designs. It itself may take different forms (with or without computer modeling, using varying forms of location services, low or high quality video cameras, different displays – as suits the given situation and available resources). This section explores the architectural aspects that underpin the application prototype design. Some issues are particularly important for users and interesting for developers of innovative ubiquitous application prototypes and architectural support, in order to exploit their potential to the full. These are resource and contingency management, end user compostion, interoperability and design for breakdown.

The work of landscape architects is already being assisted by technology. In their everyday work they use different devices such as GPS, digital compass and camera as well as GIS systems and 3D modeling. The idea behind the SiteTracker prototypes developed thus far is not to provide the landscape architects with yet another isolated device, but the ability to assemble the devices and the software functionality already present in the work environment, with some additional software services, into an assembly that provides new composed functionality.

As a means to this end we use the service oriented architecture developed in the context of the PalCom project, including their concepts of services, assemblies and communication mechanisms. In the following we describe how the concepts of the PalCom architecture have been applied in the construction of the SiteTracker prototypes and how these specific prototypes in return have informed the PalCom Open Architecture.

3.1 Resource and contingency management

One of the central requirements uncovered through testing the SiteTracker prototypes has been the need for resource and contingency management. This key requirement has been addressed with several mechanisms within the PalCom Open Architecture, all of which are designed to directly support network resilience and adaptivity. These are a palpable Resource Manager, a Contingency Manager (PalCom External Report 50: Deliverable 39) and the RASCAL prototype (PalCom External Report 58: Deliverable 44).

The Resource Manager is responsible for maintaining an up-to-date directory of all available 2nd order resources within its operational scope, be they other services, assemblies, components or devices. An available 2nd order resource may be either active and thereby currently available for use (subject to any additional usage constraints), or inactive and thereby not currently available for use. Every PalCom Assembly will nominally have one active Resource Manager residing on its associated device, participating in the assembly. Other inactive Resource Managers may also be present within the assembly, especially to support distributed replication and failover redundancy. The PalCom open architecture bases resource awareness on the reflective properties of the PalCom entities. Each resource in a PalCom system is able to offer a resource description providing essential data on how to deal with it.

The primary operations of a PalCom Resource Manager are as follows:

- Discover 2nd order resources
- Persistently monitor previously discovered 2nd order resources
- Match resources according to needs expressed by Assembly and Contingency Managers (described below)
- Describe available 2nd order resources to Assembly and Contingency Managers
- Provide available 2nd order resources to Assembly and Contingency Managers
- Describe its own behaviour when inspected

The Contingency Manager is responsible for administering fault and problem conditions occurring in active PalCom Assemblies and 2nd order resources through the application of a variable set of contingency tools and mechanisms. Every PalCom Assembly will nominally have one active Contingency Manager residing on its associated device participating in the assembly. Other inactive Contingency Managers may also be present within the assembly, especially to support distributed replication and failover redundancy. Contingency management addresses the non availability, nominally through starvation or failure, of resources in PalCom Assemblies.

Contingency implies the ability of a palpable system to automatically identify problem conditions, determine suitable means to resolve them and then apply appropriate mechanisms to prevent future error conditions. Therefore, for example, a temporarily lost network connection does not necessarily lead to an error condition, because it has to be considered as a legal operating state in system design. This not only ensures that a system becomes more resilient to failure, but also capable of adapting to ambient conditions such as resource starvation. The consideration of resource management is therefore also considered as a required step towards the establishment of a contingency paradigm for PalCom systems.

For the purposes of contingency management a distinction is drawn between errors, faults and failures. An error is an exception condition resulting from some deviation from expected behaviour leading to a fault or failure. A fault is a non-catastrophic breakdown from which recovery is expected, and a failure is a serious condition from which recovery may not be readily possible.

The primary operations of a Contingency Manager are triggered by incoming events sourced from Assembly and Resource Managers. Also, in some cases Contingency Managers can offer reduced, but specialized functionality and operate in coordination with other specialized Contingency Managers to offer a complete, although distributed, service. Contingency Managers are expected to at least provide a set of reactive contingency actions (i.e. compensations) which respond to errors, faults and failures when an event is received indicating their occurrence. Events are typically sourced from Assembly and Resource managers.

Based on the reception of events, the following primary operations characterize the reactive behaviour of a PalCom Contingency Manager:

- Monitor the performance thresholds of 1st Order Resources on specified (by events) devices. If a threshold is passed, a contingent action can attempt to trigger the re-balancing of resource load across additional devices.
- Compensate for an error/fault/failure with an Assembly-specific resource by attempting to locate an equivalent replacement resource.
- Compensate for the error/fault/failure with an Assembly-specific resource by attempting to reconfigure an assembly in coordination with the Assembly Manager.
- If replacement and reconfiguration fail then compensate for the error/fault/failure with an Assembly-specific resource by attempting to gracefully degrade the operation of an assembly in coordination with the Assembly Manager.
- Resolve dependencies in accordance with the mode and subject of a compensation. For example, a replaced service must be configured to match any residual dependencies remaining from its predecessor.
- Describe its own behaviour when inspected.

3.2 Interoperability

The SiteTracker prototypes have been assembled from a range of heterogeneous devices and existing software systems. We provide a layer of interoperability by employing the PalCom communication protocol Manager (PalCom External Report 55: Deliverable 41) defined as part of the PalCom Open Architecture. It allows loose coupling of services and supports discovery of devices and services running in the network. It furthermore allows designers and end users to inspect, construct, de-construct and re-construct compositions of services by means of Assemblies. One cannot expect the world to be redesigned to conform with a new architecture, so a key issue is how as wide as possible a range of devices and services can be incorporated in some form. We have used the SiteTracker prototypes to explore this issue and we have identified three strategies for expanding heterogeneous devices and software systems to comply with the PalCom communication protocol. These are the following:

- Devices, such as the digital compass, that have no CPU resources can be wrapped by a PalCom service that is running on a separate device with available CPU resources.
- When CPU resources are available on the device, we have the option of running a PalCom service locally on the device either on top of the optimized PalCom virtual machine or directly on the hardware. This strategy was chosen for the IP camera where a PalCom streaming service can run directly on top of the embedded Linux kernel.
- When the objective is to allow large existing software systems to integrate with the palpable environment, then gateway services can be used. This approach was used to integrate functionality from 3D modeling tools.

The interoperability of PalCom services underpins the concept of PalCom assemblies. In the context of PalCom an assembly describes a set of services and how these services should interact. Assemblies can be dynamically created and modified by users through the PalCom Assembly Browser(s). The SiteTracker prototype is currently realized as a PalCom assembly of interoperable PalCom services. This enables the landscape architects to dis-assemble the SiteTracker assembly by way of the browser, consequently allowing them to create new assemblies that can support different types of activities. An example of a situation where a need for this kind of construction – deconstruction – reconstruction arises is if the landscape architect needs to take a still picture and tag it with compass heading and GPS location. The compass and GPS services of the SiteTracker could in this case be assembled with the PalCom enabled still camera, to provide the landscape architect with the required functionality. Such assemblies could also be constructed in advance and then just loaded when the need arises.

The PalCom open architecture ensures interoperability and thus allows for dynamic construction and deconstruction of assemblies. This in turn allows us to realize our vision of the SiteTracker being more than an isolated device offering functionality tailored to a specific use. In building the SiteTracker we provide the user with a kind of toolbox of PalCom services that can be combined in unanticipated ways to solve problems arising in the dynamic work environment of landscape architectural work.

3.3 End user composition

End user composition covers the aspects of the PalCom open architecture and infrastructure where end users can put together services and devices in new, ad hoc, ways using Assemblies. The focus is on end user interaction with the mechanisms for discovery and composition/decomposition of services and assemblies.

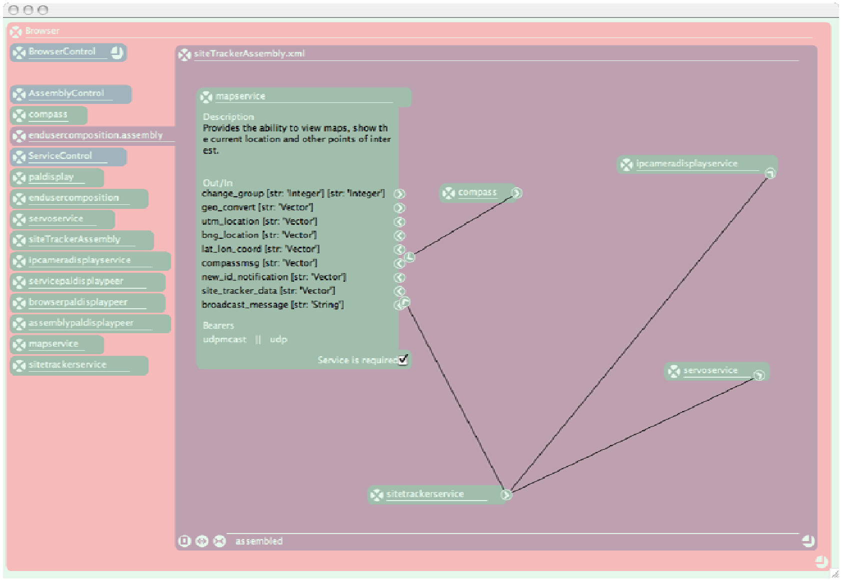

Figure 11: Inspecting an assembly and its services using the PalCom Assembly Browser

Figure 11 depicts the current version of the Assembly Browser, wherein end users are able to browse and inspect active devices, assemblies and services. It is possible to create or edit Assemblies and set up or inspect the control flow of information between the different participating services. The browser has been developed to support an accessible and simple way for end users to build, maintain and understand different compositions of services.

3.4 Designing for breakdown

Breakdowns are not just considered as something negative, e.g. failure or error, but also as something positive and constructive, i.e. as a means for gaining new understanding (Mogensen, 1994; Winograd and Flores, 1986). Consequently, we need to support the inspection of existing assemblies as well as the creation of new and unanticipated ones. In other words, to be able to create emergent assemblies people need to be able to understand the current state of affairs as well the potentials and affordances, i.e. make computing palpable. How would they do that?

Our primary tenet in achieving palpability is to address the otherwise opposing concepts of visibility and invisibility, and to support people in balancing the two. By way of example, when we think of real objects, e.g. a blender, a chair or a car, their constitutive components are all purely physical and, consequently, they are at some level readily available for inspection. We are always able either manually or using special tools to physically disassemble the blender and have a look inside. This ‘unfolding’ ability, that is, to expose constitutive components and their specific composition, is not provided in a natural way for computer systems. We need to explicitly and programmatically introduce these features into our software to achieve a corresponding ability.

Computational reflection (Ingstrup, 2006; Dourish and Button, 1998; Maes, 1987) is a technique by which a system is built and designed in such a way as to maintain a programmatically accessible model of itself. This model is at a given level of abstraction, i.e. expressed in terms of a certain set of concepts such as components, their current states and their composition. In a reflective system, these abstractions are maintained and can be used to document a system's overall composition and changing state. To be able to build a system capable of this requires an architecture that supports reflection. That is, that provides the necessary information that makes it 'readily available' for inspection and thus apprehensible to other software components or, more importantly, to users. The latter requires that the constructs with which the program is build are at some level understandable by humans. The aim of the PalCom architecture is to support both.

One of the main mechanisms by which this is achieved, in the context of PalCom, is through the concept of hierarchical maps, henceforth h-maps. Every service has an h-map as its primary structuring and message passing mechanism. An h-map is a simple hierarchical dynamic runtime data structure. Now, neither the benefit nor the novelty of h-maps lies in their abstract structure itself, but comes rather by its use. The h-map is used to both store basically all non-transient data of a process as well as to route messages among entities with association to the h-map. The h-map is further globally accessible and visible as well as externally visible and accessible through a generic simple interface, which is among others used by the Assembly Browser. One way to think about it is as the exoskeleton (Ørbæk, 2005) of a process, holding together the different software parts of the process and rendering them externally visible and accessible. The h-map strategy means a shift towards a more data-centric and extravert programming style, which potentially 'opens up' the long-lived object oriented concept of encapsulation. It is primarily a conceptual difference, as it is still up to the programmer to decide what goes into the h-map and what does not. Further, encapsulation could be supported by overall security schemes. The concept of h-maps does not in itself render anything visible in relation to a user; it only provides an intrinsic possibility 'waiting' to be utilized when things need to become visible. All services used in the SiteTracker prototype are built upon the notion of h-maps, enabling us to browse and inspect both the state of the individual services and their overall composition. As already stated, this was done by way of the Assembly Browser, capable of reading and graphically depicting the information provided by the given h-maps.

4 CONCLUSION

It seems likely that the SiteTracker prototypes may lead to useful technologies for the specific application domain that it addresses. Beyond that, the PalCom Open Architecture directly supports the highly dynamic work settings met daily by landscape architects. They are able to dynamically compose and decompose the specific functionality that they need by combining otherwise heterogeneous devices and software services. They are in addition able to inspect their state and current composition at runtime, enabling them to better correct possible errors, to adequately understand the underlying constituents of their assembly and, thus, to reconfigure these to fit new and emergent functionalities. The prototypes have also been trialed and found useful in other domains, and we are incorporating the SiteTracker services and devices in a range of technologies addressing support for major incidents emergency response.

Perhaps more significantly from a research perspective, however, iterative prototyping in this domain has helped to clarify and facilitate what we argue are advances in the conceptualization of ubiquitous computing, and how these may be realized. If ubiquitous computing achieves broad adoption then it will face a major challenge of comprehensibility: a world densely populated with interacting computation-enhanced devices and services risks being bewildering, annoying, and even dangerous. We argued that meeting this challenge calls for 'palpable computing' and we used this domain to give that specific meaning. Satisfying these requirements in turn posed sometimes radical demands (e.g. inspectability, invisibility/visibility, constution/de-construction/re-construction, and interoperability) for an architecture capable of supporting a world densely populated with ubiquitous computing.

Acknowledgments

We are very grateful for the contributions of landscape architects Lynda Thomson, Martin Stevens and Jim Wood.

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6. Major Incidents

6.1 Designing for palpability in event management and emergency response

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Designing for palpability in event management and emergency response

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ABSTRACT

This Case Study describes the design and test of a prototype in a real life setting: The MIO (Major Incidents Overview) prototype used during the Tall Ships Races 2007. The prototype was developed within the PalCom project, a large interdisciplinary collaboration concerned with the design of an open software architecture for 'palpable' pervasive computing. The MIO prototype is being designed to support situation awareness during emergencies and in the management of large events. We introduce the background, followed by an introduction to the MIO prototype and the open architecture, and a detailed description of why and how the real-life test was carried out during the Tall Ships Race. We finally describe key observations and evaluations of this experience of balancing innovative prototype technologies into real life through interdisciplinary collaboration.

Keywords
Palpable computing, event and emergency management, situation awareness, participatory design

ACM Classification Keywords
C.3 Special purpose and application-based systems, real-time and embedded systems, J.7 Computers in other systems, Command and control

1. INTRODUCTION

Since 2004 we have worked on the Palpable Computing project [20] with the goal to design an open software architecture that supports people in making computing palpable [10][9]. We illustrate what this means with concrete examples later but, in short, what we mean is that people should be able to notice, interrogate and understand what pervasive computing technologies are doing and could do for them. To support people in making computing 'palpable' we need to:

- empower users with the means to discover and interrogate computing devices and services at levels they can understand,
- enable users to share individual computational hardware and software resources over a network,
- provide support for dynamically assembling and maintaining computational resources to create a loosely-coupled whole and for breaking the same whole apart to combine the resources differently,

- supply means to manage and adapt configurations flexibly and with as little effort as possible, independent of the scale of the assembled whole and the operating environment.

In line with research into the usability of pervasive and embedded systems (e.g. [2][12]) we find that this is not just a matter of designing interfaces that provide rich feed-forward and feedback. It is also – crucially – a matter for innovative infrastructure design. To provide the capabilities needed, the PalCom open architecture [9] seeks to enable 'palpable' development, deployment and execution of applications through:

- a common runtime infrastructure to be deployed on hardware devices taking part in a PalCom assembly, enabling the deployment and sharing of computational resources on a distributed network,
- sets of components that as part of the runtime infrastructure provide common functionality used by deployed computational resources in execution.
- a programming model with API support for the development of individual computational resources and the dynamic composition of these into a whole.
- tools that support interrogation of individual resources and assemblies at all levels, e.g. the inspection of state information pertaining to a set of composed resources.

Infrastructural design brings not only conceptual and technical, but also methodological [13]. Most importantly for the case study at hand, it is necessary to anticipate and design for future uses of the infrastructure. This is difficult, because to make requirements emerge clearly enough, people need to be able to use these technologies realistically. A critical mass of working pervasive computing technologies and a degree of familiarity sufficient for confident and creative demand and use is needed. In effect, designers have to 'force' the future – or enable its colonization – and study the emergence of future practices in order to design for these practices [6].

We seek to achieve this by combining off-the shelf 'third party' pervasive computing technologies, either by wrapping them or by having the PalCom runtime environment running on them, and by designing new devices, services and applications that can utilize the features of the PalCom open software architecture. In collaboration with domain experts we strive to enable the creative appropriation of these technologies in specific contexts. Work contexts are one of the key areas where people want and need to use pervasive computing. Our 'application prototypes' and architectural prototypes have, therefore, been developed in close collaboration with professionals from a range of different work domains: landscape architecture [8], therapy and rehabilitation after hand surgery [15] physical and cognitive therapy with disabled children [18], neonatology [4], maternity care [5], and software development [8].

A further key domain is event management and emergency response. We initiated our research in this domain with a series of field studies and workshops to understand how the professionals – police officers, fire fighters, paramedics and medics – work. Evaluating the use of an ever increasing number of mature prototypes in an ever growing set of realistic settings [16][6] is an integrated part of our iterative design process. However, application prototypes are also – and importantly – a means to develop the PalCom open software architecture. So, during each iteration four different forms of evaluation are nested together, addressing the following issues:

1. Using: whether and how the application prototypes can be useful in supporting the professionals' work
2. Operating: whether and how we can make the technologies work and keep them working
3. Assembling: whether and how the prototype of the PalCom open architecture supports the assembly of pervasive devices, applications and services
4. Inspecting: whether/how the architecture is useful in supporting people in making computing palpable.

In what follows, we describe a key stage in our design process: the experimental deployment of the Major Incidents Overview (MIO) prototype and the prototype PalCom open architecture during the Tall Ships Race that took place in Aarhus, Denmark, on 5-8 July 2007. We begin with an outline of the MIO prototype, followed by a summary of the architecture. The main focus then is on how these technologies were set up and used by professionals from the different emergency agencies.

2. THE MIO PROTOTYPE

The MIO prototype is meant to support professionals from the different agencies (firefighters, doctors, paramedics and police) in a) producing and maintaining an up-to-date overview of an incident or event and the ongoing response effort and b) their collaborative management of the situation. As our starting point we wanted to focus on the work of responders on the scene of a major incident – knowing this to be the most challenging. We did that through participant observation during realistic exercises [7][16] and review of videos and experiences of real incidents with professionals. We studied work in the command centers on the scene of major incidents, created ad-hoc during emergencies as part of the effort to impose structure on the chaos of the situation, and work at remote 'centers of coordination' [19], such as the police incident room or the acute medical coordination centre in one of the municipality's hospitals. We also studied the responders' everyday work in ambulance call centers, the police station, the hospital and 'in the field' – shadowing the paramedics in the ambulance, the physicians in the medical mobile unit, the anaesthetists on duty at the hospital and fire-fighters on night duty.

A key problem – and opportunity for innovation in pervasive computing – we identified was the need for an overview of what resources are deployed, where and how. Today this has limited support. Lack of shared and/or individual overviews of other resources and other agencies' activities – for both staff on the scene and those stationed in command centers - hampers collaboration. From here we turned our focus to the potential of pervasive technologies to also support everyday work, like emergency medicine planning in the hospital, management of large and small events, and daily task support at the police station.

The MIO prototype is designed to allow professionals to assemble large numbers of pervasive computing devices and services, to get an overview of their resources, and to get data from devices to produce an overview of the situation on the ground and thereby support collaboration. MIO consists of an integration of a 3rd party application, Topos™ [1], developed in a previous project, with PalCom services. This is realized through a gateway service. PalCom-enabled resources in Topos can be shown geo-referenced in relation to 2D maps, GIS data and 3D terrains. We utilize data that the emergency agencies and their public service partner organizations (such as the council's planning and traffic engineering departments) already have. For example, satellite photography can be draped over the 3D terrain of the area of an event or emergency (Figure 2, item 1), so that real surfaces and existing buildings and vegetation are visible. GIS data draping and maps can be turned on or off for clarity (9). Additionally, the models and the GIS information of permanent and temporary structures (e.g. buildings and tents) are inserted (3, 10). A GIS inspector enables users to search tabular GIS information. The boat-shaped models (5) represent the Tall Ships, indicating where they are *supposed* to dock before the start of the race. Live tracking of GPS positions of different resources (e.g. Automatic Identification Systems (AIS), video-cameras, mobile phones (4) or fire trucks), is enabled through geo-referenced representations via signals from PalCom GPS services. Sketching functionality enables users to make drawings of e.g. newly decided access roads or cordoning off (not shown).

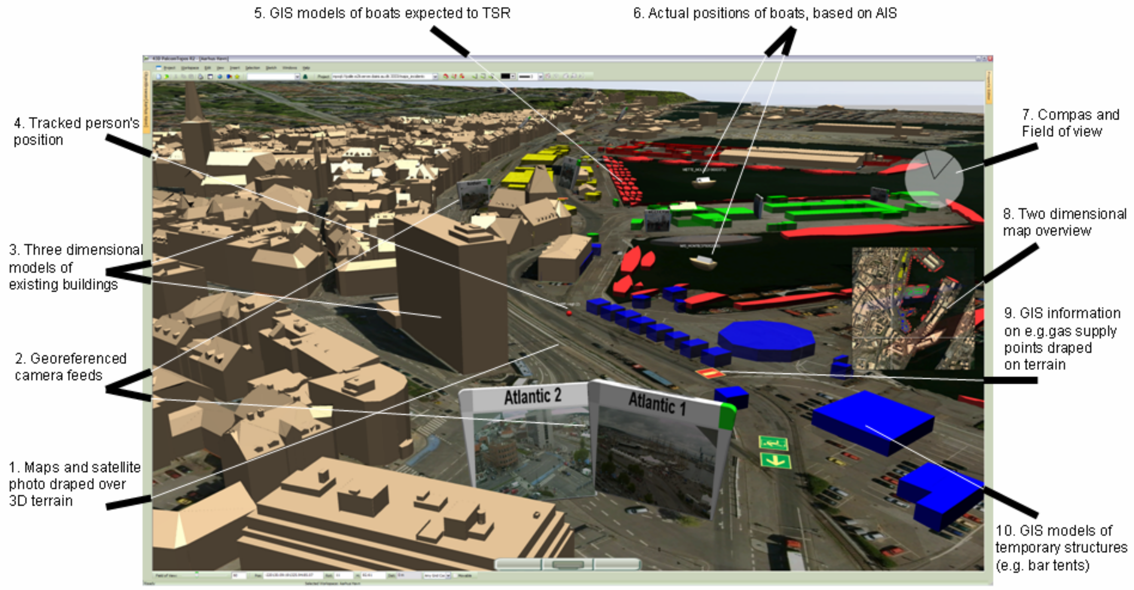

Figure 2: Major Incident Overview Prototype in 3D mode.

The screenshot, taken on the day before the event shows that two ships are arriving in the harbour (6) The small tags on top of these representations are the associated radar transponder AIS (Automatic Identification System) retrieved locations, that is, the ship's *actual* position. Live streaming of video and still pictures taken by GPS tracked mobile phones can also be shown at geo-referenced positions (2). A 2D Overview (8) provides at a glance awareness of one's own position within the model, and a 2D Bird's eye mode (not shown) enables easy navigation.

3. THE TALL SHIPS RACE

From July 5th to July 8th 2007 The Tall Ships Race 2007 was held in Aarhus in Denmark. Over 100 new and old sailing ships of all sizes and nationalities met in Aarhus harbour, before setting off for a race on July 8th. Many of the ships were open to the public during the four days and a large number of restaurants, bars, shops and different kinds of entertainments were set up in the harbour area. Ca. 200,000 people attended the event each day. Several concerts and performances were given during the event, many with free admission.

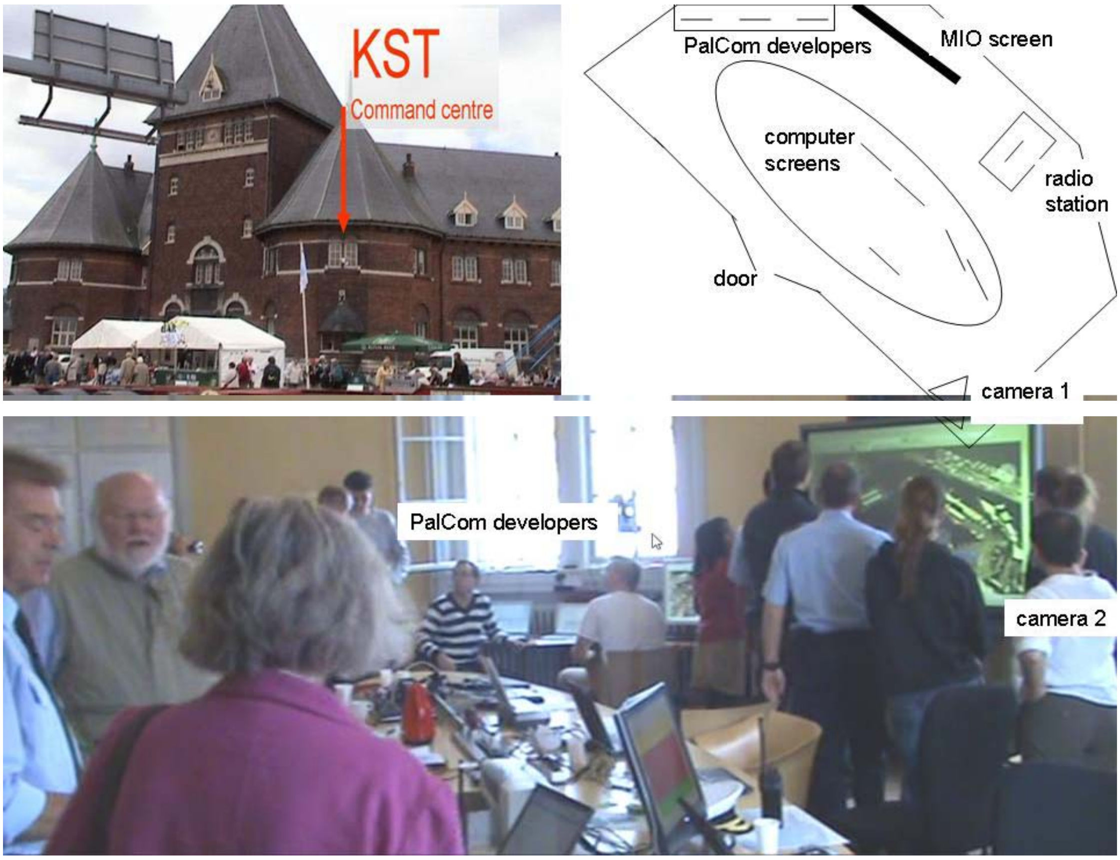

Figure 3 The Tall Ships Race command centre with MIO, and a view of the harbour during the preparations for the event.

An event of such dimensions demands emergency planning to ensure the ability to effectively respond to a wide variety of risks – and this work was planned by the ‘Preparedness committee’ in Aarhus (a group coordinating the collaboration between police, fire brigade, mobile emergency medicine services and hospitals, the Navy, and the Civil Army), together with representatives from the event-organizers, the municipality of Aarhus and the Harbour Authorities. The preparedness work began in the Autumn 2006, and from the very beginning we were invited to join the work – and we were invited to install the MIO prototype in the Tall Ships Race command centre. MIO was set up in and around the command centre established in the strategically located old customs house at the harbour. A large interactive display ran the MIO Topos application (Figure 3).

Figure 4: Tracked person (Jens Fonseca) and boat with rescue divers. Pictures taken by tracked personnel in top left corner

Figure 5: Pictures taken by patrolling officers, sent to and presented in Topos in command centre

Six geo-positioned video cameras were assembled into the MIO application via PalCom services: five fixed web cams and a remotely controllable dome-camera, all mounted in strategically important places. So too were six Nokia N95 phones incorporating GPS, four of which were carried by different officers on patrol in the event area, while the fifth was on a rigid inflatable boat (RIB) patrolling the harbour with rescue divers (Figure 4). Apart from being tracked via the phones' GPS unit, the officers also used the phones to take pictures of specific incidents they wanted to report to/discuss with the officers in the command centre. In the Topos model the images from the cameras (video and mobile phones) are geo-positioned according to where those cameras/officers currently are, thus, the staff at the command centre can see the live pictures in the context of their surroundings. Figure 5 shows an example of pictures used in managing the event. To ensure enough bandwidth for streaming video we set up our own wireless network with small directional satellite dishes.

In the command centre in the old custom house the large smartboard screen was used to display the Topos model, to sketch and discuss on the model and images sent by personnel on the ground, to interact with the devices and to interrogate them. In addition, three computers were used, mainly by developers, to monitor the status of devices within the MIO assembly and to support the staff in using MIO.

4. ARCHITECTURE

In our studies we find that 'readiness-to-hand' cannot be built directly into a technology, but evolves through use - it is an effect of human-technology interaction over time [5]. However, the achievement of readiness-to-hand can be supported through design. To this aim, we study people's practices of making technologies ready to hand through close collaboration with users and participatory design methods, ethnographic studies, and ongoing review of the relevant literature in social science, philosophy, computing and design. We describe our motivation in some detail in [10]. Here, we focus on how we have translated our research into prototypical design of an open architecture and how that architecture supports and was put to use in the course of the Tall Ships Race event.

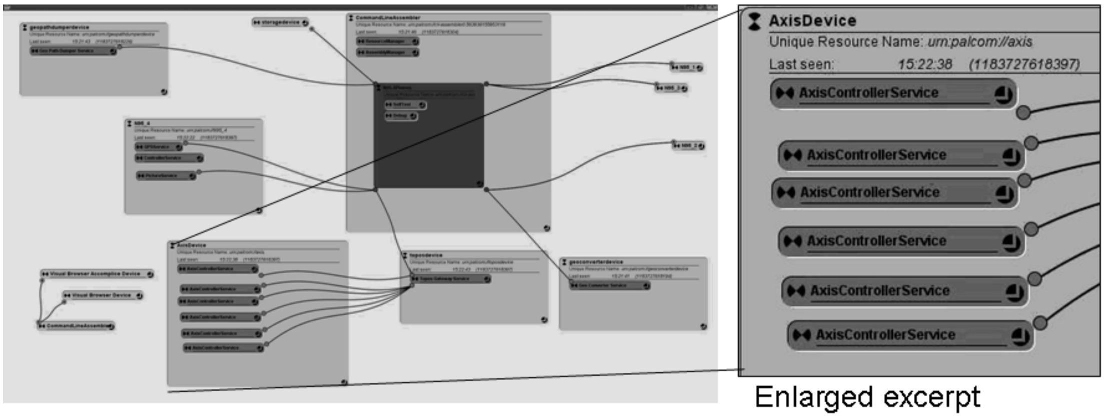

Figure 7: Screenshot of the Visual Browser showing all active/inactive devices, services and connections involved in the Overview prototype with some details of some devices and services unfolded (detail on the right)

The Overview prototype utilizes the PalCom open architecture to allow people to assemble a vast array of devices and services - palpably. Palpability is supported through the way in which the architecture facilitates construction/deconstruction as well as local and remote information access, rich feedback and inspection tools, like the Eclipse Browser and Visual Browser [11].

The current system architecture is composed of three main assemblies, each of which is responsible for orchestrating different devices and associated services. The choice regarding the exact number of assemblies utilized relies solely on a logical and conceptual separation of the different functionalities offered. This enables the designers and users to maintain a proper overview of the different constituents. The first assembly is in charge of assembling the mobile phones, the web cameras and the 3rd party application, Topos™. Additionally, the assembly manages the task of registering and storing every GPS position received from every GPS enabled device participating in the assembly. This is achieved by means of the purely virtual GeoPathDumperService, i.e., no physical device is or needs to be associated with it. There are many such purely software-based services participating in the prototype. In the case of the mobile phones and their ability to take pictures and geo-reference these, a GeoConverterService and StorageService are used. Secondly, the AIS assembly manages the task of assembling AIS information from the AISService with the Topos™ application. Thirdly, the GeoFrameDumper assembly manages the task of periodically storing images from every web camera assembled.

The system architecture of the MIO prototype utilizes/challenges the PalCom open architecture in various ways. Firstly, it challenges it in relation to the scalability of the system, that is, the diverse and large number of devices and services involved. During the event at any given moment about 30-40 devices (though, not all directly PalCom-enabled) and 80-102 PalCom services were actively participating in the prototype. The prototype also requires the ability to dynamically start, restart, remove and add services on the fly while still maintaining crucial functionality. To maintain such a complex system, various inspection mechanisms at the architecture level and inspection tools utilizing these were required.

5. USE AND EVALUATION

The command centre was a busy environment during the Tall Ships Race, with constant coming and going of staff, visitors, reporters, developers and observers. In terms of incidents, the worst things that happened were drunken brawls, minor crimes and injuries, disruptions to the safe flow of visitors, and parked vehicles obstructing emergency access routes. While the professionals were busy dealing with these issues, the relative calmness of the event provided extensive opportunity to explore and use the MIO prototype and the PalCom open architecture. This is a very exploratory application prototype and this was the first time it was seriously tested. We are still in the process of analyzing our experience, but we now present short vignettes of a series of examples drawn from developers' experiences during set up and operation, video ethnographic records and discussions with professional staff about their use of the MIO prototype and the architecture during the Tall Ships Race. For each example we then address the four evaluation dimensions described in the Introduction: using, operating, assembling and inspecting.

Example 1: Assembling the AIS

The PalCom architecture was challenged, when - just two days before the TSR event – we realized that it was possible to utilize live position tracking of most ships in the harbour, using a commercially available radar transponder AIS receiver. It was decided to purchase such a device, and to create a PalCom service that would expose the position of the ships in the harbour area to the MIO assembly, and to make them visible in Topos. Because of the functionality separation articulated in the PalCom open architecture, in terms of services that have no direct predetermined connections, a new independent AIS service could be constructed within a relatively short time using the PalCom framework and concepts.

The new service was then easily integrated into the already running assembly. Only minor changes to the Topos service were required, as it needed a 3D model of ships too. The position tracking features were already in place. All that was left to do was to add a few new service relations to the assembly, making the AIS service (re)use the already present Geo-Converter service, and then forward the ship positions to Topos.

Lessons learnt

Using: AIS integration is a good example of providing support for peripheral awareness (e.g. is the car ferry approaching, i.e. can we expect heavy traffic from it). It also proved useful with regards to relating plans with reality (e.g. whether the representation of the actual ship coincided with the allocated harbour position. Less positivley, in a significantly larger scale operation we would lack support for information management: just displaying hundreds of names of ships would not be a viable solution in such situations, and it would be difficult to compute due to the instability of the systems reporting current positions.

Operating: Although the integration of the AIS went smoothly, we had to make a few corrections on the fly. When we first plugged it in, it reported all vessels within a radius of ca 50 km, which was too many, both regarding performance and understandability.

Assembling: The episode illustrates the palpable approach of adding new functionality to an already existing environment, with a minimum of changes, while at the same time discovering and exploiting all the functionality that is already present.

Inspecting: When a new service is introduced, it is important to be able to inspect and modify in order to understand what it provides and probably alter it. In the example, there was an obvious need for inspecting what ships were being reported, and a need to modify the criteria, e.g. by specifying a radius, specifying an area (e.g. the harbour), specifying a filter (we were only interested in Tall Ships, ferries, and civil navy).

Figure 8: The patrol 'AABR-vagt' documents a wrongly parked car

Example 2: Wrongly parked car

10 am. Kristian, a fire service officer, asks two of his patrol officers to take one of the tracked Nokia phones. He stays in the command center, they set off (Figure 8, (1), 'AABR-vagt'). 10:30 am. Kristian's mobile phone rings: the patrol officers have spotted a car parked on the emergency access road on Pier 2. Kristian tries to see the MIO screen but can't. He writes down the registration number, asks them to take a picture and shouts the number across the room to a colleague who has access to the police database. With the registration number the police officer should be able to find out the phone number of the car owner in order to get the car moved. Kristian walks to the MIO screen , where one of the computer scientists is demoing MIO to the emergency response chief from a region in Norway, where the Tall Ships Race will take place in 2008. Kristian asks: 'Preben can you find that picture that just came up?' (5) and they see the patrol near a picture that was not there earlier (4). Within the 3D environment, Preben moves down to the picture to see it and its context (6). Both look at the image for a second, then Preben moves back to where he was and continues the demo, while Kristian walks over to his colleague at the police desk. Looking at his note pad, he says 'What have you written down here? XY? I think it's XP' (7). Preben overhears this and brings the pictures to the foreground (while staying where he was overlooking the harbour), just as Kristian says 'Isn't that right Preben?' (7&8). Preben reads the registration number out loud (9) and they confirm that it begins with XP. Satisfied smiles follow, and the police officer opens the database to find the owner's phone number

Lessons learnt

Some of the lessons learnt in this modest example of use are known, but strongly reinforced through the experience and worth repeating because they are so important, others are new and specific to this domain

Using: MIO seems to offer much richer information than standard means – e.g. about exactly where and how the car obstructs the rescue roads as well as such specific details as the number plate. Furthermore, the flexible interaction, e.g. possibilities of going to the object of interest to see it in its context (9), of opening it in its host application (6) or bringing the object to the front (not shown in this example) successfully supported different kinds of enquiries into the matter at hand. As described in the architecture section, all the phones were put into one assembly, meaning that we did not keep information about who was carrying a specific phone at a specific time. While this was not a problem in the example above, when we wanted to re-find the picture the next day, it was not so easy. We learnt that there ought to be an assembly per phone assembling it with different users over time.

Operating: The phones were assembled into one assembly, both for practical debugging reasons and for performance (an assembly per phone would roughly multiply the number of connections to maintain by 6). The performance issues are reasonably straight-forward to deal with, whereas it is non-trivial to find a proper mechanism for propagating corrections to running instances that are similar (same type), but not exactly the same during debugging.

Assembling: Regarding the inspection of who took which pictures when (assembling user, phone, and timestamps) the infrastructure provided all the handles, but – because our main design goal is the open architecture – we did not have the time to utilize these the whole way ‘up’ so to speak, into the interface. We expected problems here, and we were proven correct.

Inspecting: The interrogation/inspection capabilities were not used in this example (but see below).

Example 3: Where’s Jens?

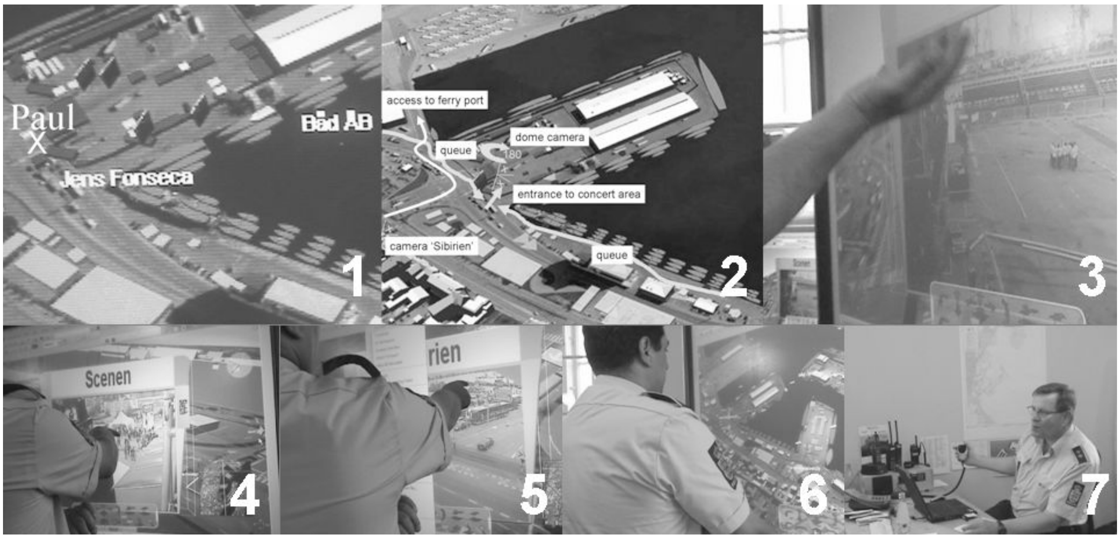

Figure 9: Producing situation awareness and assessing the risk of people queuing through radio, GPS, cameras.

7:40 pm, people are queuing for a concert due to start at eight. Paul, a fire service officer calls in: ‘I’m behind the stage (position marked X in Figure 9 (1)). It’s chaos here. I need Jens’. People are queuing all the way along the quay, and, more importantly, across the access road to the ferry port (2) This creates a dangerous situation, as cars are trying to get through. Paul wants a police officer’s opinion. The call taker in the command centre looks at the MIO screen and says: ‘Jens is on the corner of Pier 3, near you’. The police commander then asks one of the developers who is looking at the concert area using the dome camera mounted on the stage, to lift it and turn it to look at the entrance to the concert area (3). As soon as the camera reveals a view, he says ‘There’s no pressure [no problem] here’ (4). He asks the developer to move to the camera overlooking a major cross roads, and remarks ‘They’re queuing all the way down here, too’ (5). There is no camera available for a view onto the ferry port access road. Paul calls again: ‘I can’t find Jens’. In one move, the police commander turns to the developer, saying ‘Can I take over?’, and switches to the ‘home’ position to reveal the position of Jens Fonseca (6). He sees and hears the call taker looking at the screen and saying ‘But he is there’ to encourage Paul to look harder.

Lessons learnt

Using: We begin to see the emergence of practices that involve MIO in collaboratively producing situation awareness, carrying out risk assessment and responding to a risk. The staff make full use of the ability to inspect the trouble from different perspectives (the radio report, the two different camera angles), and they confidently rely on the location information provided through the N95 phones.

Operating: In general, the operation of the various cameras worked smoothly, although the bandwidth available varied with the weather and they were sometimes blocked by operations on site. The user interface for remotely controlling the dome camera was not precise enough to allow fine control.

Assembling: The camera assemblies were set up before the event and were stable during the event.

Inspecting: Perhaps the most interesting question arising from this example is, how did the call taker, the police commander and the developers know that they could trust the location information given (e.g. for Jens Fonseca)? At the current stage of our development, seeing Jens Fonseca’s position indicated by his name in the Topos application could mean one of two things: (a) his phone is where the label indicates, (b) it was there when it dropped out of the assembly (in which case we record the phone’s last known position). Looking at MIO is not like looking out of a window to verify a person’s whereabouts. As outlined in the architecture section above, many services and devices are involved, each introducing potential sources for error or failure. Methods we saw people apply in their ongoing management of trust in the technology include: triangulating shown position with people’s last descriptions of where they were/are, and with background noises overheard in intermittent radio communications from them, knowing their previous locations, seeing the label wobble (which it does due to fluctuations in GPS accuracy, even when the phone carried is not moved), seeing the label move as the person carrying the phone moves, knowing that developers are confident things are working (from overhearing their conversations or explicit reassurances), seeing someone else trust it. Although all those mechanisms are useful and will probably be needed despite improvements, there are many ways in which palpability could be supported ‘all the way up’ in the interface, using the information made available through the infrastructure. We should, for example, indicate on the representation of the person carrying the GPS whether it is ‘alive’ and connected, provide indications of its accuracy (e.g. calculated on a sample of reported positions), and provide a time-stamp of the last time we were in touch with the GPS. A further method comes to the fore in the next example.

Example 4: Heartbeats

Just before the concern about people queuing up for the concert arose, the two young fire service officers who had been on patrol all day dropped into the command centre to pick up a newly charged phone. They approach one of the developers (Jesper) to ask if they could see the pictures they took on their last round, Figure 10 (1). He browses through the list of picture entries from their current phone and opens the last one taken. It shows the window sill of the command centre (where the developers charge the phones). This is not what the officers, nor what Jesper expected (2). One of the officers points to the file name ‘N95Device_3’ (3), remarking that this was indeed the phone that they used. He is able to do this, due to the fact that the phones where physically tagged with names corresponding to their software service names. Jesper checks the full file name associated with the last picture, which also includes a time stamp (4). It turns out that the picture was taken to test whether the phone was correctly assembled into MIO just before the officers set off with it, about an hour and a half ago. A second developer, Morten, working on the computers behind them, overhears the conversation and picks up the phone and inspects whether a heartbeat is received within MIO. While Jesper promises to check what happened with the “missing” picture(s), Morten then works in the background to ensure that the new phone the officers are about to take out is working correctly. Jesper checks whether the “correct” last picture had in fact been taken and sent from the physical phone to its associated software device, the N95Device_3, representing it on the network and further on, via the PictureService running on this, to the StorageService running on an entirely different device. The pictures should then have been read from within Topos upon a message of their arrival sent from the ToposGatewayService originally sent from the StorageService, this message might have been lost due to high network traffic. In the meantime Morten, the other developer, turns on N95Device_2, starts its PictureService, GPSService and ControlService and waits for a heartbeat (provided by the architecture) of the physical phone to appear on screen (5). When it does, he and Jesper reassure the officers that their new phone will be tracked, take, geo-reference and send pictures to MIO and Topos.

After a short interruption, the two developers begin to investigate and address the problem with the officers’ N95Device_3. They turn off all services running on it and restart them, waiting to see the heartbeat appear on the screen (6). It does, as it also did when the Morten first checked, and this leads the developers to suspect that the problem is in the gateway service between Topos and the StorageService, and they inspect the storage device to see whether the photos were actually saved. They find that the pictures were indeed sent and saved, leading them to decide that a restart of the gateway service is needed, to re-establish lost or dead connections.

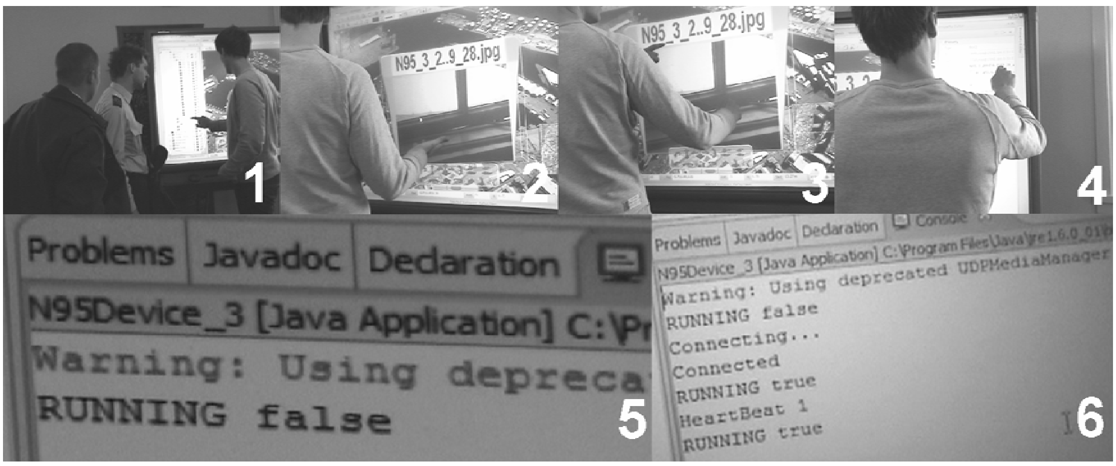

Figure 10: Making sure N95-3 is connected properly into the assembly

Lessons learnt

This example illustrates several strengths of the dynamicity and inspectability of the open architecture. It also shows that support for more complex user inspections and error finding is not a trivial task.

Using: Most of the work in this example was done by developers using interfaces and tools not meant for end users. However, the tight and visible coupling between the physical devices and their digital counterparts proved very useful. Likewise, it is evident that providing mechanisms for e.g. the fire fighters to rapidly conduct similar investigations would be very beneficial.

Operating: From the developers' point of view, the assemblies were very robust. They could stop and start services on the fly without interfering with the rest.

Assembling: The possibility to inspect each assembled service and their incoming and outgoing connections was indispensable in relation to explaining to the professionals what was actually going on. Additionally, it helped the developers to pinpoint the exact point/points of failure in an error situation and to correct these.

Inspecting: Many others have used something similar to heartbearts, the difference comes with the PalCom open architecture having the heartbeats directly integrated into the communication architecture. The Eclipse and Visual browsers allowed the developers to inspect which route the patrol officers had taken and to see how far pictures had been placed along the route and where the placing stopped. It is obvious that by extending the Visual Browser (Figure 7) this could be improved further. Still, the developers knew the 'planned' route the pictures were supposed to take. It is more of a challenge to use this information in tools and interfaces meant to support professional users (e.g. as patrol officers) in noticing and understanding the (mal-)functioning of a device or assembly of devices.

6. CONCLUSION AND FUTURE WORK

In the PalCom project we are developing ubiquitous computing right through from architecture to applications because we argue these have strong interactions. To be usable, users need to be able to make these systems 'palpable', and we have sought to design for this 'from the bottom up', so to speak, from an architectural level. To achieve this we have used participatory design methods – going through the experimental deployment of PalCom-enabled applications down into the design of the architecture. We believe this integrated approach is novel and highly productive. This paper reports one case study, which is just a small part of our overall project.

The case study was ambitious as it was the first real trial of the MIO prototype, so neither the staff nor the developers had experience with the use of the prototype during a real event let alone an event this large, taking place over several days. Furthermore the prototype is still under development and several parts of the infrastructure and some of the functionality were developed just before the event began and were modified during the event based on experience in use.

With this in mind, the trial appears to have been a considerable success: it was very enthusiastically received by a wide range of emergency services personnel, limitations were exposed, and further development paths were identified. The trial provided and tested the means to use ubiquitous computing to enhance users' understanding of work in context, as illustrated in examples 2 and 3. It provided and tested the means to make and inspect assemblies, as illustrated in example 4. At present, this is done by developers (but with users resourcefully improvising equivalents); the aim is to migrate this towards end users not only through further innovative architectural design, but also through attention to the potential for novel 'extrovert' interface. Today during an emergency response some of the staff, e.g. some police officers, are highly competent in handling breakdowns in the IT support, and there is often local technical support. In the future these may be trained in handling assemblies and breakdowns of the kind our developers handled during the Tall Ships Race. Lastly, we tested the flexibility of the underlying architecture, as illustrated in example 1.

For the future, we plan to deploy a new version of the prototype at the police and fire brigade command centers and the acute medical coordination center. A related system may also be developed for airport control and coordination. We will expand the prototype to cover a fuller range of resources, and to register and monitor accident victims. In these ways we plan to make MIO beneficial for everyday use, so that it is also ready-to-hand for rare events and major incidents.

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[20] The PalCom Project http://www.ist-palcom.org/

6.2 Designing for material practices of coordinating emergency teamwork

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Designing for material practices of coordinating emergency teamwork

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ABSTRACT

In this paper we describe the inspiration for, and the design of, prototype technologies that support emergency teamwork. We combine ethnographic studies of material practice, participatory design collaboration with emergency personnel, and knowledge of the potential of ubiquitous computing technologies to 'stretch' the materiality of environments, persons and equipment. A range of prototypes – products of an iterative, ethnographically informed, participatory design process – are described in a series of scenarios. We conclude with a discussion of potential benefits and challenges our experience raises for socio-technical-material innovation in emergency teamwork.

Keywords

Ethnography, emergency teamwork, palpable computing.

INTRODUCTION

In emergency situations, materiality is key to both chaos and order: Incidents become serious because violent or fast-spreading physical reactions cause damage to material objects and bodies. People rely on material clues (smoke, heat, smells, noise, etc.) to notice and understand threats and to monitor their success in addressing them. Equipment, people, and matter embroiled in the chaos of an emergency incident need to be physically moved, they are seen and heard to be moved, indicating the emergence of order out of chaos. In this paper we present observations from a study of human material practice – that is, people's embodied conduct and their methods of making sense of, and of anticipating, the behaviour of material agencies (fire, wind, rain, biological, chemical, etc.).

As emergency staff increasingly utilize digital technologies and 'grid' resources such as connectivity, location information, GIS services, or satellite photography, they begin to 'stretch' the materiality of environments, persons, and equipment. These technologies have the potential to support sense-making activities, multi-agency co-located and distributed collaboration, and collaboration between emergency staff, the media, and the public. However, the 'immateriality' of computational processes, coupled with endeavours to make ubiquitous computing 'invisible' (by embedding it in large and small devices and environments, and through strategies like 'autonomic computing', 'self-healing' and 'ambient intelligence') can make it difficult to make the most of innovative socio-technical potential in the context of emergency work. While embedding, autonomy, etc. are attractive and useful design goals in many contexts, we believe they must be complemented with support for making computing 'palpable', that is, 'plainly observable', 'noticeable, 'manifest, obvious, clear' (Oxford English Dictionary, http://dictionary.oed.com/).

We currently pursue this goal as members of the PalCom project (http://www.ist-palcom.org/) In this paper we draw on ethnographic observations and collaboration with emergency staff in Aarhus, Denmark, to delineate some key features of material practice in emergency response work, and some of the design opportunities we are pursuing. Analysis of observations and engagement with professionals have been part of an iterative participatory design process, which we describe in some detail in, for example, Kristensen, Kyng and Palen 2006, Büscher, Kristensen and Mogensen 2007. In this paper we focus on the inspiration for and the design of prototypical support for the production and maintenance of shared situation awareness of a changing emergency situation, and to support the coordination of the response effort. The prototype technologies have been evaluated in participatory design workshops, where personnel have been able to experiment with them and take part in the process of making palpable ubiquitous computing useful for emergency teamwork.

BACKGROUND

Situation awareness – accurate perception and comprehension of what is going on and its implications, and the ability to project future status and use this information to inform decision making (Endsley, Bolté and Jones 2003) – is regarded as a core skill for emergency personnel, especially incident commanders (Flin 2005). It is regarded as a cognitive skill that requires individuals to process large amounts of diverse information and form a mental model of the situation. Experience can help professionals build schemata of typical situations, increasing their processing efficiency (Endsley et al 2003). Apart from knowledge about different situations and effective ways to respond, they acquire pattern matching abilities, which enable recognition-primed decisions and mental simulations of possible courses of action (Klein 1998). The potential of new technologies is seen to lie in bringing together and visualizing large amounts of information (King 2006, Tomaszewski and MacEachren 2006) and to support human information processing capabilities, for example through 'information fusion' and semantic webs (Smart et al 2005). Where ubiquitous computing technologies are concerned, the potential is twofold. On the one hand, potential lies in the fact that communication can be supported and information can be made available anytime, anywhere – for example in fire engines en route to an incident, and on portable or wearable devices such as PDAs and mobile phones. On the other, ubiquitous computing makes it possible to generate real-time information – for example, about the location of resources and personnel using location tracking devices (Jiang, Hong, Takayama and Landay 2004) and about conditions on the ground using cameras (Betts, Mah, Papasin, Del Mundo, McIntosh and Jorgensen 2005).

We greatly appreciate this work and share some of the ideas expressed there. However, at the same time, we disagree fundamentally with some of the assumptions that underpin this work, most notably about the nature of situation awareness and decision making. We spell out the main issues below, but leave more detailed discussion for a different time, because such a discussion could easily take up all of this paper. However, the design of our prototypes, described in the sections that follow, embodies our understanding of situation awareness and decision making, and, as we describe them, we aim to make alternative conceptions take shape for the readers.

The focus on individual cognition, mental models and pattern matching in the literature on situation awareness and decision making in emergency situations is – seen from our perspective – deeply misleading. Most importantly, this is because, as Lucy Suchman has shown in her seminal study of *Plans and situated action* (Suchman 1987, 2002) human situation awareness and purposeful action are not just an outcome of cognitive processing. They are at least also, if not actually predominantly, a matter of collaborative material practice and accountable practical action:

- By 'collaborative' we mean that people actively work together to assess a situation (for example, talking, jointly investigating), and/or that peripheral awareness (for example, of the talk and embodied conduct of others, see Heath and Luff 1992) informs their assessment of what is going on
- By 'material practice' we refer to people's embodied physical conduct and their engagement with material agencies (like fire, wind, rain, biological or chemical agents), equipment and environments.
- By 'accountable' we mean that human action is documented in different ways, most importantly:
    - *deliberately*: People can and do explain what they are doing and why.
    - *physically:* People document where they are, what they are doing as well as intended or likely next actions, and – to some extent – what they are perceiving, thinking, feeling, for example, through their embodied orientation and expression. This is a pervasive, automatic, inescapable fact of embodied human action in material environments.
    - *inferentially:* Because action is socially, and spatio-temporally organised, people can infer meaning. For example, if a person fails to respond to an order, their lack of response is noticeable. They can be sure that the commander will infer that they are defiant, afraid, or have some other reason to disobey.

  Drawing on Garfinkel (1967), we see people's behaviour as accountable in two senses: (1) 'account-able' (i.e. visible and describable) and (2) 'responsible' – people are answerable to others about their behaviour.
- By 'practical action' we mean that people actively *make* sense of things – for example by placing themselves in a position where they can see, by trying to categorize what they experience, by using information.

This means that situation awareness and decisions are *outcomes* of collaborative, material and practical activities, not just individual cognitive skills or processes. We seek to understand the practical achievement of situation awareness and decisions *inter alia* through ethnographic studies, and aim to support the practices involved.

THE STUDY

A school bus has collided with a train carrying chemicals (Figure 1a). The incident is reported to the police as real, to test and train regular on-duty staff across the different emergency agencies. On their arrival, the staff, of course, realise that this is an exercise. However, generally, and also on this occasion, staff value the opportunity to learn under as real as possible conditions and manage to ‘suspend their disbelief’. As a result much of their behaviour is close to realistic. Researchers observed as first responders correctly classed and dealt with the incident as a major incident, requiring coordination between different agencies. Post-exercise discussions with members of the fire brigade, the police, ambulance and paramedic services, medical and trauma centre staff highlighted material practices as powerful opportunities for design. We provide a summary of inspirations from observations and discussions below. The images shown are still frames from video recordings made with a hand-held camera, shadowing personnel on the ground during the exercise in rainy weather. As such, they lack quality, but they also document key aspects of events right at the heart of the response effort. The issues pictured are explored in some detail in the text in this section, and also through the design of our prototypes and the scenarios of use described in the next section.

Figure 1a The collision. **b** Perception in motion. **c** Mirroring. **d** Performing threat assessment.

Perception in motion (Figure 1b) Two minutes after the incident has been reported, the first ambulance arrives. Police and fire fighters are already on the scene. In Figure 1b, the fire fighter (on the left) rushes towards the train past a police officer. He does not look where he is going but, like the police officer, observes the paramedics disembark from the ambulance. This behaviour of trying to take in as much of the scene as possible is typical and helps staff understand the changing situation.

Taking on/mirroring someone else’s position (Figure 1c). The most important first steps for first responders are not necessarily to rescue victims, but to make an adequate threat assessment and set in train an appropriate response (Perry and Lindell 2003). Here, the ambulance manager (on the left), is concerned about the smoke/fumes coming from under the railway carriage and the bus. ‘How dangerous are the chemicals involved?’ He inspects from a safe distance, his position ‘mirrored’ by a passing fire fighter (middle). Staff often mirror colleagues’ posture and gaze like this, frequently in response to exaggerated, almost theatrical ‘performances’ of looking intently (see also below). This almost literally puts the ‘mirrorer’ in the ‘mirrored’ person’s position. This practice can have a ripple effect, where several people are drawn to looking at the same thing, as illustrated by the police officer in the background (on the right) also looking at the issue that caught the ambulance manager’s and the fire fighter’s attention.

Performances (Figure 1d) Exaggerated, theatrical behaviour can attract attention and provide live information about important assessments-in-progress. Attracted by the mirrored looking described above, the firechief rushes to inspect the chemical spill, accompanied by the ambulance manager. Figure 1d captures their retreat. The fire chief (on the left) ‘shields’ the paramedic (on the right) from the danger, and the paramedic acknowledges and demonstratively collaborates in this move by reflecting the firechief’s shielding gesture. Gestures like this and their contribution to the establishment of rapport between team members are analysed in more depth in Büscher (2007).

Moving equipment (Figure 2a) The equipment that rescue personnel bring to the scene – ambulances, cars, fire trucks, barriers, etc. – can serve to impose order onto chaos. Positioning equipment is an important way of marking out areas or routes, for example. Having identified the chemical spill as dangerous, the ambulance manager instructs his colleague to move the ambulance. This move begins to create a rescue corridor as far away as possible from the chemical spill, to protect victims and the rescue team.

Documentation of material agency. Material agencies document their states and processes and project (at least some of) their future actions. People rely on this feedback and ‘feedforward’. In this case, however, because the chemical spill is simulated rather than real, it is difficult for the staff to assess the level of danger intended by the exercise organisers from the material documentations - green coloured fluid and smoke created with dry ice. The firechief (seen on the left in Figure 2b) radios the command centre at the police station to find out more. As he finishes his call he joins the medical staff, who have ‘huddled’ together to discuss the rescue, and thereby allows them to overhear that the chemicals are more dangerous than previously thought.

Figure 2a Equipment marks boundaries. **b** Huddles 'broadcast' meetings. **c** Uniforms document role.

Huddles and embodied conduct (Figure 2b). In his book *Encounters* (1961), Erving Goffman observed how people form 'huddles' when conversing – their feet, bodies and faces oriented towards each other. This is a cultural and material response to the capacities of human bodies in physical environments. Huddles 'broadcast' that decision-making is in progress and, like other forms of conduct, huddles are accountable, that is, they simultaneously achieve something – e.g. decision-making – and document or provide 'accounts' of what is happening. The 'broadcast' nature of embodied conduct is not necessarily the result of a deliberate effort (although it can be), but usually an automatic and inescapable side effect of getting on with the job. After the moment in Figure 2b the firechief informs his colleagues that the rescue effort has to be delayed until fire fighters with breathing masks are available.

Personnel wear uniforms and equipment (Figure 2c). The fact that staff wear uniforms and equipment like breathing masks enriches the accountability of actions. In Figure 2c the firechief (on the left) instructs a fireman wearing a mask to protect him from the poisonous fumes of the spill.

Figure 3 Imposing order on the chaos of the incident site: The personnel create areas where victims can be treated (left), a corridor for transporting victims, and a hand-over point between masked and non-masked fire fighters near the back of the ambulance.

Documenting evolving collective situation awareness through motion (Figure 3). The broadcast accountability of embodied conduct is not restricted to static postures, gaze, or orientation. Movement itself (of people and of equipment) is a socially organised form of documentation that can inform the collaborative production of socio-material order. Figure 3 gives a glimpse into how the 'corridor' is defined by the damaged bus and train, the ambulance, and by moving victims through it. The point where victims are handed over to non-breathing-mask staff marks the assumed range of the poisonous fumes. Victims are taken to the 'waiting area' (the leftmost image in Figure 3) where they can be triaged, treated and prepared for transport.

These material practices help the personnel on the scene to make sense of the extreme situation at hand. However, even those on the scene only ever get a partial picture, even though, and partly because, they are right in the middle. For colleagues in command centres, hospitals, ambulances, the picture is severely impoverished – often all they can get is a verbal description. In this exercise serious misunderstandings arose from the uncertainty about the danger of the chemical spill. The implications for ambulance access routes to the scene (ideally away from the prevailing wind direction), for preparing transport to, and treatment at, specialist hospitals were not fully appreciated and not communicated immediately when the higher than initially thought level of danger was recognised. According to the professionals in our team, such misunderstandings and delays are a common problem (see also Landgren 2005). To get more accurate, richer, and more up-to-date information, staff who are unable to see for themselves have to contact those who can, or be deliberately informed. The off-site personnel are keen to allow the staff on the scene to get on with the job and not be disturbed, and keep requests for information to a minimum. While it is vital that staff elsewhere on-site, en-route, or in command centres, hospitals, and dispatch centres develop an accurate sense of the situation, it is hard for them to know when would be a good time to call.

Our study highlights a number of opportunities for design, particularly around the account-ability, intelligibility, or broadcast character of material practice. Our design goal is to support material practice, by enabling personnel to amplify the broadcast range of material practices and to make sense of such documentary evidence in their collaboration with each other: both on-site and between on-site and off-site personnel.

PROTOTYPES AND SCENARIOS OF USE

We now delineate some prototypes (in various stages of development) through a series of scenarios we have developed. The prototypes and scenarios have been inspired by our field-studies and worked through with emergency response staff in a range of workshops and future laboratories (Kristensen et al 2006, Buscher et al 2007). Five different scenarios are explored. For each scenario we briefly spell out how the technologies address our design goal and how this may benefit emergency teamwork.

The Prototypes

The PalCom-Major Incident prototypes bring together many local and distributed devices – geographic positioning systems (GPS), wireless bio-monitors, mobile phones, radio frequency identification (RFID), still- and video-cameras, input and output devices, displays, and more, exploiting grid resources such as connectivity, location information, satellite photography and GIS data services. These ubiquitous computing devices, resources and services open up the potential to create synergy by putting them together in different ways, creating 'assemblies' designed to suit people's shifting goals. In this section we describe different assemblies and the 'synthesized services' (PalCom 2006) they provide. Our focus is on the PalCom Major Incident Overview (MIO) assembly. The prototype consists of a 3D 'workspace' containing a digital terrain model of the relevant area overlaid with roadmaps, aerial photography, GIS data (location of emergency routes, fire hydrants, dangerous industries, etc.) and an array of devices, resources, and services that make it possible to harvest information on-site, place it in the 3D workspace and interrogate it on portable and stationary devices on and off-site. The prototype supports freehand drawing on the 3D terrain, inclusion of pictures or other documents, inclusion of 3D objects (e.g. buildings, vehicles, representations of people), movement, scaling, colouring and animation of those objects. Three-dimensionality allows people to construct a sense of the topography, supporting the personnel's efforts in determining, for example, whether rescue vehicles will be able to access certain areas, or why a particular area has been chosen for the treatment of victims. By switching to a bird's eye view, a 2D overview can be obtained. The prototype supports collaboration via shared access to the incident workspaces from a variety of locations, and supports localised views and tools for manipulation. The MIO prototype augments collaboration done in and through talk with support for 'stretching' the materiality and accountability of human and material behaviour. Staff are expected to continue to use radios and mobile phones, even though their use may change. MIO is designed to utilise the PalCom open architecture (PalCom 2006), which supports inspection of the computational processes and affordances involved in MIO assemblies.

The scenario incident

On a dark, rainy evening a goods train and a passenger train collide near the main railway station in Aarhus. The area immediately affected is ca 1000 x 600 m. The incident is being reported by staff and members of the public witnessing events from nearby. An alarm goes off to various alarm centres.

Scenario I: Alarm goes off

Information about the location of the incident is provided with the alarm and fire engines, police cars, medics, and ambulances are dispatched. A police officer initiates the creation of a MIO workspace:

- S/he creates a workspace called 'Railway Station Accident'. This workspace is accessible from stationary devices, from inside the vehicles (e.g. on a dashboard display), and on portable and wearable devices.
- As (GPS tracked) rescue vehicles are dispatched they are automatically[1] assigned to sub-workspaces, named 'Fire-vehicles', 'Ambulances', etc., and represented by simple 3D objects (Figure 5) in the main workspace (vehicles are,. The various sub-workspaces may be opened or closed as appropriate.

[1] Automation is not invisible but more or less subtly available for attention, depending on automation policies. This support for making computational processes palpable mirrors principles outlined in Ghizzioli et al (2007) for automatic connectivity negotiation.

- Terrain data, GIS information and maps are being downloaded into the workspaces. These may include up-to-date satellite photography, and maps of the availability of 'grid' resources, such as electricity, fire hydrants, digital location information and connectivity.

Organizationally, a Remote Command Centre at Aarhus police station, and an Acute Medical Coordination centre at the central hospital are being established.

Figure 4 The Aarhus fire and police commanders discuss the organisation of the scenario incident site during a workshop.

Figure 5 The Railway Station Accident workspace, showing the terrain at the scene with the first emergency vehicles arriving.

Supporting material practice: Maps and satellite photography allow the staff to gain a sense of the area affected. Representing and tracking important resources en-route and arriving on the scene enriches the sense the emergency service personnel on and off site can make of the unfolding situation.

Scenario II: Fire and Police commanders create initial organization of incident site

Like his colleague in the harbour exercise, the fire commander explores the scene. He, like most of the staff, carries a GPS device in his helmet and his location is dynamically represented within the MIO Railway Station Accident workspace in a way that also indicates his role and rank. As he walks, he presses a button on his shoulder at significant points, thereby marking a first, rough boundary for the inner danger zone, that is, the zone that only fire fighters are allowed to enter. When he returns to what he has chosen to be the Local Command Centre and his vehicle arrives there, he uses a touch sensitive screen and together with the police commander amends the rough boundaries he drew while walking to organize the incident site. They draw directly on the 3D terrain (Figure 7). Due to the distributed nature of the prototype, the site organisation is immediately available on displays in dispatch centres, remote command centres, vehicles, and on the sleeve mounted displays of on-site personnel.

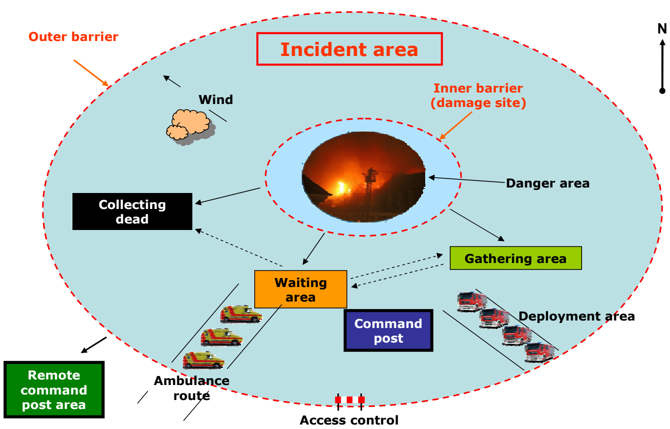

Figure 6
Schematic showing an abstract organization of an incident area.

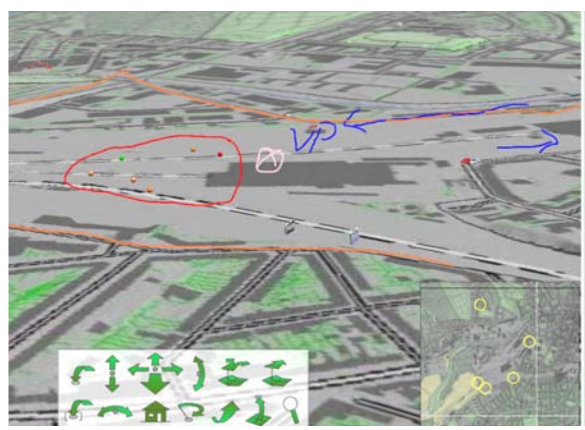

Figure 7 Detail of the organization of the scenario incident site drawn by the Aarhus fire and police commanders, with inner and outer barrier. The waiting area (Vente Plads, VP) is marked by a cross and transport routes are indicated.

Supporting material practice: Being able to ‘draw’ with their physical movements on-site allows the staff to amplify the broadcast range of their in-situ assessment through very little extra effort. They can amend such first impressions collaboratively, and quickly share their assessments (and revisions of such assessments) with others.

Scenario III: Victims are found

As fire personnel enter the crash scene, assessing the situation and preparing the rescue operation, they position communication base stations. The base stations communicate via Bluetooth and relay data from individual devices or assemblies via WiFi to the general network. When the fire fighters find victims, where possible, they take a patient-ID device assembly (consisting of RFID-tag and reader, bluetooth communication to base station, plus a location device), and attach it to the victim’s body in a prominent position (Figure 8). Representations of victims identified and located in this way appear in the corresponding location in the MIO terrain (as orange spheres) and are organised in a ‘victims’ sub-workspace. At first the spheres indicate only *that* there is a victim in a certain location. Later, when rescue personnel attend to victims they may also attach biosensors to these victim’s bodies. Each sensor should be swiped over the ID device before it is positioned on the victim. This association of ID and sensor means that the information sent by these sensors is accountably measuring this specific victim’s vital signs. To indicate this, the ID device and the sensors blink in common patterns and are shown as ‘working’ in a map of the assembly, where users are also able to inspect more detailed information (assembly maps and inspection are described in Scenario IV). The representation in MIO changes colour to show that additional information is available (accessed by double clicking the representation, Figure 9).

Figure 8 Fire personnel find and tag victims.

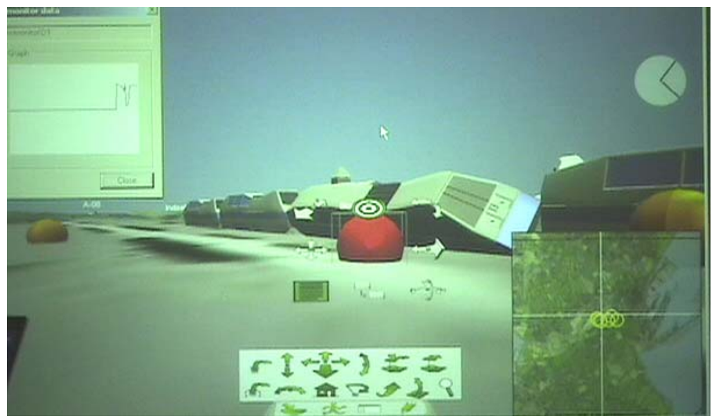

Figure 9 The red sphere marks the location of a critical victim, whose biodata is being inspected in the window on the left.

Supporting material practice: Ordinarily short range material documentation (e.g. a victim’s vital signs), but also ‘invisible’ information (e.g. about the connection between a wireless sensor and an ID device) can be ‘stretched’ and made palpable with this assembly of ubiquitous computing devices and services. Bio-sensor data can be inspected wherever the MIO is available, on-site, but also, for example, in the Acute Medical Coordination Centre, where such information can inform the allocation and organization of treatment for victims in hospitals. The functioning of the technologies and their connectedness, can be made palpable by glancing at the blinking patterns, reassuring staff on the scene and allowing them to narrow down potential causes for alarms, as well as through inspection (see below).

Scenario IV: Staff may provide visual and audio information

As staff move around and notice important issues they can operate a button on their helmets to take still photographs or short video clips with a GPS and compass augmented wireless camera embedded in their helmets. Pressing and holding down the same button, they can make a voice annotation, indexed with the same location and orientation information. These actions establish a GeoTaggerAssembly (Figure 11), which connects camera, compass and GPS with a GPS parser service (which translates coordinates if required) and a geotagger service (which sends and places the images in the Railway Station Accident workspace). As they are taken, the images are inserted in a MIO images workspace at the correct spot and orientation (Figure 10), which is shown on the picture-taker’s sleeve mounted display of MIO (not least to reassure the fire fighters of the functioning of their cameras and GPS’s). If they consider what they record very important, fire fighters can also raise an alert at this position.

Figure 10 Pictures taken on-site, inserted automatically and oriented at the correct spot.

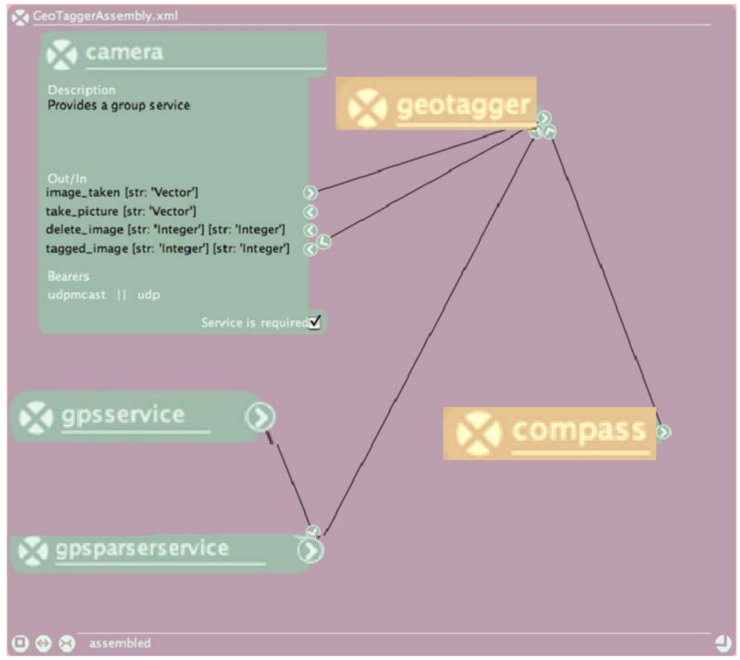

Figure 11 Map of the 'GeoTaggerAssembly'.

Supporting material practice: These assemblies of devices and services support more than taking and sending pictures. They transpose and amplify material practices, by allowing people to translate 'performances' of looking intently into account-ably recording images or video, giving others – both nearby or far away – an opportunity to put themselves in a position where they can see what the recorder is/was seeing. The scenario also illustrates support for material practices of depending on and working with technologies. If, for example, the image did not appear on the sleeve mounted display, the fire fighter might abandon the attempt and ask a nearby colleague (potentially one who is already mirroring his behaviour) to take the picture. After the incident, or perhaps during a less pressured moment, he may call on IT support personnel to request that they inspect his malfunctioning GeoTagger assembly. Through remote inspection of the GeoTagger assembly map (Figure 11, PalCom 2006), IT support staff may see that the compass is red, which means that the geotagger service does not receive compass data and thus cannot function. Having pinpointed the cause for the failure of the assembly to provide its synthesized service (take photos and place them in MIO), IT staff – who know from experience that the most common cause for compass failure is lack of power – may advise the fire fighter to change the battery in his helmet.

Scenario V: Avoiding chaos

As more and more information becomes available, overload may become a problem. Intelligibility is lost with too much detail. In part, it is a matter of training and experimentation to develop conventions to juggle the benefit of gaining rich information from staff on the site with the danger of overloading the MIO workspace. Therefore the various resources (pictures, patient representations, sensor information, vehicle and person positions, etc.) are organized in a range of automatically generated sub-workspaces that may be hidden or automatically made visible differentially for example in line with the normally expected information needs of the various groups:

- *Fire crew:* interested in the risk area, atmospheric, geographic, or other factors that affect the range of the threat
- *Medical teams:* interested in the situation at the waiting area and in hospitals
- *Paramedics and ambulance drivers*: interested in the waiting area queue and access roads
- *Police:* interested in boundaries and the status of the gathering and waiting areas

It should be easy to establish that one is seeing a partial view and how one might switch to the common overview workspace, which is probably annotated by authorised staff only, and contains all key elements of the ground plan.

Supporting material practices: Provision has to be made to manage the amount and complexity of 'amplified' and 'stretched' material documentation, embodied conduct and motion compiled with the help of MIO assemblies. By providing 'palpably' automated filtering of direct, detailed, close-up information colleagues who are unable to see for themselves – whether they are on-site or off-site – can focus on their respective tasks while being able to take part in the construction of overall situation awareness, allowing 'virtual' teams to collaborate more effectively.

Benefits of using MIO support for material practice

Through the live information of movements, impressions and situation assessment on-site, staff located elsewhere on the site, in vehicles or in command centres are able to construct a richer sense of the situation without having to 'disturb' personnel on-site via radio or phone. When communication is possible, MIO assemblies enrich contextual knowledge through redundant and additional information, for example, about location and conditions on the ground at that location. This enables staff to put themselves in the scene and participate more sensitively and constructively in the emerging coordination of decision making and acting on the ground.

For example, returning to the harbour exercise case, using MIO, staff in ambulances approaching the scene could see images of smoke/fumes being blown over the initially planned access point in the 3D MIO map and terrain. They would be able to see the first ambulance being moved. From this they may suspect that the initially planned access point may be no longer optimal. Being able to see where senior staff are (from the representations of the role, rank and location in MIO), they may be able to time requests for information more appropriately than otherwise possible, e.g. by timing calls to coincide with, and thereby remotely 'joining', huddles. At the Local Command Centre, the fire- and police-commander can get an overview over the location of various vehicles and some of the personnel, and they may see where victims seem to be 'clustering'. They do not have to rely solely on their own eyes (and feet) or verbal accounts, but receive pictures taken and positioned precisely where they were taken as a resource from all over the incident site. Using conventional communication devices in combination with MIO, they can discuss issues with others (on or off-site) who are seeing the same material. They can draw and annotate images and the terrain collaboratively. At the remote command centre, the police may construct richer situation awareness of the incident area as well as the area outside the immediate incident site (which is their responsibility to control) helping them to efficiently ensure that the proper resources are, or are made, available on-site. At the waiting area on-site, the coordinating doctor (and others) may see a continually updated overview of the conditions of victims located at the waiting area or still situated where they were injured. As she triages the patients, the doctor marks the respective triage category by swiping a triage card over the patient-ID before she attaches the card to the victim's body. This amplifies and stretches triage categorization by causing the representation for this victim in the MIO workspace to change and show victims as relatively unharmed (green), critical (red) or deceased (white). At the Acute Medical Coordination Centre, staff may see where victims are located, how many there are, and, as bio-sensors and triage categorizations are gradually employed, what their conditions are. This information can assist greatly in determining which hospitals to send victims to.

These uses of MIO assemblies amount to a stretching of collaborative material practice and accountable practical action, amplifying the broadcast range of physical and embodied behaviour. We are conscious of the fact this potential needs to co-evolve with organizational and practical innovations and are engaged in a process that pursues such holistic socio-technical innovation (Kristensen et al 2006, Buscher et al 2007). We also appreciate that the technologies we propose rely on ubiquitous connectivity and are collaborating in research to ensure it more reliably (Ghizzioli, Rimassa and Greenwood 2007).

SUMMARY AND DISCUSSION

We have sketched out a range of prototype ubiquitous computing technologies aimed at supporting material practices of coordinating emergency teamwork. Design is inspired by ethnographic studies and collaboration with emergency services personnel in Aarhus, Denmark. From these studies, it becomes clear that situation awareness and decision making are not just individual cognitive skills and processes, they are collaborative practical achievements. Close attention to the materiality of everyday practice brings to light opportunities for design to support the production of shared situation awareness and joint decisions, involving colleagues both:

- *on-site*, where material documentation and embodied conduct is crucial to ongoing risk assessment and the coordination of the team effort, but perception may be hampered by buildings, darkness, fog, or the chaos of vehicles, people and equipment, and

- *off-site*, where members of the team located, for example, in vehicles or command centres find it difficult to juggle the need for information with the need to let on-site staff get on with the job, and where verbal accounts of conditions on the ground, or instructions can be difficult to understand.

The MIO prototype allows staff on and off site to capitalize on the 'stretching' capacities of ubiquitous computing technologies. It allows staff to accurately represent tracked vehicles, personnel and equipment (such as ID devices and sensors) in a 3D terrain model of the incident site, and to add data and annotate both 2D images and the 3D topography. In addition, one of the main challenges our design approach addresses is the need to complement the autonomy and invisibility of ubiquitous computing with support for making computing 'palpable'. We use our analysis of material practice to define ways of supporting people in making the states, processes and affordances of the technologies involved in MIO assemblies palpable. But while MIO advances the state of the art in support for material practices of emergency teamwork and for making computing palpable, it also raises a number of tough questions for future research, e.g. with regard to innovations in best practice, with regard to scalability and handling complexity, and with regard to balancing (2D) overview and entering 'into' the multi-dimensional situation.

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6.3 Supporting Palpability in Emergency Response

Authors: Morten Kyng, Margit Kristensen

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Supporting Palpability in Emergency Response

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ABSTRACT

This paper investigates how to design ICT support for emergency response. We conceptualize the incident site with people, vehicles, buildings etc. as boundary objects over which complex and imperfect work of coordination is done – and discuss how a 3D representation of these entities may be used as a way of bridging between the physical entities and the body of digital information about the site and the different entities, accumulating as the incident unfolds.

1. INTRODUCTION

To get an impression of the characteristics of an emergency response situation it is important to remember four central issues that characterize incidents: 1) they are (most often) life threatening, 2) time critical, 3) happens in unknown settings, and 4) there is lack of resources. This gives an idea of the level of stress and confusion that easily may arise in en emergency situation – and of the conditions for the design and use of technology support.

As a part of the PalCom project [8] we develop ICT support using Participatory Design [1, 3, 5]. We experiment with prototypes that can support all those involved in response work in major incidents: police, firefighters, ambulance personnel and medical staff. We develop support both for those who are working at the emergency site and those who are carrying out work away from the site (e.g. in the alarm centers, at the hospitals who are receiving the injured people and the vehicles going to and from the incident site). The structures, processes and problems in emergency response are described in more detail in [4].

As described in [4] each of the involved emergency responders takes responsibility for – and carries out each their part of – the response work, depending on the incident and its characteristics and the person's role, training and skills. Often a certain person has a predefined role in a specific emergency response situation, depending on a set of known – and exercised – rules, e.g. the first doctor, arriving at the incident site becomes the medical coordinator, and the first ambulance driver who arrives becomes the ambulance manager. It is also decided on beforehand who is in charge from the police and fire brigade. Those of the responders, who are working 'on the floor', i.e. those who are in direct contact with the incident and the victims, are assigned to specific tasks most often when they arrive. It becomes more and more common that these principles, describing who is going to do what and how things are structured and organized, are described in what is called an *Incident Command System, see e.g. http://training.fema.gov/EMIWeb/IS/is100.asp*.

Today most of the information used during the execution of a rescue operation is acquired by interacting in the setting, e.g. with (other) rescue workers and injured people at the incident site. Information from the incident site to hospitals, remote command centers, rescue vehicles etc. are communicated via incident site radios and cell phones. In addition some text-based ICT systems are used to communicate between some of the remote command centers and hospitals and these centers and hospitals and the rescue vehicles. Paper documentation is formally required, especially regarding the medical work, but is seldom produced on site. However, during ambulance transport an ambulance patient record is partially filled out and when the emergency response is over more paper documentation is produced, especially by the doctors. Thus the setting itself is the primary source of information and for this reason we, in line with [4], conceptualize the incident site with people, vehicles, buildings etc. as boundary objects over which complex and imperfect work of coordination is done. We term this the “physical information space”.

2. A SCENARIO

As a background for our discussion of how to design for palpability we sketch an incident situation and some of the issues involved:

In a level crossing a train at high speed has crashed into a truck, causing the train to leave the rails. Moreover the truck has exploded and that has caused a fire also in one of the railway carriages, resulting in many heavily injured people. The incident has happened in the country side in a sparsely populated area around 40 km from the nearest hospital with emergency response capacity. As the involved responders are carrying out their work they need different types of information to do so.

A) One of the medical teams, carrying out first aid treatment of some of the injured people from the train incident has realized that they have almost run out of pain killer. So, they have asked for a rather huge amount of pain killer and should receive it soon with one of the returning ambulances. They now want to know when they will receive the medicine.

B) The ambulance manager wants to know where the available ambulances are.

C) The police manager and the fire brigade manager in charge both need to know where ‘their’ different groups of responders are.

D) The police manager needs to have more police at the train accident. Since he knows that the most obvious road is blocked, he wants to give the three specific wanted crews information about which route they should use, to get there.

E) The fire brigade manager recognize that a certain tool is needed by a specific firefighter crew, and he wants to find the tool, which he believes is in a certain fire engine, and have it brought to the crew.

F) The incident is huge, and the police and fire brigade managers in the On Site Command Post needs support regarding specific tasks, e.g. to handle the press and the contact to relatives, but also to support with specific information about available resources. At the nearest police station a Remote Command Station is established, to support the On Site Command Post. It is important that there two groups can communicate.

G) At the triage[1]/waiting area the medical coordinator wants to see how many injured people there are of each triage category, and he would also like to know the conditions of the injured people, who are trapped in the train carriages. He needs the information to find out if he has to call an extra medical crew to the emergency site.

H) At the main hospital in the area, the doctor in the remote acute medical coordination centre working as hospital coordinator is going to plan and coordinate the medical emergency response at the hospitals. S/he has to coordinate with the involved hospitals based on information on which types of injuries each hospital can treat – and what the capacity is.

I) In addition the hospital coordinator needs to how many injured people of which type and triage category there are and when they leave the incident site

J) The receiving hospitals need to know how many injured people of which type and triage category they are to receive and the estimated time of arrival.

K) When the injured people arrive the trauma team at the receiving hospital need information about the condition of the patient.

L) And the hospital needs to be able to follow each patient as they are moved around the hospital from the receiving trauma room to e.g. scanning, operational theater and intensive care.

3. DESIGN PRINCIPLES AND VISION

A main characteristic of emergency response is that acting in the physical world, e.g. treating the injured people to save lives, is what matters – ICT support is secondary and should improve the actions in the physical world. However experiences from real major incidents, e.g. [9, 10, 11, 12] show that use of ICT systems have been sparse or difficult due to e.g. malfunction, lack of interoperability and integration, and lack of usability and usefulness in the context of the incident. In [4, 6] it is argued that when developing ICT support:

- focus should be on issues that are immediately relevant to the saving of lives
- systems and devices has to be effective and efficient – in reality this means that they should preferably be understood, known and practiced by the users on beforehand, and
- they should be technological stable and trustworthy.

In our current work on ICT support we use these principles as a starting point for investigating how to enhance what we in the introduction termed physical information space with palpable, digital information space.

A first observation is that most of the response workers on site are interacting with physical entities directly: other response workers, injured people, medical equipment, vehicles etc. The digital information space will contain information about these entities and to avoid adding an extra ‘information access method’, we have formulated the following principle:

Physical entities, people, vehicles etc., should act as “access points” also for the digital information.

[1] During triage victims are categorized by a doctor according to the severity of their injuries and treated according to these categories: 1) Needs treatment immediately, 2) Needs treatment as soon as possible, 3) Treatment can wait, 4) Deceased/beyond treatment.

Secondly, we noted during our field work that virtually no information is entered on site, due to time critical work and lack of resources. At the same time we noted that a lot of the information formally required for documentation, is available through inspection of the physical entities, primarily the injured people, e.g. when looking at the injured person it is immediately visible if a neck collar has been mounted or intravenous infusion is given. This led us to formulate the following principle:

When providing digital information focus should initially be on information that is not immediately available through inspection of the physical world.

Finally, it is a characteristic of many major incidents and all disasters that some equipment and systems as well as parts of the infrastructure malfunctions or break down. In these situations the rescuers could benefit from ability to improvise and use alternatives [7]. To illustrate: One of the firefighter managers involved in the 9/11 response once said in an interview: “I have looked and examined the whole response to the trade centre. I whish we would have seen while we heard what everyone saw on TV. We didn’t get any messages that the top 15 floors were glowing red or the building looked like it was going to collapse”.

This led us to formulate the third principle for design of ICT support:

Allow for – and support – use of not preplanned technologies.

The vision

Two issues play a pivotal role in supporting the many different emergency responders (and/or groups of responders) in getting information and creating and maintaining overview on the levels they need:

a) information about *where* people (injured and/or responders) and things are

b) information about the *conditions* (broadly speaking) of people (injured and/or responders) and items

This – together with the above listed principles – has led to the following design vision:

The ICT-support for emergency response should align the physical and the digital information space.

4. THE PROTOTYPES

As a first step towards realizing the vision we have decided to work with 3D maps of incident areas, and to locate the entities of interest in this map, cf. Figure 1. This is the first step in the alignment. The second step is to provide access to digital information about an entity both via the physical entity itself and via its representation in the 3D map.

Until now we have worked with representations of the following entities:

1. Emergency responders
2. People who are involved in the incident (and who may be injured or not)
3. Emergency vehicles (e.g. ambulances, police cars or fire engines)
4. ID devices, e.g. RFID tags and readers

5. Location devices, e.g. GPS
6. Bio-monitors
7. Cameras (video or still picture)
8. Radios
9. Base-stations (computers with communication capabilities)
10. Displays

The first three types of entities are those of primary interest. The rest are used to provide and handle information about the entities of primary interest. Thus the ID devices are used to provide unique IDs for the primary entities. The biomonitors provide information from one or more biosensors etc.

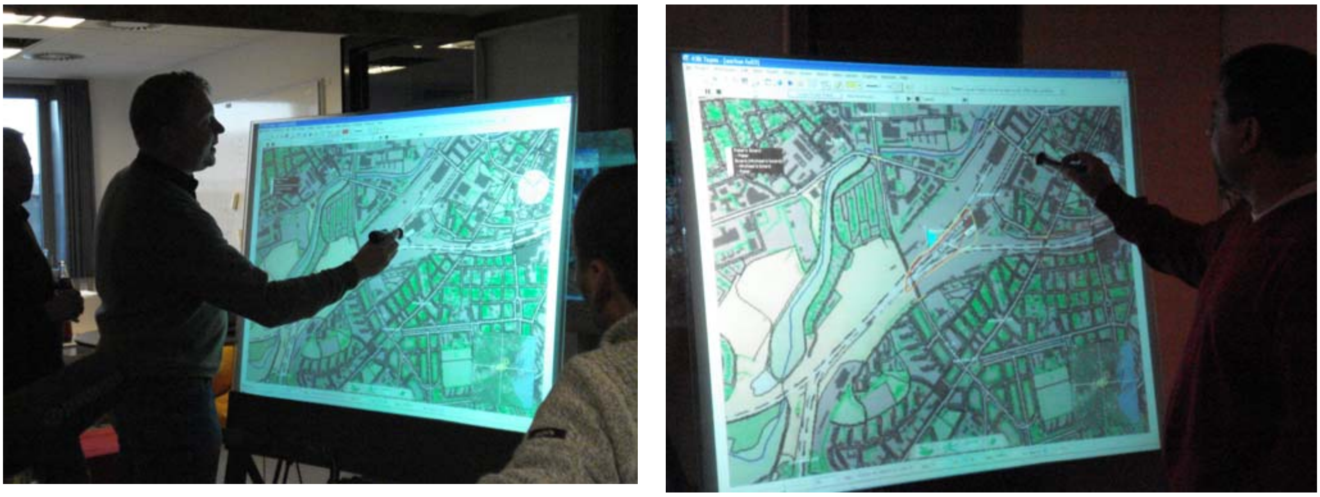

Figure 1 Shared views on maps

When combining physical entities (e.g. an injured person, an RFID reader, a GPS and a biomonitor,), these will be represented as an assembly in the digital world (and e.g. shown on a display running the map prototype). This assembly provides information regarding the assembly (e.g. "Patient X is at position A and his biomonitor signals are …").

We have chosen to represent not only the entities of primary interest and the information available about them, but also the devices involved in providing and handling that information. There are two reasons for this – and they are both related to the issue of palpability:

First of all, if one wants to inspect one of the devices, e.g. a biomonitor, it is important that this device itself is also part of the digital information space. Secondly, when these devices are part of the digital information space we may also support interacting with them through this space. To illustrate: if a motor controlled video camera is represented in the digital information space we may use that representation to turn and zoom the camera – and to inspect its status incase of malfunction.

It is also possible to draw on the 3D map – to show a digital representation of e.g. where the inner and outer barriers are, where the triage area is and which roads ambulances or fire engines have to use as access roads to the incident sites. These sketches are also available on every display running the map prototype and can be used by any responder who needs the information.

The prototype takes an already developed software product, *Topos* [2], as a starting point. Topos is 3D dynamic visualization software that can be used for modeling and representation of different objects. Moreover it is developed to support collaboration across distances through shared views on different screens.

5. DESIGNING FOR PALPABILITY

The principles and prototypes presented above work together to provide palpability in use. First of all the alignment of the physical and the digital information space support the user in transferring 'material strategies' to the digital space. To illustrate: information about an entity may be acquired through physical interaction with that entity, e.g. examining person with a broken leg. In addition digital information may be accessed through the physical entity, e.g. by RFID scanning. And finally digital information may be accessed through the representation of the entity in the 3D map.

Secondly, the alignment supports transfer from the digital to the physical by exploiting the 'well-knowness' of maps. To illustrate: creating - and communicating - digital entities in the 3D map, such as inner and outer barrier, simplifies the work of transferring these barriers to the physical world tremendously compared to a verbal description communicated over a radio.

Thirdly, the digital representations of the different devices supports inspectability, that is, the digital representation of e.g. a camera can be used to inspect that device: if it is working as expected, if failures have occurred, the type of failure etc.

Finally, the digital representation may support users in dealing with complexity in the physical world, especially when things scale up, i.e. when an incident is major, with many injured persons, spread over a large area and involving a huge amount of rescuers and vehicles and other equipment. In this case moving around in the 3D map may be used as a way of focusing attention on the entities nearest to one self.

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6.4 Designing for palpability in event management and emergency response

Authors: Monika Büscher, Margit Kristensen, Preben Mogensen

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Making the future palpable: Notes from a major incident Future Laboratory

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ABSTRACT

Future laboratories allow users to experiment with future technologies in as realistic as possible conditions. We have devised this method because, to realize the potential of ubiquitous computing technologies it is essential to anticipate and design for future practices, but for prospective users it is often difficult to imagine and articulate future practices and provide design specifications. They readily invent new ways of working in engagement with new technologies, though and, by facilitating as realistic as possible use of prototype technologies in Future Laboratories designers and users can define both opportunities and constraints for design. We present 11 scenes from a Major Incidents Future Laboratory held in September 2005. For each scene we point out *key results*. Many raise tough questions rather than provide quick answers. In the discussion we summarize important lessons learnt.

Keywords
Ubiquitous computing, future practice, emergency response

1. INTRODUCTION

Ubiquitous computing refers to the fact that computation is increasingly embedded in small and large devices (biomonitors, mobile telephones, personal digital assistants, ambulances) and dependent on digital services (connectivity, storage, geographical information services (GIS), location tracking). Ubiquitous computing technologies have enormous potential to support (new forms of) emergency response work. Resources like ubiquitous connectivity and location information, combined with sensors, wireless communication, displays, or data devices like cameras, etc. could enhance people's ability to make sense of emergency situations, to formulate an appropriate response and collaborate with colleagues – both on the scene and remotely, in hospitals, and incident control rooms. However, the urgency of emergency situations makes invention and adoption of new technologies and new practices hard to realize. Two issues in particular hamper innovation:

- *Future practice*. In interaction with new technologies people change established practices. Unpredictable and sometimes unintended consequences ensue. Future technologies should anticipate and support new ways of working. Yet, it is impossible for designers to predict future practices and consequences of change. As realistic as possible experimentation is required. This general challenge is exacerbated in real life emergency response work where there is little room for experimentation.
- *'Invisibility'*. Weiser's 'invisibility' principle for ubiquitous computing (1991) prompts many designers to make computing literally invisible by embedding it

and by automating processes e.g. of establishing networks. This protects people from complex choices, but it takes the human 'out of the loop' (Endsley, Bolté and Jones 2003) and makes it hard for people to know what technologies are doing and to trust them.

We carry out field studies, and take a participatory design approach (Grønbæk, Kyng and Mogensen, 1997) to address these difficulties, bringing together an interdisciplinary team of practitioners, designers, and work analysts to design ubiquitous computing technologies for a range of different domains. Researchers/designers have to understand existing and future work practices, as they create prototype technologies, while professional practitioners take part in analysis/design and explore new ways of working. Currently, our main design goal is to provide infrastructural support for making ubiquitous computing 'palpable', that is, 'noticeable, 'manifest, obvious, clear' (http://dictionary.oed.com/). In other words, we seek to enable people to put themselves in the loop where computational processes and services are concerned. The work described in this paper is part of a project called PalCom, which pursues this goal (http://www.ist-palcom.org).

Supporting the work of emergency response personnel is a particularly fruitful part of this work, because there is a clear potential for ubiquitous computing to augment the work and a need to be understand and trust the technology. To maximize the 'hard test case qualities' of emergency work for design, we focus on 'major incidents'. Within Europe, major incidents are declared when massive damage to persons or property is caused or projected. They require collaboration between different emergency response agencies (police, fire services, hospitals, etc.), giving rise to many uses of ubiquitous information and communication technologies.

2. METHODOLOGICAL BACKGROUND

Within socio-technical innovation in general, naturalistic experiments with new technologies have been used productively. They can inspire ideas, but also function as 'breaching experiments' (Garfinkel 1967) that draw the practices on which participants ordinarily depend to the designers' attention. In one of our examples below, we see, for example, how cumbersome a request like 'take a picture of that victim' can be when one of the speakers is only virtually on the scene and neither knows what the other can see or where s/he is looking.

Within participatory design, approaches such as co-realization (Hartswood, Procter, Slack, Voß, Büscher, Rouncefield, Rouchy 2002) draw experiments, analysis and design inside the process of socio-technical innovation, helping greatly in producing viable and desirable innovations. However, this approach is difficult when more futuristic socio-technical imagination is the goal. In particular, experimentation and futuristic imagination are highly desirable, but impossible to achieve in the context of real emergency response situations. Seen from a practitioners point of view, training exercises are well known and well used, both regarding everyday response and major emergencies, but they are designed to hone use of existing technologies and established ways of working rather than explore the potential of new technologies and new practices.

To facilitate imagination and experimentation, we have devised the method of Future Laboratories. Future Laboratories introduce functional prototypes into realistic enactments of work. They foster the emergence and exploration of new ways of working – not only through discursive 'what if' scenarios, but also as practically discovered, often tacit but observable possibilities. Ideally, the practitioners should be experienced professionals.

3. THE MAJOR INCIDENTS FUTURE LABORATORY

The major incidents Future Laboratory took place over two days in September 2005. It generated a host of design ideas and activities, described elsewhere (e.g. in Kramp et al. 2006, Kristensen and Kyng 2006, Büscher and Mogensen 2007). It was the first major incidents future laboratory, and the first time we experimented with the prototypes and mock-ups[1]. The first day was held an a training site for emergency response personnel – an area where car accidents, building fires and other incidents can be staged (**Error! Reference source not found.**). The participants included 14 researchers, 10 practitioners and 3 'victims'. We started with a short introduction in a class room, then moved into the grounds, where we had staged a car accident (**Error! Reference source not found.**), to explore – hands-on – 11 incident 'scenes', planned beforehand. The professionals had brought new radios they wanted to test and, with the help of researchers/designers, they used the PalCom prototypes and mock-ups at the 'accident site' and in an 'Acute Medical Coordination Centre (AMC)' which would normally be at the hospital, but which we had set up in a barn close by. Responders from all major incident agencies participated in the Future Laboratory.

Figure 1 A car accident staged at Aarhus 'Brandskolen'.
Source: http://www.aarhuskommune.dk

While our main focus is on major incidents, our technologies must also support response to everyday incidents: One key insight from our field studies is that new technologies should not only be used in major incidents situations – they also have to be used and be useful in everyday situations. This – together with the level of maturity

[1] We seek to develop technology to support all the agencies involved in the emergency response effort: police, firefighters, ambulance people and medical teams (doctors and nurses) and all levels of the hierarchies in the emergency response. At the time of the future laboratory described in this paper, we had mainly realised prototypes for the medical staff, but were starting to move into development of technologies also to be used by the police and firefighters. Our location within this overall design process is reflected in the (im)maturity of technology development and the focus of the future laboratory.

of the prototypes – informed the set-up in this first major incidents Future Laboratory. Below we describe the prototypes and the accident set-up, followed by analysis of 11 Future Laboratory scenes – where professionals enact realistic work, using prototype ubiquitous technologies, designed to allow staff to make their functioning 'palpable'. Key results are highlighted after each scene.

3.1 The prototypes and the set-up

To make realistic enactment of work possible, we set up an accident, where two cars have crashed and one has spun several meters away through the impact. There is one severely injured person trapped in the car shown in **Error! Reference source not found.**. Petrol is spilling out of this car, which means only specially trained rescue personnel will be allowed to approach it. The other car carried two persons. The passenger has been thrown out of the car and lies, heavily injured, on the roadside. The driver managed to crawl out into the road.

A passer-by has called 112 (911) and the emergency responders arrive at the site. At the hospital AMC is activated, meaning the doctor there opens her connection to the emergency responders and the technologies at site: She can see live video from the scene, she receives pictures of the injured persons, taken by staff on the ground, she can speak with personnel, e.g. the medical responders and she receives signals from biomonitors mounted on injured persons.

Figure 2 A wireless biomonitor prototype, its data inspected on a 'wearable' display.

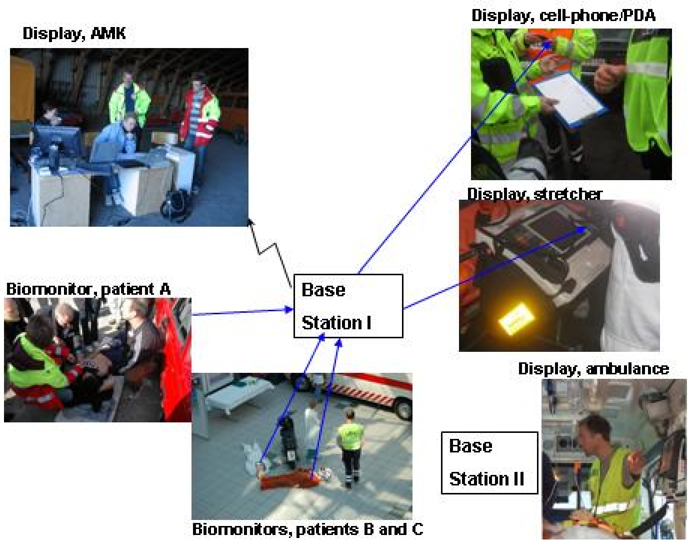

Figure 3 The wireless bio-monitoring system.

To realize a prototypical technological future the researchers/designers set up or brought:

- A wireless network
- Wireless biomonitors (Figure 2)
- Wearable displays (these are simulated by portable PC's)
- Basestations (relaying communication from sensors into the network)
- Still and video cameras
- Mobile phones

- Radios

The wireless biomonitoring system comprises a wireless biomonitor (Figure 2), basestations and connectivity. It works as shown in Figure 3.

As a biomonitor is mounted on a victim, it collects bio signals from the victim's body by use of sensors. The collected signals are – via BlueTooth – sent to a basestation – a computer that can store those signals. From the basestation (and, within a radius of about 100 meters, also by use of Blue Tooth) the signals can be shown on any number of displays. One can see data from all patients on one display or focus on the data of individual patients. In the Future laboratory we had three biomonitors and two 'wearable' displays (simulated by laptops). The data can also be accessed elsewhere, e.g. at hospitals (in AMC or the emergency department) using existing networks such as WIFI, GPRS or ad hoc networks. In the future laboratory a wireless network was used to communicate to the AMC.

A video camera is mounted on one of the 'response vehicles' nearby (in the Future Laboratory this was simulated by a car wreck in the training area, but in 'real life' the camera is meant to be on a telescopic pole on the roof of an emergency vehicle), and live video is transferred to the AMC. Moreover, one of the researchers takes pictures, including pictures of injured persons. In the Future Laboratory a digital camera was used, but in future cameras could be embedded in helmets or glasses, so that the action 'taking a picture' could be done by looking at the point of interest and pushing a button. The process could also be automated – taking pictures at specified time intervals, for example. These pictures are also transferred to AMC (Figure 4).

Figure 4 The 'Overview' relayed to the AMC, and a researcher taking pictures of victims to send to the AMC.

In addition, all the professionals brought mobile phones. They were used for communication (e.g. between the incident site and AMC). The professionals also brought and tested a new radio system for communication across distances and at the incident site.

3.2 Exploring socio-technical futures of major incidents work – 11 scenes

Scene 1: Multiple teams arriving

The police, the medical team and the fire service arrive at the scene. They bring with them different kinds of equipment such as wireless biomonitors, wearable displays, cameras, mobile phones, radios and video cameras.

Key results: Enactment and verbal accounts of what would happen if this was real combine and 'take' people 'into the scene', enhancing the realism of this future populated with professionals and future technologies. During a think aloud session researchers and professionals discuss what each group/person would do in this situation. What is needed in terms of information and equipment?

Scene 2: Forming a first picture of the victims

The medical team forms a first picture of the victims on the roadside by examination. In this way they judge who needs help first. One of the victims lay on the ground on his back, the other facedown.

Figure 5 Wireless biomonitors are placed on the injured persons

Key results: The discussion focuses on whose responsibility this task is: If the doctor is there the responsibility is his/hers. If not, it is the ambulance staff that is responsible. Hands-on experience provides insight into the handling of monitors. An important discussion develops regarding where to place the wireless biomonitor – theoretically it can collect data, no matter where it is placed on the body, but during this hands-on session we realize that it should probably not be on the back since almost all injured persons are placed on their back during transportation.

Scene 3: Patients in dangerous situations

The doctor cannot get close to the injured person trapped in the car, who is also threatened by leaking petrol. The fire fighter places a biomonitor on him. If this was a real situation, he would be wearing thick, heat resistant gloves.

Figure 6 The victim trapped inside the car

Key results: An expansion of the discussion regarding responsibilities begins to explore important questions:

Is it realistic to expect firefighters in a real major incident situation where medical staff are unable to get to injured persons (e.g. in a train), to mount wireless biomonitors? If this could happen – what influence would it have on the emergency response organization and process, regarding division of work, responsibility, accountability and continuity? How would one know from a distance that the biomonitor is working? Taking a more technology focused turn, the discussion explored how biomonitors could be inspected on site and remotely. Moreover, could biomonitors be designed to be more 'foolproof' and robust in terms of the:

- casing that protects their 'insides'
- connections they need to the victim's body
- connectivity they need to be a part of PalCom assemblies?

Scene 4: Collecting information for an overview

The doctor creates connections between his wearable display and the biomonitors.

Figure 7 Linking biomonitors to a wearable display (here a laptop carried by a researcher/designer)

Key results: A series of questions emerged when the professionals tried to establish connections and use the information. For example:

- How does one establish the connection?
- How does one know the connection is working?
- What if there are a number of different biomonitors?
- Are pictures a good way of identifying injured persons?
- What should happen automatically and what should the doctor (or others) do explicitely?
- How should data be presented in the overview and for individual patients?

Moreover, it became obvious that personnel working with injured persons should *not* access their wearable display with their hands – the hands are needed for other work.

Scene 5: Cordoning off the area

The professionals describe and demonstrate how they would cordon off the area and police the boundary

Key results: The professionals had found different movable marking materials. It is common practice to use large cars for cordoning off. However often there will be shortage of responders and equipment, so that other solutions should be investigated. This led to a discussion of ideas that could exploit and augment material practices and material objects to support and police the structuring of the incident site (Büscher and Mogensen 2007).

Scene 6: Freeing the victim trapped in the car

The doctor works with the firefighter to ensure the person is harmed as little as possible in the effort of freeing him from the car. However, the doctor must work from a safe distance, as fuel has escaped and sparks may trigger a fire.

Figure 8 The doctor working with the fire fighter to free the victim from the car

Key results:

- How does the doctor use the information s/he receives from the wireless biomonitors, if s/he is not right beside the injured person?
- What other information does s/he need? How much can intelligibly be displayed on the screen and how?
- Could an audio-visual link between the doctor and the victim be useful? Perhaps a link that shows the doctor what the firefighter sees, using the camera embedded in the fire fighter's helmet?
- If the alarm is coming from a distant source (even a few metres away), the receiver should have some local notification – a beeper, message on radio?
- Should there be audio-visual links to the hospital trauma unit?

Scene 7: Patients' conditions change

As the doctor is treating one of the injured persons, the status of another, who is out of sight, worsens. The biomonitor data reflect the change.

Key results: A discussion of how the the medical team should be supported in perceiving such changes raises a number of important questions:

- Should people routinely monitor all data? How?
- Should there be alarms? How would they be triggered? A system could not easily 'know' when a change is critical. After an accident bio-data that would normally be considered critical (e.g. bloodloss) may not seem critical. Dynamically determined thresholds were discussed. They raise issues about who would do the adjusting. If it was done automatically, how could staff be sure that the levels are correct?
- What form should alarms take in a stressful environment that is already saturated with stimuli?
- What actions are to be taken? Who is to act? What support for coordinating action is available?

Scene 8: Technical failure?

Suddenly the doctor does not receive data from one of the biomonitors.

Key results: The professionals check potential causes and discussion reveals a number of further possible reasons for the lack of data. The person may have died, the monitor may have fallen off, there may be a loss of power, system failure, the network could be down, … (Büscher 2007). The question is how staff could be supported in finding out and addressing the problem. Data streams should not simply stop but document their ceasing according to the cause. Moreover it becomes clear that it will *not* be the professionals on site that can analyze and solve the problems. It is suggested that a person off-site could be responsible for remote inspection and repair. However, an on-site presence of technical responders – already introduced by some large disaster response organizations – seems highly desirable.

Scene 9: The ambulance stretcher

While the patient is moved onto the ambulance stretcher, the data from biomonitors is still received on the doctor's wearable display.

Key results:

- Should there be automatic changes to subscriptions? That is, should data now be displayed on the paramedic's wearable display? On the screen inside the ambulance?
- Should the doctor be notified of the change? Should his subscription be terminated?

Scene 10: Emergency room

The patient arrives in the emergency room with biomonitors, evidence of emergency treatment (e.g. intravenous fluid infusions, neck-collar or bandages) but with very limited records/documentation and a temporary ID.

Key results: Since it is mainly the on site emergency response effort we focused on in this future laboratory we had not established an emergency room setting, so this scene is only discussed, not enacted. Nevertheless important questions were raised:

- How to switch assemblies and subscriptions for data transfers between pre-hospital and hospital systems?
- Should the wireless biomonitor also be used within the hospital setting?
- How could emergency room staff prepare to receive injured persons? – Which information would help?

Scene 11: In AMC at the hospital

For each of the scenes above, Erica, the trauma doctor, was in the AMC. She remotely participated in the activities on the scene and joined all discussions, providing valuable insights from the AMC perspective.

Erica's job is to coordinate the transport of victims to hospitals that have the capacity and specialists to deal with the victims' injuries, and to prepare the respective trauma teams for the arrival of the patients. Below we describe key moments in her collaboration with the staff on the scene and her use of the prototypes.

Figure 9 Discussion of events seen from the AMC perspective

Erica gains a sense of people's injuries from the data she receives from the incident site. On the screen in front of her she sees live video from the scene (**Error! Reference source not found.**, left). The camera was mounted on one of the 'response vehicles', and – in communication with Erica – a researcher/designer acting as a 'remote controlled motor' moved it to show an appropriate overview (**Error! Reference source not found.**, right).) Erica communicates with her colleagues via radio.

Figure 10 The 'Overview' relayed to the AMC,
and a researcher taking pictures of victims to send to the AMC

She has two more screens with pictures of patients and data from the biomonitors placed on victims (**Error! Reference source not found.**, middle). Initially Michael, a researcher/designer does takes pictures of victims on the scene. Erica finds it necessary but difficult to know where the victim is located in the video overview, because, while she can see where Michael is taking pictures, their arrival on her screen is delayed (due to a design flaw discovered as a result of the future laboratory). Moreover, Michael is photographing whole victims' bodies, but Erica needs close-ups to see the nature of the victim's injuries. At the discussion after Scene 2 ('Forming a first picture of the victims') she asks whether one of the medical team could take pictures instead. Troels, the on-site doctor, agrees to do so. This provides Erica with a better sense of the victims' injuries. However, in order to tell Troels what she needs to see, fairly cumbersome communications are required:

> *Yes… Ok…now I received one ((picture)). He lies with one arm under his head and dark hair …*

As Erica requests more and more specific pictures, Troels is getting stressed. He needs to treat the victims, not just take pictures of them. He puts his radio in his pocket. Erica notices this on the video overview. She recognizes that she can use the video to find out when it is appropriate to disturb Troels, and when not.

Key results: Scene 11 was carried out in parallel with all other scenes with common discussion regarding AMC after Scene 10. The participants agreed that being able to see the incident site and the injured persons and their biomedical data gives the AMC physician a valuable basis for coordinating work across hospitals. The experience points to design opportunities which Erica summarizes thus:

> *What I need is that I can use [and remote control] the camera myself …. when I get pictures of individual patients, I need to know how [where] are they [located] in the overview? Then I need some identification of the patients because when I say 'oh this was the dark haired guy and this was ...' [it can be difficult for others to know which victim I mean]. And then one thing that is very good is that I can see if the doctor is very busy and then I'll not call him, [knowing that] he's not able to talk to me.*

Moreover:

- Information from biomonitors, video, location information, still cameras, and communication channels should be linked. For example, when selecting an image of an individual patient, the biomonitor data of this patient should be highlighted. The location of this patient should be available. Communication channels (if available) to personnel currently dealing with this patient should be visible.
- The video overview and the data for individual patients creates a sense of involvement and a desire to help as well as a demand for more information. This seems difficult to integrate into the frantic work on the incident site. Moreover, such remote collaboration could complicate the production of situational awareness. However, it *could* be a vital component of the response effort, making the AMC doctor a resource that – because of the distance – can 'keep cool'.

4. DISCUSSION - SUMMARY OF LESSONS LEARNT

On the following day we split into a researcher and a practitioner group and identified a set of key insights from the different perspectives, before meeting in plenum. The Future Laboratory produced insights and experiences otherwise very hard to gain and allowed us to share them across the team. As staff appropriated the prototypes a host of issues arose concretely, with many pointing to a need for further research:

- The physical design of the wireless biomonitor should be flatter and use softer material.
- Without doubt technologies need to support people in making their states and processes palpable, or to put themselves 'in the loop' (Endsley et al 2003). While staff on the scene of an accident may be too busy to notice and attend to failures of assemblies and opportunities for better kinds of assemblies, staff elsewhere may be able to address some of these issues. Technologies should facilitate inspection, assembly and repair remotely. Such practices require a live representation of assemblies. How this should be realized needs research, as does the collaboration between technical personnel and the professionals on site.
- Bringing the AMC closer to the incident site supports communication and collaboration, but
    - it is difficult to refer to things and patients economically and intelligibly across different spaces. Use of pictures seems useful, but how should pictures be taken?

  - intervention from ‘outsiders’ (e.g. AMC doctor) could seriously complicate the production of situational awareness.

- It is difficult to notify people of relevant events in appropriate ways and at appropriate times. Research into sense-making practices in stressful situations, and how alarms may fit into these is required.
- It is necessary to explore how wireless biomonitors would be used: How should they be kept before use? What happens when a biomonitor is taken from the bag (?) by a doctor (?)? When is it turned on? When does it connect, to which display? How is it connected to person IDs, location information or pictures? (A separate workshop on this has informed design and will be reported upon in due course).
- If assemblies are automatically established, the professionals need to know whether connections and services have been activated, whether they are (still) working, and which elements belong together. In an assembly of bio-monitors and an ID tag on a patient, how could one be sure that they are in one assembly (and not sending the heartbeat to the display of the patient on the right). One example we explored were patterns of synchronized blinking (known from marine buoys) (**Error! Reference source not found.**)

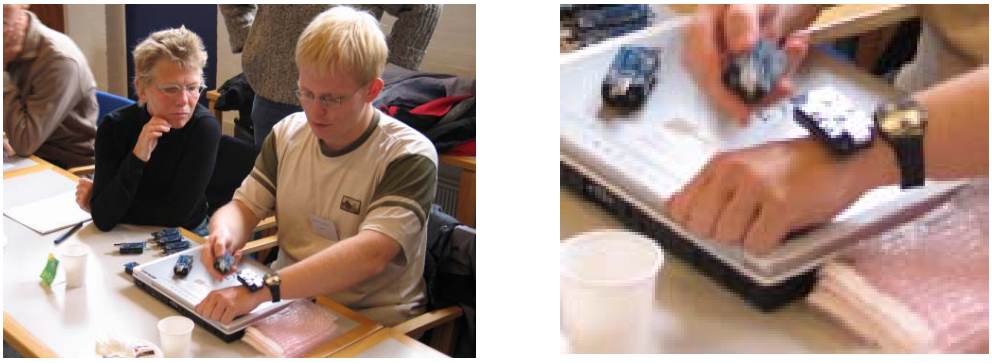

Figure 11 Bio-monitors blinking in synchronized patterns

- We should investigate in-hospital efforts, especially the transition and transfer of responsibility for patients, and the change from temporary identifications and rudimentary records to more accurate information.
- In interaction with the new technologies existing work practices change, and ongoing evaluation is needed
- Further research into how the information from the scene can be utilized for situational awareness is needed (Büscher and Mogensen 2007).

5. CONCLUSION

Future Laboratories, as a part of a participatory design process, are an extremely powerful way of bringing reality and visions of future desirable socio-technical integrations together. By enabling hands-on, as realistic as possible, *experience* of such socio-material-technical integration, Future Laboratories provide insight and knowledge that could not be obtained through discussions or “play” around a table. Most importantly, they give rise to the intuitive, embodied (i.e. more than discursive and rational) invention and exploration of potentially viable future practices emerging around future technologies.

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6.5 Technology and work within emergency medicine

Authors: Margit Kristensen

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Technology and work within emergency medicine

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1. INTRODUCTION

From medical research it has been recognized that physicians doing medical work in the pre-hospital area can make a difference for the acutely ill people, meaning higher survival (Høyer, Schønemann). In the light of this it has during the last years – in the biggest cities in Denmark – been implemented that anaesthesiologists[1], employed at level 1 hospitals, can sometimes be on duty outside the hospital; some shifts they work in hospital, other shifts they perform in the pre-hospital field. No matter where they work – if they are in or out of hospital – their tasks are the same – they support human life on the most basic, physical level – and they are mobile and carry out nomadic work (using the definitions of mobility and nomadicity, as described in Bogdan (2006). However spaces and places in which they work, the degree of mobility and nomadicity, they 'practice', and the artefacts and technologies, they make use of, are most often of very diverse character.

Below I describe the characteristics for the mobile and nomadic work for the two different work situations of an anaesthesiologist – in-hospital and pre-hospital – and in these descriptions I include description of which technologies are used and how they are used.

The paper builds on use-driven research carried out through the last 3½ years within the context of the PalCom project (PalCom). As a part of the research we have carried out extensive fieldstudies within the emergency response area, have held interviews and have had a series of different workshops with the different responders. The work is described in more detail in (Kristensen, 2006 (1) Kristensen, 2006 (2), Kyng, 2006).

2. ANAESTHESIOLOGISTS ON DUTY IN- HOSPITAL

An anaesthesiologist on duty at the hospital takes care of the basic physical treatment of seriously ill people. Some of their time they spent in the Intensive Care ward, planning and monitoring the treatment of the patients in respirators. Moreover they are responsible for prescriptions of and carrying out anaesthesia for all those who are operated. They are also called for help when patients at the hospital get cardiac arrest, have pain that can not sufficiently be treated by other specialists, or when special catheters have to be placed in the more central part of the blood circulation system. So, anaesthesiologists on duty in-hospital can be described as a kind of 'handy-man' regarding everything belonging to keeping up the basic functions of the body.

2.1 Mobility and Nomadicity

[1] An anaesthesiologist is a physician trained in administration of anaesthetics, treatment of pain and use of life-support systems (e.g. tubes, respirators or infusions) in critical care medicine

Due to the tasks described above the anaesthesiologists at hospital are very mobile – they are moving around (walking) almost all the time during their duty. Their main working areas are the intensive care unit, the operating ward and the recovery ward – and they shuttle between these units and the patients there who need their attention and professional knowledge – but several times during a duty they also go to other wards around the hospital for treatment or supervisory examinations of severely ill patients. The anaesthesiologist on duty works in loads of different collaborative or units during a shift. His/her ‘basic group’ is the other anaesthesiologists and the group of nurse anaesthetists but carrying out a specific task is most often done *not* with people from this basic group but with healthcare professionals within other specialties and of course the patients and relatives. So, the different work constellations change all the time – and people do dot always know each other personally, but anyhow the mutual division of roles is relatively clearly defined.

2.2 Space and Place

The work *space* of the in-hospital anaesthesiologist can best be described as ‘the whole hospital’. However this superior space can be divided into different (smaller and smaller) subspaces, where the (maybe) narrowest space could be described as ‘a bed with a patient’. No matter which level of space we look at – superior or sub – it is basically wellknown to the anaesthesiologist – or, maybe, more precisely the *characteristics* of the space – the hospital, the wards, the walking areas, the offices, the lab’s etc – are wellknown. Everything is build and organized in *hospital-style*.

Because of the high degree of mobility and nomadicity, *place-making* takes place all the time. However this place-making can be looked at in different levels; on a kind of meta-level the in-hospital working physician works in a well-known and – of him/her – well-defined place. On a micro-level he/she has to ‘set up the place’ all the time – every time a new situation is dealt with.

2.3 Technologies and Artefacts

The anaesthesiologist in-hospital makes use of many complex and modern technologies to support his/her work. To mention a few: Heart/lung machines, respirators, kidney machines, infusion pumps and different kinds of sophisticated sensor equipment. Most of this equipment is pretty heavy and huge and cannot easily be moved around. The anaesthesiologist also makes use of a huge range of paper documents, most of which is somehow related with the medical record. Some parts of the medical record are today in electronic form, so the anaesthesiologist also have to make use of pc’s for handling this part of the documentation work.

3. THE PRE-HOSPITAL PHYSICIAN AT WORK

Being the pre-hospital physician on duty means being called to acute medical incidents (people are injured or acutely ill) where it can make a positive difference with medical aid. The incident can be everything where humans are directly involved (damaged or ill) or are in a potential risk for injuries. Most often the pre-hospital physicians are called to people with symptoms on cardiac arrest suddenly occurred respiratory problems or unconsciousness or people injured in the case of traffic accidents or accidents in homes or in workplaces. Thereby the specific tasks of the pre-hospital physician can be very diverse, but the overall goal is to observe and do life-saving treatment of people; to establish and/or maintain free airways, breathing and blood circulation.

3.1 Mobility and Nomadicity

The pre-hospital physician move around in a special equipped medical mobile unit, driven by an experienced trained paramedic. This crew use the ambulance/fire station as their base – it is here they meet, when they begin their shift, and here they sleep, eat, drink coffee and relax. They also carry out some administrative tasks here. Most often they have several short stays in these surroundings during their shift, but it happens that they spend all their time 'on the road', moving directly from one response situation to another. As might be obvious a pre-hospital physician will be in several, almost constantly changing collaborative relationships during a shift. First of all s/he goes with the same driver during a specific shift, but it might not be the same driver from shift to shift. Additionally the most typical relations will be the staff in the different ambulances they meet in specific situations, and also staff, manning fire trucks, police cars, etc, in incident emergency response. In these situations they also collaborate with staff in the emergency room(s) at hospital, the coordinator at hospital and maybe external resource persons. Moreover, of course, they also collaborate with those who are sick or injured, and – often – their relatives. Also 'the public' should be mentioned as a 'group' of people that can become an integral collaborative partner. So, the collaborative constellations the pre-hospital physician will be in during a shift are much broader than when being in-hospital.

3.2 Place and Space

The physical conditions for the pre-hospital work are – also as the word says – everything else *but* the hospital. Only in the situations where the pre-hospital physician follows an acute patient to the emergency room, s/he will go into the hospital – but only to hand over the patient to the hospital staff. So, working as a physician in the pre-hospital environment can mean everything; in people's (very different) homes, in workplaces, at locations where leisure time is spent or where transportation is carried out. Often the space is in the open, meaning special attention is drawn to the weather, the season and the time of the day. Always changing space means that *place-making* also takes place all the time – the pre-hospital physician has to turn every (new) space s/he enters into a (medical) emergency response place. Essential here is that not only is this necessary – the time for doing it is short (or almost non-existing); s/he cannot spent time on staging – or 'finding' the place – it is (have to be) a place in the moment the responders turns up. So, (medical) emergency responders must find – or define – their place for carrying out the response, most often in unknown places and without spending time on it. And they do it! This could point to that place-making is more (or also) to a very high degree a mental process. However it is also a matter of use of technologies and artefacts – no one who gets close to an incident site where emergency responders operate doubts on what is going on and where the limits between 'the emergency response area' and 'the rest of the world' is.

3.3 Technologies and Artefacts

The technologies in use in pre-hospital emergency response are numerous and of very diverse character. Fire trucks, police cars and ambulances (and maybe other) have typically two functions: a) being used for the original purpose, and b) being used as an integral part of the cordoning-off process and organization – to make a clear boundary between 'the accident' and 'the surroundings'. So, they are used as artefacts in the place-making process. Other specific technologies are also used for more definite purposes. Regarding the medical response, the physician (and/or the paramedics) brings many different medical technologies and artefacts. To mention the most central: Portable (but heavy) monitoring equipment, medication, infusion systems, ventilation systems, tubes neck-collars, blankets and stretchers. For the mutual communication at scene all the rescuers use radios. But also mobile phones play a central role in communication, especially with 'the world outside'. As a part of the documentation process – but which also forms a part of the communication with 'the world outside', the pre-hospital physician uses a 2-pages highly structured paper record. S/he has to fill that out at scene – it has to follow the injured/ill person. One characteristic of these medical technologies and artefacts are that *they are all kept comparatively simple.*

4. DISCUSSION

In this paper I have described the characteristics for the in-hospital anaesthesiologist's work and for the pre-hospital physician's work, with focus on the tasks, mobility and nomadicity, space and place and technologies and artefacts. It is all described on the basis of fieldstudies and interviews and is not as such analyzed. However, as I see it, there *is* a link between *all* the entities (the tasks, mobility and nomadicity, space and place and technologies and artefacts) – when trying to understand the use of technologies and artefacts in mobile and nomadic work – at least the kind I have described – we *also* have to take into account the space- and place angle. By relating them to each other, it seems as the more complex and unforeseeable the situation is – regarding the tasks to carry out, the 'degree' of mobility and nomadicity and the conditions for establishment of 'ad hoc' – or 'interim' places – the less sophisticated the technologies seem to be. Moreover it seems as technologies just by their very presence supports the responders in their work. This might give us some input to the design of technologies for use in mobile and nomadic work. However further investigations are necessary.

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6.6 Media Spaces, emergency response and palpable technologies

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Abstract

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Introduction

In this chapter we will present and discuss a case on the development and use of media space like technology for emergency response. We take emergency response as our starting point and begin with a description of how emergency response in major incidents typically is carried out, in terms of organization, division of work and collaboration. Then we move beyond this to describe our initial observations regarding emergency responder's action and interaction and their use of tools and artefacts. On this background we present our vision and the important challenges and principles, on which we build our technology development. This is followed by a description of the Information Systems (IS) prototypes we are developing, to support those who act in emergency response – prototypes that supports *entity information* and *overview*. As part of the prototype descriptions we also describe their purpose and how they are meant to be used in future emergency response situations and we describe how they have been used in a "real world" event.

Use of these prototypes forms what can be considered as (a) media space(s). However it supplements – or challenges – the traditional understanding of the media space concept in several ways:

- the emergency response media space(s) have to be dynamic and mobile in the sense that they have to be established in ever changing physical settings – depending on *where* and *what* the incident is
- the settings can *also* be outdoor
- it allows use of a range of (not necessarily predefined) media – in fact the different applied media can be *whatever* the participants want to use
- the people who join the media space(s) are *not* a pre-defined, static or limited group of users – in fact people come and go, can be unknown to each other, both regarding name, appearance and role.

In media space terms the prototypes in use creates spaces where users of – or participants in – the media spaces obtains and maintains possibilities for orienting themselves in the common space and be oriented about other persons and things. These possibilities of knowing/seeing bodily position (subjects and objects) in the space by itself afford cooperation. We will show how this can be practiced in "our" dynamic media space(s) that emerge when and – especially – *where* needed, and we will focus attention to the differences and similarities with respect to the more traditional Media

Spaces. We will end up with a discussion of advantages and challenges to be further explored in the future.

Our discussions of where to take the original Media Space concept are grounded in ongoing work in a large European Union project investigating ‘palpable computing’ [17]. This project takes its starting point in a future where ubiquitous and palpable computing is a natural part of everyday life.

Ubiquitous computing refers to the fact that computers are increasingly embedded in small and large devices (mobile telephones, personal digital assistants, cars, monitors). Ubiquitous computing depends on different digital services embedded in our environment (e.g. networks, storage, geographical information services (GIS) or positioning). Ubiquitous computing technologies have an enormous potential to support future work and daily life and was originally thought upon as *’Invisible’* [Weiser]. Making computers invisible has made – and still – prompts many designers to make computers literally invisible by embedding them, by automating processes, and by leaving control e.g. of network establishment to machines. This makes in many ways people lives easier. However it makes it hard for people to know what the technologies are doing and to trust them. So, in PalCom our main design goal is to provide infrastructural support for making ubiquitous computing ‘palpable’, that is, ‘noticeable, ‘manifest, obvious, clear’ [16]. In other words, we seek to support people in understanding what the computers do, to make them being able to interact with them by letting the computers being noticed and apprehended.

So, palpable computing will go beyond state-of-the-art ubiquitous computing by complementing the ubiquitous computing visions with palpable computing visions. Especially we want to complement invisibility, (automatic) construction and automation with visibility, inspection, the possibilities of de-construction and re-construction and user control. However, “complementing” should not be understood as “either” - “or”. On contrary it should be seen as having the possibilities to choose the most appropriate level between (e.g.) total invisibility and total visibility, depending on the actual technology and setting in which it is meant to/wanted to be used.

Thus palpable computing complements the unobtrusive effectiveness of ambient computing with a focus on making the means of empowering people intelligible.

Emergency response: State-of-the-art

Some of the main characteristics of emergencies are their unforeseen occurrence and the need for immediate response from several types of professionals. The response to an emergency is in almost all cases initiated by someone’s call to an alarm centre. When activated, the emergency response resources on stand-by are allocated to the incident and directed towards the incident site itself and assisting sites (e.g. hospitals) through use of the country and/or region specific code of practice. Each incident and emergency response situation is assessed regarding needs for and availability of resources. In Denmark this is initially done by the receiver of the call at the alarm centre, and later on by the incident commander(s) on site and dedicated officers in the involved coordination centres. The larger an incident is (regarding physical spread, severity and/or number of casualties), the more resources (personnel, equipment and hospital capacity) are needed and the more complex and difficult it becomes for the involved emergency responders to create and maintain overview of the situation and thus to organize the activities. Many different types of emergency response professionals are involved (especially police officers, fire fighters, medics and paramedics), and they follow a pre-planned and – in most cases – well known Incident Command System (ICS), see e.g. [13, 24]. In the ICS the roles of the different professionals, the structure for collaboration and their mutual routes of communication are specified, together with directions for physical configuration of the incident site.

The spatial organization of the incident site is illustrated in figure 1.

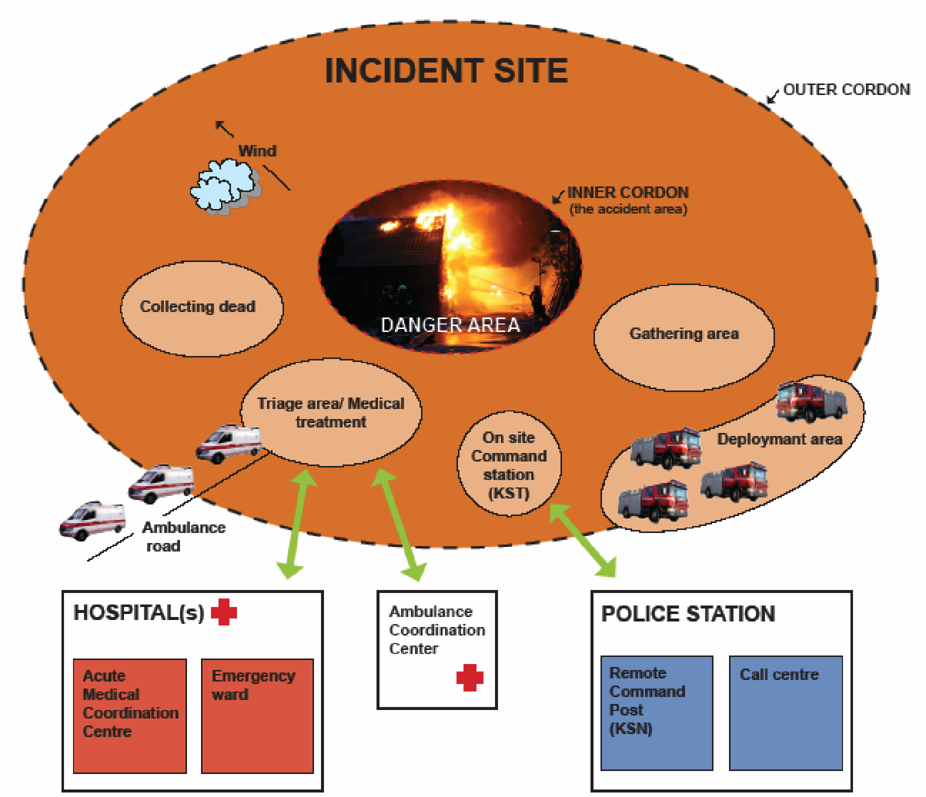

Figure 1: Spatial organization of the incident site

The actions taken – and the communication – are supposed to happen within a structured hierarchy, both within each profession and across the different professions. Working and communicating within a certain hierarchy is intended to support each professional in recognizing what to do, who to refer to and who to collaborate with. This means that each person should be able to concentrate on exactly his/her task in close cooperation with other professionals involved.
Briefly explained the overall division of work between professional skills is as follows:
1. The fire fighters are the primary rescuers – they are responsible for securing and getting people out of the primary *danger area*.
2. The police are the overall responsible professional group. They establish the cordoning off around the *incident site* and are responsible for deciding on and securing routes for transportation of equipment and people. They are also responsible for registration of all involved people – both injured and non-injured. Moreover they have to take care of the public, the media and the relatives.
3. The paramedics are responsible for providing ambulances for transportation of injured people to hospital(s) and for the transportation itself. A major part of this is to maintain a flow of ambulances that are as close as possible to the capacity needed.

4. The medics[1] are responsible for handling the injured people – the initial assessment, treatment and transfer to hospital. This is carried out in close cooperation with the ambulance service people.
5. The fire fighters, police officers, medics and paramedics respectively are managed by each their manager: the fire brigade incident commander, the police incident commander, the medical incident officer and the ambulance service manager. The fire brigade incident commander and the police incident commander man the on-site command centre, called KST. These two incident commanders together are responsible for the overall response – the firebrigade manager for the direct, primary rescuing effort and the police manager for the overall effort. Therefore they need to act in close collaboration with each other and also with the medical incident officer and the ambulance service manager who are responsible for the medical treatment and transportation of injured persons.
6. At the hospital the medical coordinator in the acute medical coordination centre (AMK) is responsible for coordination of medical resources at the hospitals, regarding the actual emergency response, and for coordinating to which hospital and in which order the individual casualties are treated. At the hospitals the different medical professionals, most often collaborating in teams, are responsible for the medical examination and treatment of the injured people.
7. The remote command centre (KSN) (often physically situated at a police station) is manned with resource persons relevant for the concrete emergency response. The resource persons in KSN are not directly responsible, but have an indirect responsibility in the way that they give advises and respond to specific or overall issues regarding the emergency response or to carry out concrete tasks of more investigational or non-emergency site organizational nature (e.g. knowledge about overall amount of available ambulances or fire trucks in their own district and request for help from the neighbouring districts).
8. The receiver of the alarm call in the alarm centre at the police station has a well-defined responsibility; s/he is responsible for the initial judgement of the incident – a judgement resulting in the first allocation of the emergency response resources.

The involved emergency responders are taught to take responsibility for – and carry out the best they can – each their specific part of the response work. What they do and how they act depend on the kind and size of the actual incident in a combination with the person’s role, training and skills. In everyday emergency response it is comparatively easy for the rescuers to follow the emergency response procedures, described in their ICS system (and sketched just above) – they know what to do – it is simply a deep-rooted way of working. However, the bigger an incident is the more complex, unusual and rare the situation becomes for most of the responders (most of them have never participated in a real life major incidents emergency response before) – and this does of course affect the responders: they become more stressed and have to carry out their work within more complex settings. Often procedures they are supposed to apply are no longer well-known, and – even if they are well-known – in many cases it is not possible to do as prescribed, e.g. due to not functioning communication lines. In addition to this, major incidents emergency response often involves rescuers from ‘foreign’ regions, meaning the rescuers do not know each other.

With this in mind – a) that the responders theoretically *know* what to do *also* in a major incidents situation, but they have not necessarily *practiced* it before, and b) that the bigger an incident is the more complex becomes the whole situation (e.g. physical spread and character of damage, number of casualties and responders) we will below describe in more depth relevant observations from our research and its relation to media spaces.

[1] In most of Europe during the last years it has become more and more a permanent routine that medics (physicians or nurses) work as part of the e12, 22, 27]. Additionally special teams of medics are sent out in major incidents, e.g. in response to the London Bombings in 2006 and the Volendam Café Fire in 2000[12, 27].

Moving beyond state-of-the-art

Some initial observations

Emergency service is done by responders through direct interaction with a huge amount of different physical objects – both people and things. To illustrate:
A fire fighter interacts with other fire fighters, a fire engine, fire pumps, his helmet, his radio, debris, police officers, medics, victims (injured and/or not injured).
A medic interacts with injured people, medical monitoring equipment, medical equipment for treatment (e.g. medicine, drips, neck collars, stretchers, bandages, drainage tubes), paramedics, fire fighters, medical staff at hospitals, radios, mobile phones, ambulances, documentation forms.
Through interaction with others, their tools and artefacts the responders carry out their tasks, but at the same time they – through their specific location, bodylanguage and use of tools/artefacts *signal* to the surroundings – the world that surrounds the incident site – and to each other as well. Some examples: a) The way a police vehicle is parked and the way a police officer position himself indicates "do not go through here" (Figure 2), b) a certain hand posture by a fire fighter manager walking around a crashed train wagon may signal "possible danger near the wagon", i.e. others should not come closer, and the change of direction of an approaching police officer talking on his radio signals his awareness of this [2], and, c) a large number of rescuers helping with transportation of an injured person from the scene to the ambulance signals that the person on the stretcher is severely injured (Figure 3).

Figure 2: Positioning of the police car and the police officer signal "do not go through here"

Figure 3: A large number of rescuers around a stretcher indicate that the person on the stretcher is severely injured

Information from the incident site to hospitals, remote command centres, rescue vehicles etc. are communicated via incident site radios and cell phones. In addition some text-based ICT systems are used to communicate between some of the remote command centres, hospitals and rescue vehicles. Paper documentation is formally required, especially regarding the medical work – and is also used as a means to communicate and collaborate between medical professionals pre- and in-hospital – but documenting is seldom done on site. Normally the ambulance patient record is partially filled out during ambulance transport and when the emergency response is over the paper documentation is finally produced, especially by the physicians.

However, most of the information used – and produced – during the execution of a rescue operation is acquired by and through interactions in the setting, e.g. with (other) rescue workers and injured people at the incident site. Thus *the setting itself* is the primary source of information and for this reason we conceptualize the incident site with people – casualties and rescuers – vehicles, buildings etc. as *boundary objects* [1, 8, 14, 23]. Through these different boundary objects complex and often imperfect work of coordination is done; the victims themselves serve to coordinate the work and work trajectories of EMS personnel – and so do the rescuers together with the different tools and artefacts used during the emergency response. In this perspective we also refer to the incident site as the "physical information space".

What *matters* to the emergency responders on site during an emergency response is to improve the state of the emergency through direct *action* in the physical world, e.g. to move injured people to safety and to treat them to save lives, to fight a fire or to get in control of a chemical spill. ICT is – and can only be – considered as secondary and should focus on improvement and support of the direct actions in the physical world without being an extra burden to the rescuers. Current experiences from real major incidents, e.g. [18, 19, 20, 21] show that use of ICT systems is usually sparse and that many systems are difficult to use due to e.g. malfunction, lack of interoperability and integration, and lack of usability and usefulness in the context of the incident. These experiences are supported by findings in our own research [6, 7, 8, 11]: The responders are *expected to* use technologies that a) they do not use in their everyday work with minor incidents and thus are unfamiliar with, or b) that are *not* developed for use in major incidents situations and thus only fits the needs poorly when many people are injured etc. (Expected) use of non-proper / non-familiar technologies adds even more complexity and stressfulness to the emergency response and the responders. The bottom line is that these technologies most often are not used in major incidents situations.
Three examples:

- In major incidents the medical responders are expected to use a) coloured cards to mark injured people regarding which triage category[2] they belong to, b) an Incident Site Card per injured person, to document uncovered injuries and treatment carried out, and, c) an Incident Site Log in which all injured people are registered with basic data and which hospital they are brought to, to ensure they do not 'disappear' (illustrated in Figure 4). None of these three tools are well known from everyday work. Experiences from real major incidents show that the Log is used – the other's are not.
- To be able to plan emergency response in major incidents, covering a large area, the incident commanders use large paper maps. However these are pretty unhandy. For this reason a new police incident command vehicle has been equipped with a lap-top with map-information and a whiteboard on which the commanders can draw sketches of ideas and plans (illustrated in Figure 5). This is a large step forward. However a laptop display is not easy to share and sketches on a white board can not be stored or distributed.
- Finally the audio communication systems are often not used – radios may be left unused in pockets because both hands are needed, cell phone systems get overloaded, the conditions on site may be too noisy etc. This is well known and has contributed to developing the un-official but common procedure that the commanders who are responsible for the overall

[2] During triage casualties are categorized by a physician according to the severity of their injuries and treated according to these categories: 1) Needs treatment immediately, 2) Needs treatment as soon as possible, 3) Treatment can wait, 4) Deceased. Every victim is supposed to be marked with a colored, numbered card.

coordination of the emergency response and – because of this – *must* collaborate, try to stay together physically during a response (Figure 6).

Figure 4: Triage cards, incident card and incident log – three different documents meant to support documentation, collaboration and coordination during major incidents emergency response

Figure 5: White board in the back of a new police incident command vehicle supports the possibility to make sketches when discussing and deciding what to do

Figure 6: Incident commanders physically stay together to ensure mutual communication

In a media space perspective we note that a lot of information is a "*visual by-product*" of doing the real job and that this opens up some unique design possibilities:

- The responders on site carry out their work by and through interaction with physical entities directly. Through this direct interaction with each other and/or tools and artefacts they *signal* what they are in the process of doing and – often – also their evaluation of the situation (e.g. if something might be dangerous or life-threatening), both to the surroundings (those "outside" the incident area) and to each other.
- Virtually no information is entered on site *for its own sake*. This is due to pressing, time critical work and lack of resources. However, a lot of the information required for documentation, communication and collaboration support, is available through inspection of the rescuer's (mutual) interaction and/or inspection of physical entities, primarily the injured people, e.g. when looking at the injured person it is immediately visible if a neck collar has been mounted or intravenous infusion is given.

Thus video seems to have the potential to *provide* information through visual-inspection-at-a-distance of the primary boundary objects in the physical information space, and to do so at virtually no extra costs in terms of time.
At the same time we note that different kinds of video have the potential of *adding* important qualities to the available information on site. To illustrate: One of the fire inspectors involved in the 9/11 response once said in an interview: "I have looked and examined the whole response to the Trade Centre. I wish we would have seen while we heard what everyone saw on TV. We didn't get any messages that the top 15 floors were glowing red or the building looked like it was going to collapse"[Danish TV2 channel #date?#].

Thus it seems that media space like technology could play a prominent role in future systems for emergency response. We would like to create spaces where users of – or participants in –the media spaces obtains and maintains possibilities for orienting themselves in the common space and be oriented about other people and things.

Vision, challenges and principles

As mentioned in the Introduction we are in the EU-financed PalCom project [17] designing for a near future where information and communication technologies, including sensors and actuators are attached to people and artefacts and integrated in most of our environments. In some cases we might want these technologies to 'disappear' into our environments, but in many cases and situations it will be appropriate – and maybe even necessary – to make direct use of them – that the users can interact with the technologies: assemble technologies in meaningful constellations, make them work different from what they were originally programmed to or inspect them to see if they are working as wanted or to repair break-downs. – Technologies for the future should be adaptable to a *dynamic* world. Viewed in this light our vision regarding development of technologies for major incidents emergency response is to provide the means for emergency responders to co-create the organization of the physical incident site, its role as physical information space – where the site with its people, tools and artefacts acts as boundary objects – and a number of partially shared digital information and media spaces. The main principle guiding the design is *digital alignment with the physical world*. And a key element in this is to augment the physical entities with ICT.

As we shall se in the next section, a key element in the alignment of the digital with the physical is the alignment of media spaces with 3D models of the incident site.
The emergency response, unfolding at the incident site itself, is however, in many challenging ways very different from settings where traditional media spaces are applied. In addition emergency response has some characteristics, which poses major challenges to ICT support in general. In the following we first discuss the challenges in relation to media spaces and then we go on to consider those in relation to ICT support in general. It is what one may describe as "emergent": it starts out as chaos and through their actions the emergency responders appropriate the site and transform it into something they can understand and operate effectively in. Thus the incident site is usually unknown to the responders, the responders may for a large part be unknown to one another, the technologies are not deployed on beforehand and the rescuers cannot spend time on deploying technologies they do not urgently need in their direct rescue tasks. On the other hand the command centres and the rescue vehicles are known territory, and may be equipped with the necessary technology from the outset. This has led to the formulation of the following principle:
Anchor the media space part of the emergency response in more well-known and stable parts of the response organization, i.e. the command centres and the vehicles, cf. figure 7.

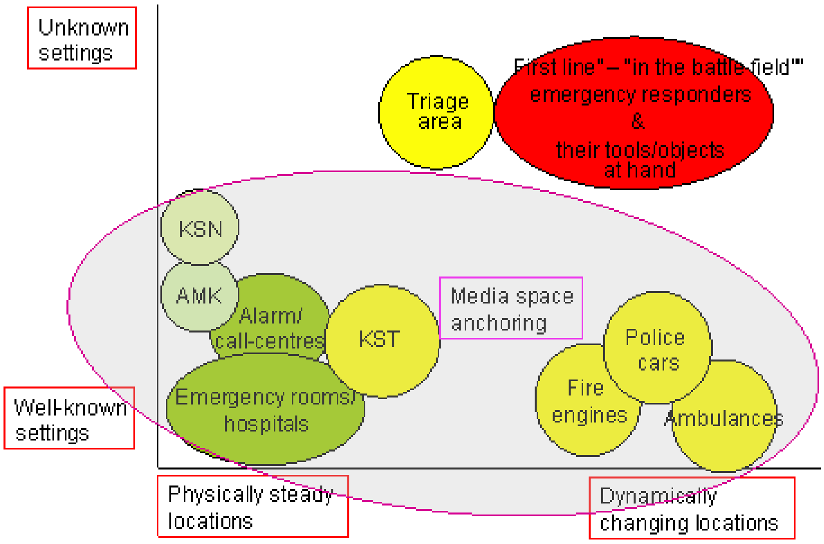

Figure7: Characterization of emergency response situations according to "knownness" and stability

In the lower left corner of the dimensions depicted on figure 7 are the emergency rooms at the hospitals and the command centres. These may be equipped with rather traditional media space hardware. At the upper right corner is the incident site, which is unknown and where people and equipment come and go. In general such sites are unsuited for traditional two-way media space technology, however, with careful design they may function as "media space information sources", and – to some degree – Media Space interactors, cf. also the section "MI and Media Space – Analysis and Discussion".

When we then move on to consider other aspects of the ICT support we note that – because of the incident site with its content of people, tools and artefacts are conceptualized and serve as boundary objects – the ICT should provide effective means of getting and providing information both in the physical world and in the digital. To avoid adding an extra 'information access method', we have formulated the following principles:

- *Physical entities, people, vehicles etc., should act as "access points" also for the digital information.*
- *Representations of physical entities in the digital space should also act as access points for digital information.*

Furthermore to reduce the number of shifts between different spaces we have formulated the following principle:

- *Representations of physical entities in the digital space should also act as points of manipulation of the physical entity.*

In addition, to make systems more efficient and thus up-take more likely, information available through inspection of the physical entities should primarily be accessed physically and not be required to be entered digitally on site. This has led us to formulate the following principle:

- *When handling digital information focus should initially be on information that is not immediately available through direct or video-mediated inspection of the physical world.*

Also we have to consider and implicate some characteristics of emergency response that pose major challenges to ICT support in general. Based on findings like those described in the previous section we have, in [8, 11] argued that when developing ICT support to be used in emergency response:

- focus should be on issues that are immediately relevant to the saving of lives and/or keep damage to materials to a minimum, and
- systems and devices has to be effective and efficient – in reality this means that they should preferably be understood, well-known and practiced by the users on beforehand,

and as a corollary:

- ICT support for major incidents should preferably also be useful in the daily work with minor incidents – to support "well-known and practiced"

Support for future emergency response: Design and Prototypes

To provide effective and efficient support and to avoid information overload as well as the creation of unused systems, we have chosen a use driven and experimental development approach where future users are included in the design team [3, 5, 6, 7, 8, 9, 10, 11]. Our work follows two strands: one on *entity information* and one on *overview*. We begin by briefly describing the support for entity information, since entity information is a major part of the overview.

Entity Information

The support for entity information, took as its point of departure the need for information about injured people, and the main element of our design is still the so-called 'BlueBio' biomonitoring system primarily providing biosensor information from the victims. The Bluebio system also contains infrastructure for the wireless distribution of the information generated "at" each injured person using ad hoc network infrastructure deployed as part of the emergency response. The system is illustrated in Figure 8 and discussed in more detail in [6, 7].

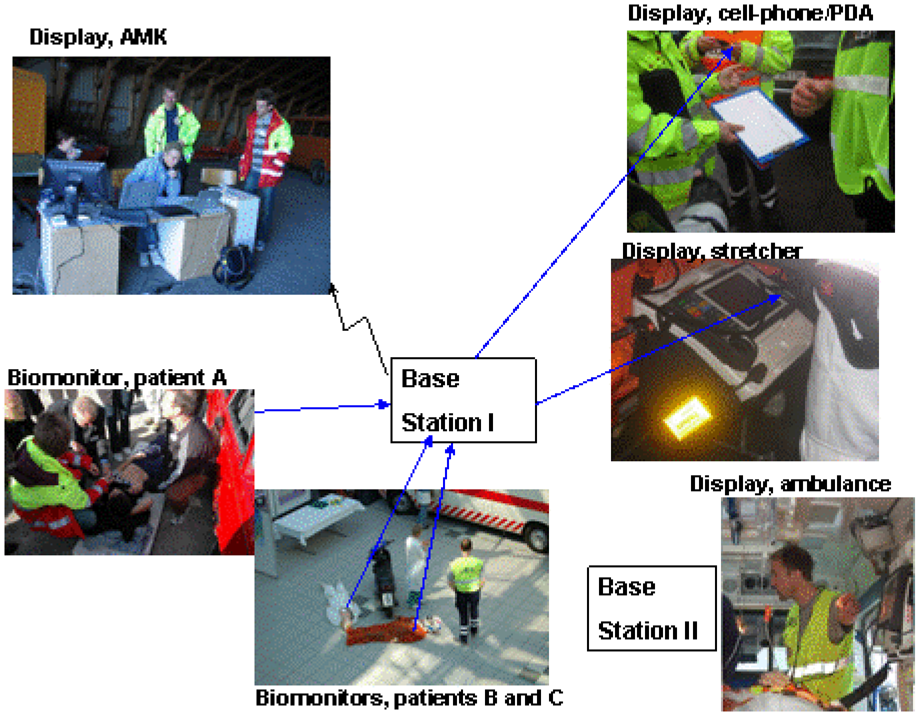

Fig 8: The BlueBio monitoring system

In addition to biosensor information we work with information pertaining to each injured person, like photos, position and identity information. Thus we handle the following types of entity information:

- State, e.g. biosensor data
- Position, e.g. GPS data
- ID, e.g. unique system ID, picture(s), description (e.g. age, gender, hair colour), social security number and name
- Digital photos
- Video

And in addition to the initial focus on injured people we are now working with information on several types of entities:

1. People
    a. Victims
        i. Injured
        ii. Non-injured
    b. Emergency responders
2. Equipment
    a. Primary emergency equipment
        i. Emergency vehicles
        ii. Medical equipment and other emergency equipment, e.g. for smoke divers
    b. ICT
        i. RFID tags and scanner
        ii. GPS equipment
        iii. Radios and cell-phones
        iv. Video cameras and digital cameras
        v. Computers and displays

Thus in addition to information pertaining to injured people (1.a.i) we are also working with production and distribution of entity information of non-injured people (1.a.ii), of emergency responders (1.b) and the primary equipment 'involved' in the incident (2.a). This is no big surprise and was on our agenda from the beginning: one wants to be able to judge the health condition and safety of emergency responders, the position of vehicles, the battery of ECG equipment etc. However, we have chosen to represent not only the entities of primary interest and the information available about them, but also the devices involved in providing and handling the information about the entities of primary interest. There are two reasons for this:

First of all, if something indicates a problem, e.g. missing GPS signal from a fire fighter, one wants to inspect the GPS device in question. And in this case it is important that the device itself is also part of the digital information space.

Secondly, when these devices are part of the digital information space we may also support interacting with them through this space. To illustrate: if a motor controlled video camera is represented in the digital information space we may use that representation to tilt and zoom the camera.

Finally it is important to note that the provided ICT support is not static, i.e. does not consist of a certain defined amount of technologies. It is in contrast *dynamic*. As mentioned earlier we are developing a new type of software architecture and infrastructure that makes it relatively straightforward to add new types of data (e.g. related with or representing different entities) and services that handle them in the digital information space. To illustrate: in a recent real life test of the system in a harbour it was one evening (two days before the test) decided that we should try to include tracking of ships using the Automatic Identification System (AIS). The next day we acquired the hardware and guessed the proprietary protocol and the following day the software developers in the project without any big effort had managed to ad the AIS as a new service, enabling the different ships positions to be included in our digital space.

Overview

The second strand took as its point of departure the need for overview of the incident to support coordination and collaboration of the on-site work as well as the on-site work and the remote response work. The key idea is to provide a 3D model, representing the incident site and share this model among all involved parties. The model is accessed via software tools running on a number of devises with different types of displays: some large, interactive displays and several smaller ones, e.g. tablet PCs, PDAs and smart phones. Thus, those, who use the tools (right now in the form of prototypes) may share views and interact from different locations.
The prototype holds different so-called *workspaces* each containing different kinds of information and interaction possibilities, much of it as a presentation of the *entity information*, sketched in the subsection just above; one workspace contains different drapes regarding the terrain; e.g. a layer with aerial photos, a layer with terrain-data and maps with technical data, indicated by colours. Another workspace provides sketching functionalities, to sketch ideas during a discussion, and save the visuals and other data on approved plans. Yet another workspace contains 3D models of buildings. The overall idea is that as many workspaces as needed can be created (e.g. workspaces containing information about power supply and gas stations).

Figure 9: From workshop: Police officer (left) and fire brigade incident commander sketch organization of incident site.

Sketching and planning will usually be carried out by the different incident commanders and officers, situated on site or remotely (see Figure 9), and be aimed at the professionals carrying out the direct response work "in the field" as well as the involved incident commanders. Thus plans and

other information created and/or made visible via one display is available at any other display-device, including equipment, carried by the personnel "in the field" (e.g. fire fighters inside a crashed train, police officers at barriers, or paramedics in ambulances).
The prototype uses the 43D Topos software product as a starting point [4]. Development of Topos was initiated in another EU-financed project, called "Workspace" [28].
As mentioned earlier it is argued in [8, 11] that when developing ICT support to be used in emergency response it is important to develop it so that it is used (and useful) not only in major incidents situations but also in the everyday emergency response – to support "well-known and practiced". For some time it was a bit difficult for the research group (researchers and users) to see how the overview prototype could be useful also in everyday work. Though in the winter 2006-2007 the users suggested that we should make a prototype set-up in a Command Centre, established during the major event "The Talls Ships Races 2007" in Aarhus, July 5th-8th [25]. So, we put a great deal of effort in configuration of the prototype – a 3D model, covering the main-area for the Tall Ships Race Event; a 6 x 3 km area of the harbour – and keep it running during the whole four-day-long event. This testing the prototype in real life, but not an emergency response situation, gave us a lot of valuable input, which have to be reported on in the nearest future. However we will now describe some of the set-ups relevant in a Media Space perspective.

A first example on an important workspace is a workspace showing on-line Geo-tagged video-streaming. In the picture below (Figure 10) a police officer in KST uses a large interactive display with the 3D model and on-line video streaming to see how status is in one of the pretty crowded places at the harbour. In total we had mounted 6 video-cameras in strategic important places; one of the video-cameras could be tilted when interacting with it on the large display. Since each video-camera was Geo-tagged, "opening" a camera means opening it in its correct position on the 3D map.

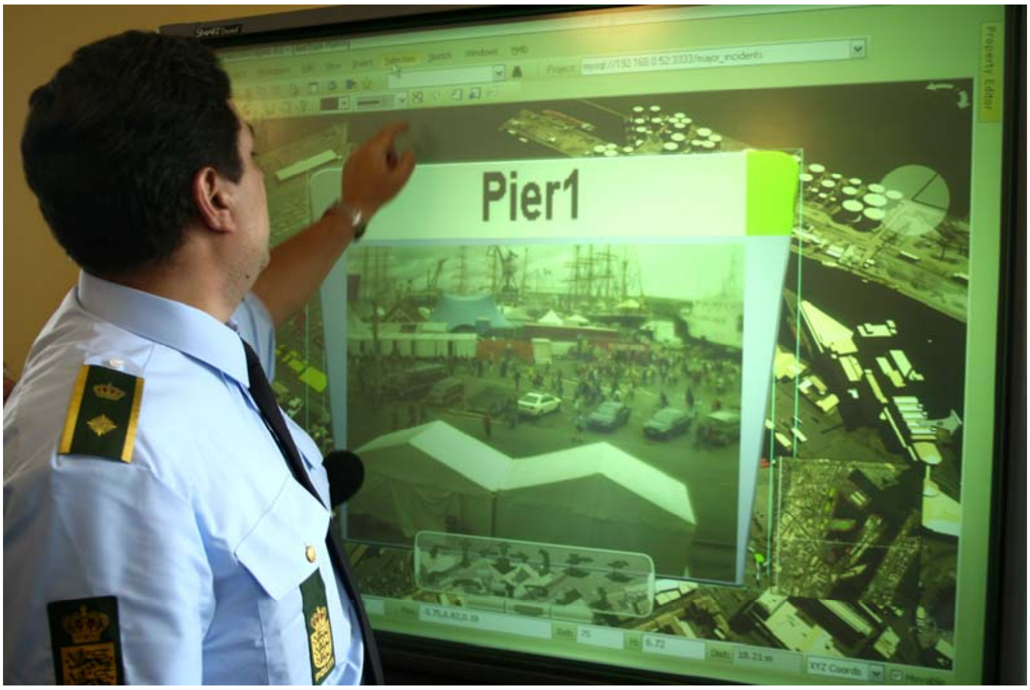

Figure10: From Tall Ships Race 2007: Police officer gets an overview of a section of the harbour area by opening one of the on-line video-cameras in the Overview Prototype

A second example on an important workspace is a space showing (GPS) tracked persons and moving objects (e.g. GPS tracked vehicles and AIS tracked boats) In Figure 11 the long white arrows point to three GPS tracked persons and the GPS tracked rescue boat. Since the GPS is build into a cell-phone with a camera, pictures taken by the phone will appear in the workspace in the exact location it is taken. Figure12 shows a picture taken by a police officer patrolling at the harbour. The car is parked in a non-parking area – actually a fire access road, which is not legal.

Figure 11: White arrows point to three GPS tracked persons and the GPS tracked rescue boat

Figure 12: Picture of illegally parked car, taken by police officer in the field and immediately visible in the Overview Prototype

As demonstrated with the examples above the 3D model gradually has become populated with many different entities of interest and information about an entity may be accessed via its representation in the 3D model.

Finally we will note that – as mentioned in the Introduction and in the description of our vision – an important aspect of the PalCom project [17] is to develop for inspection of the different devices, tools and services – e.g. what they represent and how they work in our 3D model. Inspection is implemented to be carried out through interaction with the entity in the digital space. However at the same time we have developed information access methods that support the inspection of information pertaining to an entity via direct interaction with the entity in the physical space. An example: A medic, working with the victims in the triage area may like to inspect the bio-sensor data of a specific victim. He does this by RFID scanning; an action which selects the data of the victim for presentation on the primary display associated with the person doing the scanning, typically a PDA, carried around by the medic.

Emergency response and Media Space – Analysis and Discussion

Today emergency responders are only able to extend their spaces by use of tele- and text based communication tools. By enhancing the spectrum of tools with the possibility of producing and using still-pictures, video-streaming (including audio) and other types of entity information seems to have demonstrated a valuable improvement to the users.

Our prototypes support:

- overview including 3D area models that can be presented at different kinds of displays, with different interaction possibilities,
- supplemented with information regarding different kinds (but not a certain predefined amount) of entities, including video- and still cameras,
- and all of it can be shared across different locations, to support – also – remote collaboration.

To us such a set-up is very Media Space like. However it differs from a traditional Media Space in different ways. This will be analyzed and discussed below.

Figure 13 shows how a traditional Media Space is: Video-cameras are mounted in different offices and are connected, so that people in the respective offices can see, speak with and be aware of people and what is going on in the other office. This can be described as a *symmetric* Media Space.

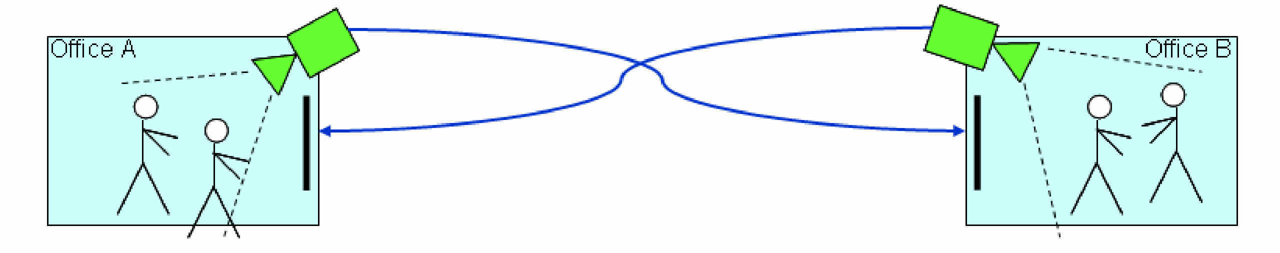

Figure 13: A (traditional) symmetric Media Space

Considering the prototypes for emergency response as a Media Space, responders working in the Incident Site might not be able to – or want to – see the people in the remote response centres (AMK, KST, KSN and different alarm- and call centres). So, the emergency response Media Space is to a large degree *asymmetric* (Figure 14). (Parts of it might be symmetric – a setup of video cameras in KST, KSN, AMK and maybe also in the alarm/call-centres (not illustrated). However, in our research we have not focused on the collaboration *only* between these (almost) stationary units).

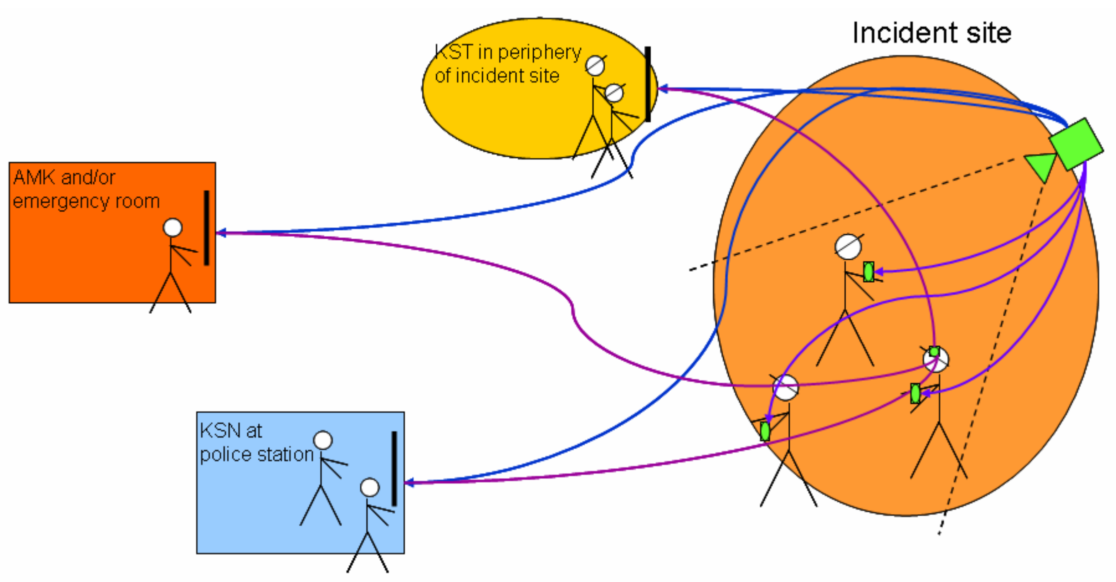

Figure 14: The emergency response Media Space is assymetric

A set-up like the one sketched in Figure 14 – including the incident site itself as a part of a Media Space – poses several possibilities, but also several challenges:

First of all the alignment of the digital information space with all the different types of physical information and the augmentation of non-stationary entities support the user in transferring material qualities and characteristics to the digital space. To illustrate: Information about an entity may be acquired through direct physical interaction with and inspection of that entity, e.g. examining a person with a broken leg – the entity itself acts as a boundary object. In addition digital information about the physical entity may be accessed also by physical interaction with the digital information source, e.g. getting access to data, collected by a biomonitor mounted on the injured person; Scanning the RFID-tagged biomonitor causes data to be shown on the display, nearest the scanner. And finally digital information may be accessed through different kinds of representation of the entity in the 3D map (positioning, ID, description, bio-sensor data, pictures and/or video). Additionally the digital representation may also support users in dealing with complexity in the physical world, especially when things scale up, i.e. when an incident is major, with many injured people, spread over a large area and involving a huge amount of rescuers and vehicles and other equipment. In this case moving around in the digital world – the 3D map – may be used as a way of focusing attention on the entities you want to focus on – instead of physically moving around in a huge, chaotic incident site, where specific people and things can be impossible to see or discover, searching for what/who one want to find in the digital space can be easier – in the digital space you can use the different workspaces to choose, delimit and select for specific purposes.
Information access by use of still pictures and on-line video streaming is assessed as being very valuable and useful in all kinds of emergency response. In many situations still pictures will be very informative (e.g. like the picture of the illegally parked car in Figure 12). However, in many situations the possibility to *see* action adds important information. An example: if the picture in Figure 3 had been a video-stream the way the responders walk (pace and target-ness) would really tell more about the severity.
Different possible solutions are still subject to further research and discussion: We have until now only experimented with video-cameras mounted on distance, surveying pretty huge areas, supplying the digital space with – among other things – information about how the responders *act*. First of all we have to explore more on especially where these should be mounted in a – very mobile - emergency response world. They *could* be mounted on top of e.g. fire trucks and/or ambulances – but we need to investigate more on that. Moreover we don’t know if the overall surveying video-streaming-information profitably could be supplemented with information from video cameras mounted in the responder’s helmets, supplying the digital space with video of what the specific responder(s) *see*.

Secondly, the alignment supports transfer from the digital to the physical world by exploiting the 'well-knowness' of maps. To illustrate: discussing, creating - and communicating - digital entities in the 3D map, such as inner and outer cordon (Figure 1 and 9), can simplify the work of transferring the position of cordons to the physical world tremendously compared to a verbal description communicated over a radio. So, in the 3D digital world you can make drawings of how and where you want something to be (e.g. where the inner cordon or access point should be) and those who are in the field will be able to access these drawn decisions on a display they wear – and will not be in doubt of where they are decided to be. However, how things are decided to be does not necessarily reflect how it is actually executed in the physical world – this stages for *feedback* from the physical implementation by tags, GPSs, photo and/or video.

Thirdly, the digital representations of the different devices supports inspectability, that is, the digital representation of e.g. a camera can be used to inspect that device, both regarding its physical and digital state: where it is, if it is working as expected, how the power level is, if failures have occurred, the type of failure etc. The digital representations of the devices also support interaction with the devices: e.g. allow for tilting the video camera or sending a message to a cell-phone with information about low power level.
However several challenges are to be further investigated here. Just to mention a few:
If the emergency response Media Space is set-up as sketched in Figure 14 – with on-site commanders in one location (KST) and other commanders in other locations (e.g. AMK and KSN) – and these commanders all are in control of video-cameras that can be manipulated remotely – who of the commanders then have the primary power of tilting the camera?
Inspectability and interaction refers to all levels of the prototype, from end-user level to programming level. This demands different solutions for inspection and interaction in at least two dimensions: First, it should be possible to inspect and interact both directly with and remotely from the devices, tools and services. Secondly the inspection and interaction interface has to be designed so that it is aimed at different types of users, spanning for software architects and –designers to high level end-users (fire fighters, physicians, police officers). – We have the initial designs, but they definitely have go through several further iterations.

Finally the mobile setup concept, containing use of different media, seems to have proved its value – it has got a lot of positive feedback after its use in the Tall Ships Races 2007 – it worked and was used many, many times during the event for many different purposes. However, turning it into something *real* mobile – in the sense of being able to bring it around as an integrated part of the emergency responder's response-set-up – demand more well-researched solutions regarding especially bandwidth and wireless network technologies.

The work, this chapter builds on, is still an integral part of ongoing research – the PalCom project [17]. This project runs until end of 2007. What will happen afterwards no one knows yet. But it is for sure that the end-users want the prototypes developed into products. This would definitely be an interesting process to follow – also as researchers; especially to monitor the development process of daily use of a mobile medial space could give useful new insight to – among other things – the ongoing Media Space research.

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7. Pregnancy and Maternity

7.1 Interaction Ecologies

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Interaction Ecologies

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Abstract

In this paper we present one approach to understand palpability from the perspective of eco-systems of palpable devices. We will introduce the notion of Palpable Interaction Ecology that particular focus upon the properties that emerge from the interaction between people, their practices and palpable devices.
This approach is derived from research into the use of pervasive healthcare services that support women during their pregnancies. This is a situation where information is currently distributed among many parties. This makes it very difficult for the pregnant woman to assess her situation. To address these issues we have designed digital artifacts that support the pregnant women's information management as well as facilitating the interaction with healthcare providers. The concepts have been examined using workshops, user scenarios and low-fidelity prototyping through active participation of both healthcare personnel and pregnant women. The results of this work suggest that the proposed concepts have the potential to be incorporated both in healthcare and in the household routines if particular focus is given to understanding shifting needs and uses over time.
Visibility and invisibility, construction and de-construction, and supporting people in making computing palpable are among the important challenges facing the Palcom Project. Originating from the biology field, an ecology is often used to illustrate relations between an organism and the surrounding environment. We have in our case found a similar need to describe diversity in use situation and the interaction between invisible and visible information as well as the interaction of construction and de-construction of devices and data. A Palpable interaction ecology incorporates both a pervasive computing presence and the ability to add and subtract devices and data as desired. The ecology notion offers here an analysis unit of properties that emerge from the interaction between people and palpable services and devices. It is argued that by study how these ecologies emerged we could create a new understanding of palpable interaction and the making of palpable computing.

Keywords
Palpability, interaction, ecology

1 INTRODUCTION

The PalCom project aims at researching and developing a new perspective on ambient and pervasive computing named palpable computing (Palcom, 2004). One main objective for this project is to develop a conceptual framework for palpable technologies and their use. Visibility and invisibility, construction and de-construction, supporting people in making palpable end-user compositions, and hence making computing palpable are some of the most important challenges for the Palcom project. One of the primary goals for the project is to demonstrate ubiquitous technologies with properties clearly available to the senses. Palpable systems should support understanding and user control regardless of the level of interaction.

We have studied the use of pervasive healthcare services to support women during their pregnancies. It is the result of a joint effort between healthcare professionals at the Skejby Hospital in Aarhus, Denmark and the Palcom Project. The concepts have been developed using workshops, user scenarios and low-fidelity prototyping through active participation of both healthcare personnel and pregnant women.

Our project on maternity care is one of several case studies within the PalCom project, where application prototypes were developed to inform the design of the PalCom open architecture. Our main interest was to investigate the impact and use of pervasive technology to support pregnant women and healthcare professionals. The conceptual framework developed within the PalCom project was used as a vehicle for the design and evaluation of the study and its results.

2 CASE: DIGITAL SUPPORT DURING PREGNANCY

2.1 Background

Currently in Denmark, a pregnant woman is in contact with several different healthcare professionals in different locations over an extended period of time. This includes midwives, general practitioners, and in some cases various specialists. This situation has several implications regarding both the interaction between the different actors within the healthcare system and the pregnant woman (including spouse or other persons) as well as the addition and distribution of information.

Many data items are created during the pregnancy; some are valuable and necessary for the healthcare professionals, others are mostly of interest to the pregnant woman and her family, and some are used both by the pregnant woman and the professionals but for different purposes. Presently, the medical information is stored both on paper files and digitally on servers and local hard drives. The information is thus scattered between several professionals in different locations. This leads to a situation where some data is multiplied and updated independently, creating a need for synchronization. The current solution to this situation is a paper folder the pregnant woman physically carries with her containing all the necessary and updated information added at the various visitations.

2.2 Study outline

To acquire a deeper understanding of the situation at hand and to explore the different problems the women encounter throughout the pregnancy, various techniques and methods were used and employed. The overall approach is rooted in the participatory design (PD) tradition (Greenbaum and Kyng, 1991).

The work could be divided into four main areas: ethnographic studies, inspirational workshops, functional prototypes, and evaluative workshops. In this paper we will draw on the results of several parts of this work, but focus on the lessons learned developing and using the prototypes, specifically from the perspective of interaction ecologies.

Various types of field work were carried out within the study, including ethnographic observations at a pregnancy center. In this we focused on pregnant women with diabetes, using interviews and ethnographic 'shadowing' of the pregnant women, midwives and general practitioners to gain a better understanding of the current work practices and situation.

During the study a series of workshops have been held. The main idea behind these workshops was to bring practitioners and other users into the laboratory where they could appropriate prototype technologies by working seriously on a particular, authentic job. The workshops were of both inspirational and analytical kind. The former was used for prototype conceptualization and iterative development, the latter included both analysis of information management and user experience as well as prototype interaction evaluation. Following the PD tradition we have used several different methods such as *Artifacts as Triggers* (Morgensen and Trigg, 1992) and *Future Labs* (Büscher et al, 2004).

To address the issues of social and artificial (via artefacts) interaction and information management, a number of functional prototypes were designed and evaluated. These were intended to support the pregnant women, her spouse and family during the pregnancy and the first time after birth as well as contributing to the professionals situation of e.g. a consultation (figure 1). These prototypes have been implemented to explore different aspects of pregnancy and maternity care practices that are likely to emerge using assemblies of innovative ubiquitous computing devices and services within the PalCom framework. They were used to determine what kind of assemblies users would wish to create, which data the different actors in our scenario need to have, to view and to share, as well as how the information should be presented.

Figure 1. Prototype concept

2.3 Palpable prototypes

There are major opportunities for ubiquitous computing and assemblies of various technologies within the domain of maternity care. In our case, these centre around (shared) access to multimedia information and support for collaborative articulation in many different settings. As a starting point for our work we proposed to supply pregnant women with a digital artifact, primarily intended for storing and communicating information. The idea is to ‘augment’ the pregnant woman with a network-enabled, modular, configurable digital artefact for holding and communicating information as well as interacting with other people and devices in the environment. Another aspect of the concept is aesthetic and is partly grounded in product semantics. It is intended to be an attractive artefact that could act as a congenial focus for the integration of experience in pregnancy as well as elicitate emotions of security, permanence and control regarding storage of personal and intimate information.

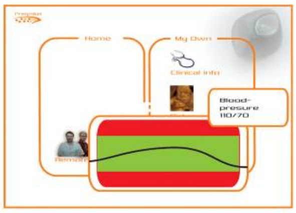
The design of this device built on the knowledge acquired from several different prototypes as well as the lessons learned during the workshops. These prototypes were produced in order to investigate various aspects of palpability. One dealt with displaying information on external screens, another challenged user interaction by providing a minimalist interface. Other were concerned with management of medical information. A third kind of prototype was used to investigate the collection and handling of personal and intimate information in the daily life of the pregnant woman. This prototype (prototype 2 in figure 2) deals with content production and handling and is the main prototype considered in this paper. It was implemented in two ways. Half of the pregnant women participating in the study got a prototype implemented on a PDA and half got a low-fi mock-up in the shape of a scrapbook diary and a real stone. The primary task was to use the prototype to take notes during the pregnancy. That is, to write down what kind of data they would like to keep, how they would use it (e.g. to remember things to ask the midwife), as well as other things related to the use and content of the prototype. The duration of the test was two months and included two workshops, one in the middle and one in the end. In a third follow-up workshop, the findings of the pilot were discussed with the healthcare personnel (general practitioners, midwives, nurses and others). The pilot provided many suggestions on which data the pregnant women and their spouses were interested in as well as ideas concerning the design of the device itself.

Prototype 1: remote display

Prototype 2: information collection and evaluation

Prototype 3: one-button interaction

Prototype 4: database management



Prototype 5: information presentation

Prototype 6: data transfer

Figure 2. Prototypes

3. FINDINGS

The key findings concerning the palpable aspects of our study can be described in two major themes: information management and distribution; and interactive and performative aspects.

One important lesson was the great variation in the individual circumstances and preferences of the pregnant women and in their contact with the healthcare system, and hence in the kinds of support they wanted and/or needed.

Another lesson was that the participants asked for an enormous range of features and functionalities, seemingly impossible to collect into one device (cf. Swiss army knife). This included both different kinds of information and media, various technical functionalities as well as functional simplicity and access to content.

3.1 Information management and distribution

The pregnant women reported problems with communication, both in respect to healthcare professionals as well as sharing information and experiences with their spouses. They felt that there is a lack of coordination between the different parts of the healthcare sector, which in turn results in situations where the pregnant woman has to repeat the same information over and over again, a situation which is perceived as annoying and discomforting. Thus, there exists a need to facilitate communication between all parties involved, not only to avoid repetition and unnecessary redundancy of information but also to be able to prioritize consultation time differently.

The women also stated that information found on for example the Internet regarding the development of the fetus could be incongruent which was experienced as confusing. Thus they would like to have coherent and professionally revised information available on the device in order to avoid misunderstandings and anxiety.

An overarching discussion in study was a possible differentiation in the levels of information. For example, one pregnant woman suggested that it would be nice for the mother to be able to record the heart rhythm of the fetus. However, she also acknowledged that this could also give rise to concerns if the rhythm sounded odd or couldn’t be detected by the mother. The specific interest and capability of the individual is thus a crucial factor to be considered.

Figure 3. Data display situations: the midwife’s office and a café

The proposed device also introduces intimate information to be included at the same level as the medical data. This mix of personal and medical information on the device generates some new requirements about privacy and integrity (figure 3). It was for example notable that when collecting the diaries for evaluation, all subjects removed at least a couple of pages considered to contain information valuable but too intimate to disclose. Healthcare personal confirmed this by reporting that even if increased communication is desirable there are many cases where confidentiality has to be stressed. Hence different sets data need to be visible in some cases and invisible in others. Thus there is a need for clarity regarding data access control which is fundamental for the palpability when it comes to integrity and privacy.

3.2 Interaction and performative aspects

In Denmark and similar countries, a pregnancy is not normally a medical condition but could rather be considered a psychological, social and biophysical. The pregnant woman is not a patient, she is not ill in a medical sense and is not treated. The main concern of the healthcare professionals is to monitor the health of the mother and the development of the fetus. This has some implications when it comes to the possibilities of involvement of the part of the mother-to-be and her kin.

From our study we observed several aspects of this involvement. Firstly, the participants expressed a wish for co-creation of media and information selection. Most of the participants were highly educated and used to personal responsibility and control from their own professional lifes. They expressed interests in adding personal annotations such as notes, images, sound recordings and video along with the medical information stored on the device. Some of them even explored the possibilities for making certain types of data collection at home, e.g. monitoring their blood sugar levels or their blood pressure, and thus contributing to their own and the child’s health record. Moreover, the women wanted to prepare for the different examinations and pregnancy stages using the device. These ranged from reminder and timer functionalities to reviewing the purpose of the examination.

Secondly, the learning and information compliance were enhanced and supported by engaging the pregnant women and her kin in the information loop. Phenomenologically speaking, the knowledge became grounded in the lifeworld of the participants. Information was updated in dialogue with the healthcare professionals, not automatically synchronized. The information is thus commented and related to the understanding of the individual. It was reported in the study that it sometimes was preferred to have outdated information which is thoroughly explained by a professional rather than updated information which is left without comments.

Finally, in addition to the personal interaction level, the inclusion of an assistive device permits the user (pregnant woman) to interact with the healthcare information. This is currently not supported technologically by the healthcare system, which makes the interaction between healthcare provider and pregnant woman unequal. Using the device the pregnant woman thus gains tangible and explicit means to express, clarify, and communicate ‘soft’ data relevant within the specific context. This type of information is currently exchanged verbally and is mostly not recorded in any of the present healthcare systems. The device thus functions as a personal counterpart to the electronic patient journal in the interaction ecology and enables construction (and deconstruction) of personal information with the healthcare information.

4 INTERACTION ECOLOGIES

The result of our work suggests that our proposed pervasive healthcare devices and services have the potential to be incorporated both in the present healthcare system and in the private household routines if particular focus is given to understanding shifting needs and uses over time. In order to understand and analyze the various settings and to describe the how to find a useful mix of both information and devices and services we would like to draw on the ecology concept. Ecology ('oekologie') as a term was coined by Ernst Haeckel in 1866 and is currently used to denote the scientific study of the distribution and abundance of organisms and their interaction with the environment. Traditionally, ecology is concerned only with living organism such as animals and plants. Gibson used the ecological metaphor when introducing the term 'affordance' in relation to the provision of abilities by things and organisms in the environment (Gibson, 1977). Here we would like to include human artefacts into this 'ecosystem', much in line with the sociological actant network theory (Latour, 2005). It is obvious that more and more human-made artifacts make dramatic impact on almost any ecosystem. Frenay compellingly summaries current trends and the emergent need to rethink our relation towards technology and ecological thinking—with its fluid dynamics, its approximations and gradations; with its self-organization, shifting patterns, and awareness of widespread interconnections (Frenay, 2006).

Nardi and O'Day notes that the ecology term points towards that: "…technological development involves defining our own local information ecologies - creating a local habitation and a name for the technologies we use". They use the notion of information ecology to describe a system of people, practices, values, and technologies in a particular local environment (Nardi & O'Day 1999). In information ecologies the spotlight is not on technology, but on human activities that are served by technology. Suchman, et al (1999), use the ecology metaphor when proposing the necessary conditions for successful and innovative design, a more or less normative standpoint also taken by Norman (Norman, 1988). Luff et al have reversed the use of the term and talks instead about 'fractured ecologies' to address design problems in communication technology (Luff at al, 2003).

Nardi et al use the example of a hospital intensive care unit to illustrate an information ecology. All these people (doctors, nurses, etc.), machines (monitors, probes, etc.) and information (such as medical information, instructions and recommendations) — all have roles in the handling of patients. For us it makes sense to apply a similar perspective on our case of pregnancies to create an understanding of how various actors and artifacts form a context in which the pregnant women meet healthcare personnel.

In our case the information is currently distributed among many parties thus making it very difficult for the pregnant woman to understand and handle the situation. The Palcom project have been suggesting that construction and de-construction of devices and services is a useful concept to describe how to make computing palpable. Using the information ecology notion we can see that each context has it own unique mix of both information as well as devices and services to accomplish a specific task - at home, at the general practitioner, and the midwife clinic – and that finding this mix is a critical part of making a system useful. In ecological terms, it is a matter of homeostasis, a functional balance. This lead to that the construction and de-construction of information is yet another useful design dimension.

Moreover, we have observed that pervasive computing for healthcare services not only should focus on making information visible but also on interaction and integration of information – not only a passive consumption of healthcare information. This includes medical information, instructions, recommendations and other relevant data, as well as personal and intimate entries. In the use of the PDA and diary prototypes we observed that this combined set of data and relevant tools for producing, distributing and handling this information along with the individual's understanding, knowledge and experience creates a new meaning. We hence rather suggest that an interplay between visibility and invisibility creates meaning in the actual interactions which becomes a useful design dimension for pervasive computing. Here, we can also use the ecology metaphor to understand the richness of interactive relations and complexity of everyday interaction patterns (compare e.g. with Löwgren's use of inspirational interaction patterns; Löwgren, 2005). Krippendorff (2006) uses the term 'ecology of artifacts' as a description of how artifacts are related to each other when talking about meaning. Krippendorff claims that in an ecology of artifacts, the meaning of an artifact actually consists of its possible interactions with other artifacts rather than the more traditional view on the individual usability.

These ecologies, constituted as a functional set of artifacts, people and the surrounding environment, in combination with the rich interaction between people and devices we identify as an 'interaction ecology'. There are many examples of these ecologies that help us through the everyday life, from the kitchen in your household to the city where we live. In this text we focus on specific situations observed in our pregnancy case. We argue that by using the ecology perspective we can get a further understanding of the nature and function of a palpable system.

In the analysis of our results we have developed a new analytical level that helped us expand our use of the Palcom challenges. An interaction ecology rejects the notion of simple design principles that create systems that are more simple, more invisible, etc. Accordingly, in an interaction ecology we must include the fact that users are in continuous dialogue with each other, as well as with distributed physical artifacts, and we must be aware of shifting needs and how those artifacts trigger and guide our actions in the world.

Invisibility	Visibility
Scalability	Understandability
Construction	De-construction
Heterogeneity	Coherence
Change	Stability
Sense-making and negotiation	User control and deference

Figure 4. PalCom challenges

5 DISCUSSION

In conclusion, there are several reasons to why the ecology metaphor could be a fruitful one. Firstly, originating from the biology field, an ecology is often used to illustrate relations between an organism and the surrounding environment. The relations in focus here are between people's everyday practices and the surrounding infrastructure of information and communication technology available, for example electronic calendars, e-mail and messaging systems, broadcasted radio, music download services, e-commerce systems or on-demand television. In an interaction ecology, people are in continuous dialogue with a wealth of different services and their interfaces. Secondly, an ideal state for an ecology is one of harmonic interplay, where the relations between actors run smoothly without too much trouble. In an interaction ecology, this state of balance between people and artifacts could be characterized as a state of awareness and control. Hence, in a balanced ecology people are informed about the status of surrounding resources, they can bear with the attention demands from surrounding artifacts, and the ongoing dialogue is experienced as well in hand. Thirdly, people and artifacts in an interaction ecology will show mutual dependencies, negotiating matters between themselves and with their environment, resembling the way different species are connected and dependent upon one another in a biological ecosystem. Finally, the balance of an interaction ecology – and the creation of meaningful relations – is the result of an ongoing and dynamic interaction between people and artifacts in the ecosystem. The interest in how people perceive their environment is prevalent also in a branch of cognitive research – the ecological way to understand perception. In this line of thought, the strategy for exploring and understanding how things work is interaction per se, and a threefold relationship between the individual, an activity, and the objects and surfaces of the environment is a central point of reference. Hence, the focus of interest when looking at interaction ecologies is the everyday meaning people ascribe to things and events they encounter, as well as strategies for how to act accordingly.

Acknowledgments

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8. Surgical Rehabilitation

8.1 Metamorphing as aligning actants – the case of hand surgery

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Metamorphing as aligning actants – the case of hand surgery

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In this chapter I want to proceed reflecting the concept of Metamorphing by showing how artefacts are transformed and used in different ways and in different formats within a completely different domain, that of recovery from hand surgery. Exemplified in the story of patients learning about injuries and changed life conditions, within the domain of rehabilitation from hand surgery, transformations is described as a constant alignment between different actants through the transformations of hand representations. This work has been carried out within the frames for the Palcom project. The Palcom project (http://www.ist-palcom.org/) is an integrated project in EU's 6th Framework Programme under the proactive initiative The Disappearing Computer in Future and Emerging Technologies, part of the Information Society Technologies. I would like to address a notion of interaction that I find has a valuable role in the context of transforming and Metamorphing; namely how forms of interaction can contribute to shared understanding of what's going on in an environment and how Metamorphing at times requires the visibility of actions. Even though the cases of design and hand surgery apparently seems to reside in completely different domains, there is a clear analogy in the sense that rehabilitation, just as design work, proceeds through engagement with material and artificial set-ups in a way that can be described with the concepts of transforming representations and Metamorphing. It is not only a question of translating sketches into scenarios or understanding processed rehabilitation data as real life activities. It is not the subject designer working on top of an inert design object and it is not a passive and obedient patient understanding his body through general information leaflets. Metamorphing tries to capture the deep engagement with objects and things in situated instances in a way that diffuses the distinction between subject and object.

I will now again use the concept of actants, borrowed from Latour, to illustrate how they align other actants, human and non-human, in the process of rehabilitation. Especially I have a focus on how digital media can serve as a boundary object in these processes. This idea is the offspring and continuation of the work carried out by the "Everyday learning within health care" project, and has been carried out partly in co-operation with that project. As an interaction designer I try to make a contribution by showing a possible framing for how handheld devices can be used to access various central resources mobilized when interacting with the various states in the life cycle of digital media. This is exemplified in the design of a "docking station" that can be used during video recordings taking place during consultations. The design is another example of how the RFID technology travels between different domains, now having quite a different expression. The act of Metamorphing relates not only to how representations are transformed, but is here also illustrated as a transformation of devices, interfaces and computational resources. Related here is the issue of how we can experience immaterial resources, individually or collectively, such as wireless connectivity. On a conceptual level I try to make contributions through the concepts of collaborative articulation and explicit interaction, which are addressed by the design which we developed in the project group.

Again taking offspring in the writings of Bruno Latour, on how we talk about the body and the concepts of actants referred to in the previous chapter, I will try to apply the idea of circulating references to the case of rehabilitation. In an article Latour brings forth the story, as described by Geneviève Teil, of the odour kit that is used to train noses for workers in the perfume industry (Latour, 2004, pp.205-229). The kit is made of series of distinct fragrances, arranged in such a way that it is possible to go from the sharpest to the smallest contrasts. Registering the contrasts is trained through a week-long session in where the participants end up becoming, as he writes, "noses". They are called "noses" because they acquire a body organ while at the same time learn to use it in a world of fragrances. So acquiring a body is from this perspective a progressive enterprise that produces at once a sensory medium and a sensitive world. The point is to show how "…bodies are learning to be affected by hitherto unregistered differences through the mediation of artificially created set-up." (Latour, 2004, pp.209). Of course every difference in smell won't be perceived by every nose and to deal with the differences in perception and the relation between perceiver and world he uses the word articulation rather than referring to accuracy of reference. The odour kits articulates the students rather than, at a particular time, giving them, a once and for all, accurate indexing of fragrances. So the local, materialized and artificial setting is not a mere intermediary. It is rather the case that it is the artificiality of the kit that allows the subtle perception of differences. Again he makes a case against the subject-object model inherent in Kantian or Cartesian philosophy. While accuracy of reference is a true or false statement the concept of articulations allows for a discourse that is progressive and which never converges into single statements, and contrary to statements they are propositional.

THE ENACTMENT OF "HAND TALK"

Typically rehabilitation times are very long, in specific cases up to several years. Success of rehabilitation of injury is dependent on engagement and active training by the patients themselves. Even though there is no archetypical patient, some major groups can be observed such as younger men subject to trauma, related to accidents at work, and patients around 50-60 with worn out tendons due to work related activities. This means that the process of rehabilitation most often is critical for the patient's life-situation in a long time perspective. Patients often confront a situation in where they have a major part of their working life still ahead, but no guarantee whether they can return to their profession. In other cases everyday life situations are getting most cumbersome due to the injury. Undergoing surgery and rehabilitation you meet a variety of different actors, doctors, physiotherapists, occupational therapists etc. In addition to this, patients living in other parts of the region might consult local healthcare as well.

For patients it is not uncommon to meet, and receive information from, all these actors at one single appointment at the clinic. This means that during several short-time meetings, patients might go back home with a complex set of instructions that is of importance for progress. Progress is typically slow, with low feedback mechanisms apart from staff judgments. Most of the indicators of progress or drawbacks stay in the formal patient record. Different patient narratives are common during consultations and can give information on why rehabilitation does not work. From this point of view the social dimensions of the process, for instance patients' possibilities to adhere to instructions, are of importance.

Figure 1: Physiotherapist and patient

The concept of collaborative articulation is addressed as a situated negotiation of the state of the injury and the necessary steps for successful rehabilitation. With collaborative articulation, we do not introduce a new concept to health care. It's rather a perspective that stresses the act of mutual agreement in consultations. Health care literature has used the terms compliance and concordance to discuss different degrees of patient empowerment. Whereas compliance refers to a traditional/conservative model where the doctor decides on the treatment and the patients should comprehend and follow instructions, concordance concerns how patients take an active stance in rehabilitation. Rather the patients participate as partners in consultations where mutual agreements are the goal. Patients understanding of their injuries and trust for the caregivers' competence is viewed as supportive for adhering to instructions. For the caregivers it can be a challenge to understand circumstantial problems that might cause problems for the patient to follow the treatment plan. Patient narratives are one way of easing this understanding.

Figure 2: Receiving and going through training programs are but one instance where quite complex sets of information must be understood and remembered

This "Hand talk", evolving during consultations, is performed rather than spoken. A number of tools and log sheets are used to assess and monitor the flexibility of hand and fingers, grip strength, tactile sensitivity and pain. They also serve to make progress visible, which can otherwise be almost imperceptible to the patient. Therapists and physicians also use other artefacts to articulate the stories they want to tell. During a consultation, the physiotherapist uses, for example, a poster showing the anatomy of the hand to reveal and explain what kind of injury the patient suffers from. In conjunction with the poster, he complements the story by pointing at corresponding parts at his own hand. The patient might respond with a story of how he feels strange tickling when taking a shower. This in its turn urges the therapist to take a towel starting to rub the patients hand while explaining perception, pain and how he must get used to different surfaces. In many cases they use everyday metaphors or relates to the experiences of other patients. Considering this and the fact that there are specific outcomes even within the same type of injury, it is easy to see that general information is hard to use, but also to produce. The diversity of artefacts & instructions can at times cause a stressful situation for the patient in where memory easily gets overloaded.

Fig 3: “Hand talk” is performed rather than spoken

Figure 4: From left to right, information leaflet, training tool, X-rays are all examples of representations and objects that patients must relate to

During the patient’s trajectory of his/her recovery process and different encounters with healthcare professionals and their diverse forms of artefacts, a picture of the patient’s overall situation is gradually taking shape. From the healthcare professional’s point of view, the patient record works as a centre of gravity for this evolving image. However, in our work it became clear that the patient has no explicit tool to rely on regarding the creation of this image. And patients do have their own agendas preparing by writing down questions or just mentally going through the consultation to be.

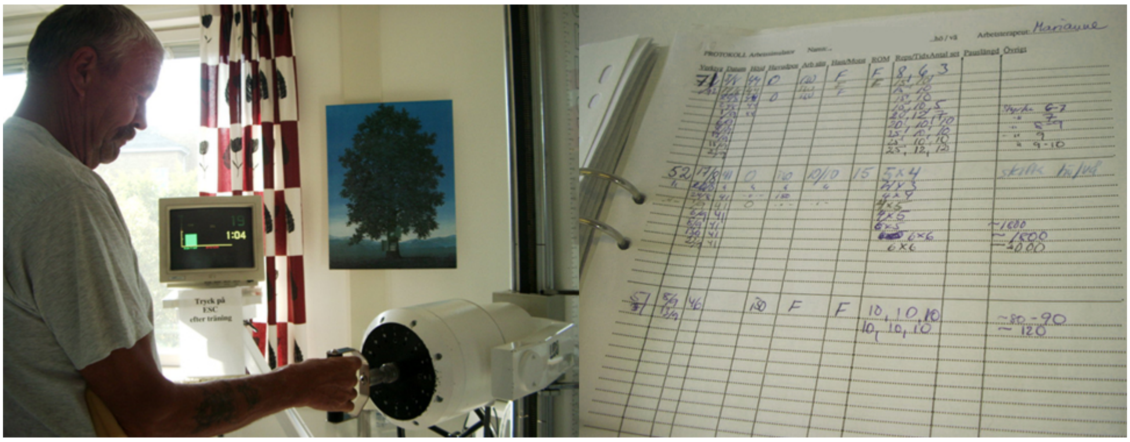
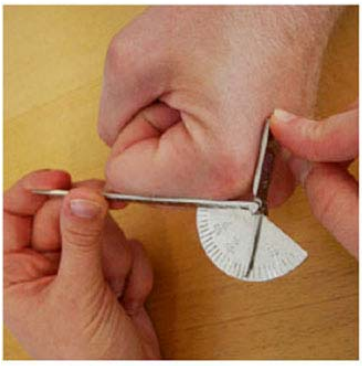


Figure 5: Training with the work simulator

During several instances processed data must be understood and translated by patients into "real-world" facts. One example is illustrated in the picture above, where a patient is doing exercises in the work simulator. The work simulator is a set of machinery which simulates real activities such as climbing a ladder, driving a car etc. The strength used is measured in numbers and logged in individual sheets for each patient. The log sheets accounts for how rehabilitation is going, but can be hard to relate to actually performing the tasks in real life. Another example of data that can be hard to translate and understand is in the picture below. Measuring the flexibility of the hand is done by using a goniometer, the measures are put in the status sheet that is a central part of the patient record which can tell how rehabilitation is going.



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Domain	Instrument and quantification	Months	3	6	9	12				24
Sensory Innervation	Semmes-Weinstein monofilament, minikit 0=not testable 1=filament 6.65 2=filament 4.56 3=filament 4.31 4=filament 3.61 5=filament 2.83	Result:0-15 Normal median:15 Normal ulnar:15	0.07	0.33	0.40	0.60				0.60
Tactile gnosis	s2PD (digit II or V) 0=≥16mm 1=11-15mm 2=6-10mm 3≤5mm	Result:0-3 Normal:3	0	0	0	0				0
	STI test (digit II or V)	Result:0-6 Normal: 6	0	0	0	0.17				0.33
Finger dexterity	Sollerman test (task 4,8,10)	Result:0-12 Normal:12	0.42	0.42	0.58	0.58				0.67
	Mean score sensory domain:		0.12	0.19	0.25	0.33				0.40

Figure 6: Goniometer and status sheet

So, meetings and artefacts help the patient to form a picture of his/her recovery process. Much of the relevant information is embedded and of a situated character, revealed with the help of aligning different artefacts to the patient's injury. The evolving picture is negotiated between the parties forming a unique story for each patient and during consultations learning and instruction is mutual and negotiated in interaction.

BUILDING A DISCOURSE AROUND DIGITAL MEDIA AS BOUNDARY OBJECT

Per-Anders Hillgren and Erling Björgvinsson, in the project *Everyday learningwithin health care*, have made promising experiments (Björgvinsson and Hillgren, 2004) to capture such situated occasions, by various ways of recording and documenting parts of consultations that can follow the patients. Digital media has the potential for easy and instantaneous documentation that renders a situated character to information.

While resting in between the general and the particular, it can be related to the specific moment in which it was conveyed. In the first experiment, they used a DV camera on a tripod to film meetings between a physiotherapist and different patients recovering from the same injury (an incision to a tendon). The movies were about 15 minutes long and you could easily see both the patients and the physiotherapist's hands and the poster they use as illustration. The contents were to some extent similar between the movies, but there were also important differences. The patients received the movies on regular CDs after the consultations, and they used them several times in ways that were not anticipated. They all used them to show their relatives what they experienced at the hospital. A professional athlete showed the material to his regular physiotherapist. The movies were used as references, in order to compare movement capability with previous rehabilitation exercises. One patient explained that this was much easier to refer to than, as he put it; "the cryptic numbers filled into the status sheet". The patients also used the movies while doing their exercises. Exercises include fine grained movements which are easy to understand while seen, but hard to recapitulate afterwards. Used today are paper templates that are slightly individualized from case to case. The movies has potential to act as a memory re-enforcer, enriching the crucial situation at home where training must succeed only on behalf of the patients' ability to re-enact the instructions.

Another experiment from their project included the use of screen capturing software. Often during consultation sessions, a physician and a patient collaboratively watch the patient's X-ray pictures on a computer screen between them. In those cases, the physician uses the X-ray pictures to explain what kind of surgical procedure he is planning to perform. The software used allows the physician to draw and mark the X-ray pictures to emphasize the patient's status and what the surgical procedure will be about. All this was recorded as an animated movie together with their discussion. The format is playable on all Windows platforms and the patients received CD copies before they left. Similar to the previous experiment with the movie recordings, they found differences in the explanations and discussions among different patients also when patients suffered from similar injuries. All the patients also used the material to show their relatives.

I find these experiments as enriching patients' landscape of aligning artefacts. While traditional clinical representations often circles around general, and for patients often abstract, information, the movies and screen recordings refers to the situated nature of communication that can support translation and Metamorphing between all the artefacts used in the process. Looking at the picture below we can see how they fit into a chain of "circulating references". From left to right are different representations of the hand; the anatomical poster which is "the idea of the hand" in a Platonic sense, the X-Ray picture which represents the invisible individual hand, the status sheet which is the "processed hand". The final pictures are from the Everyday learning project; the X-Ray augmented with the physician's drawings and recorded an explanation which is the "talked about individual hand" and finally the "video hand".

Figure 7 – Different hand representations

Mol and Law highlight in a text on hypoglycemia how the sickness is performed and ‘done’ rather than being described and known (Mol and Law, 2004, pp.43-63), including treating the patient as a human being far beyond the sickness or disease. They propose that healthcare take an ethnographic turn that is not accounting for general states of bodies but rather looks into pragmatic ways of dealing with the state at hand. The use of the “ethnographic” label indicates, to my interpretation, that it:

- addresses how dysfunctionality of the hand is *performed* rather than being described as a finite or general state of the body
- tries to capture these *doings* of hand surgery in the instant and specific moments of rehabilitation rather than being instructional and generalized
- includes the patient’s body as a lived human body, including the life-world of the patient from healing of tendons to work ambitions and love life, rather than treating her as primarily “ill”)

I think our observations at the Hand surgery clinic confirms the aspect of performing and that the experiments from *Everyday learning within health care* addresses capturing parts of *the doings* of hand surgery. In the Palcom project we’ve made a first round of experiments trying to address the inclusion of the patient’s life-world by reversing the media stream, letting patients bring media to consultations to see in what way that can strengthen the articulations and the overall process of Metamorphing. In a first exploration of how pictures taken by a patient were brought to his meeting with an occupational therapist it seems like they can contribute in several aspects.

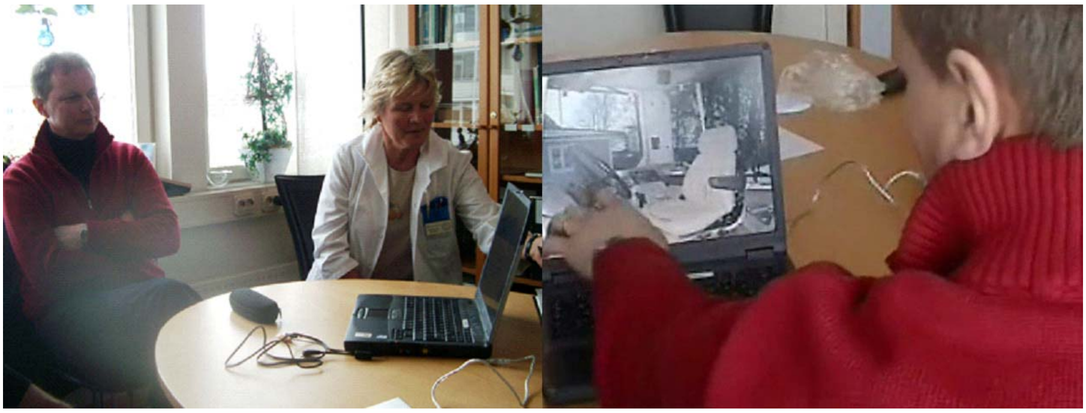

Figure 8:
A patient explaining his work situation to a therapist, aided by pictures he’d taken

The patient, that had undergone repeated surgery after a severe injury, had been in rehabilitation for more than a year. He had been one of the patients that received CDs recorded during consultations and is enthusiastic about the idea of recording videos and using images as part of rehabilitation. Having spent a lot of time at the rehabilitation ward, he knew the staff quite well and especially the occupational therapist, which had supporting his adjustment to everyday-life after the injury for a long time. He was at this period about to start work-training at his regular job, coming back for a limited time each day, performing only limited tasks. This meant that the therapist is supposed to write a work place description, which is handed over to the national insurance office as basis for evaluating the patient’s ability to come back to his old profession as a caretaker at a school. This document is another example of a rehabilitation artefact that is used to align the different actors involved in the process. They are produced by the therapists based on their judgment of the injury and recovery, and it is balanced against the patient’s narratives of how work is performed.

It used to be the case that the therapists went to on site visits at the workplace while preparing this document, but due to financial reasons this is no longer possible. It is often a challenge for therapists to evaluate how the injury affects a work situation, to which he/she has a limited understanding. While we as researcher had asked the patient to bring basically any pictures he found would enrich the consultation and especially things he wanted to share with others, the therapist had asked him to take some pictures from his workplace. Though being a quite simple way to enrich the therapist's understanding it is not a common procedure and she asking him to do this was instantiated by our experiment.

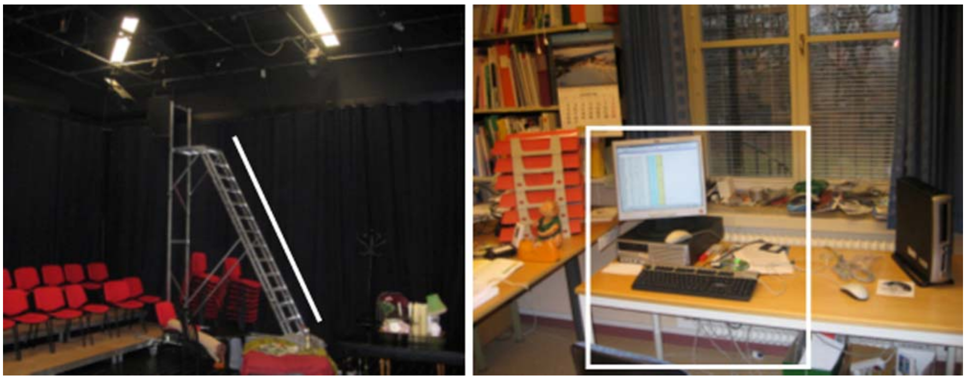

Figure 9: Pictures from the work place

It is not surprising that the pictures taken made up for new possibilities for discussing the issue. They of course provided the therapist with a broader basis for understanding. They also shifted the focus from how she usually asks the patients questions, to a situation where the patient was the most active, storytelling with the support of the pictures. According to the patient, taking the pictures was also a way for him to organize his narrative. It enforced him to search for situations which now might be troublesome for him. For example, he had previously not mentioned that he at times had to climb a very steep ladder or how small his office place was.

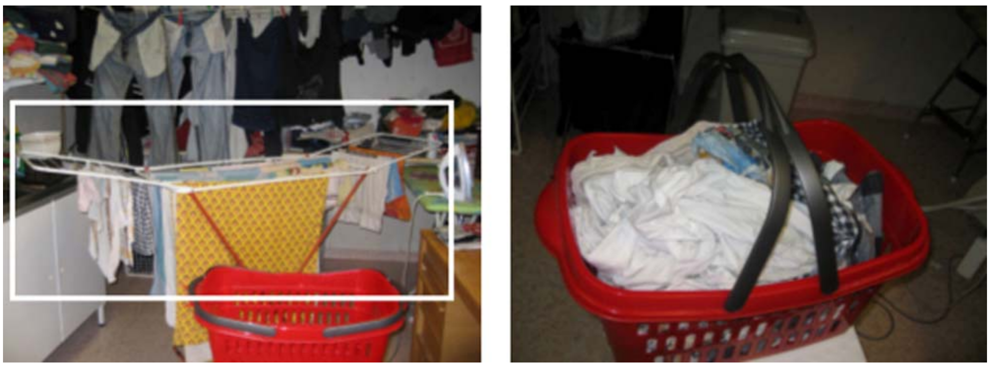

Figure 10: Pictures of solutions to everyday problems

However, the content of the picture he had taken went far beyond his work situation. An apparent area of concern for patients undergoing hand rehabilitation is how they no longer can perform tasks as usually. For example such a trivial situation such as buttoning the trousers is far from straight forward. This is certainly an unwanted social situation, but also not good from a medical point of view, since not using the hand makes the parts of the brain, which is connected to the hand, passive and thus further prolonging rehabilitation. The patient had spent considerable time to find workable solutions for several such troublesome situations. Among other things he had bought a construction for hanging drying laundry which permitted him to take care of the laundry without having to stretch the arms upwards, which caused him severe pain. He had also bought a basket which didn't strain the hand too much; he could carry it with his injured hand. He found that this was an example he wanted to share with other patients. The occupational therapists know professionally, from her education, catalogue browsing and commercially arranged demo events, about a lot of products that can support patients with hand disabilities. But in her work she also hears a lot of informal stories on solutions created or found out by different patients. Looking at the pictures and discussing opportunities with us researchers, she found that she wanted to create a database of examples that she could share with patients. For this she found the patients themselves a rich resource.

Figure 11: Pictures from home

Finally, the patient also had taken pictures from his home and the surrounding environment. He used them to give a brief encounter of how he lived, but also to talk about his trauma at the occasion of the injury. The picture to the right above is taken from the site where he was injured in a machine related accident and where he had been laying waiting for help for a long time. These are also important aspects of rehabilitation and staff at the ward spend time working in groups with patients suffering from especially severe injuries. They often have a strong urge to talk about their traumas. The therapist found that in cases where she knew she would have a long standing relation to the patient, she could well imagine to spend the extra time needed for viewing pictures taken by patients and listen to stories, that were not "needed" from a strictly clinical point of view. Concerning the idea in general, that patients can bring media produced by themselves to consultations, she states that; "…I see lots of possibilities to increase communication and understanding through such a way of working".

The case of hand surgery illustrates how a diversity of artefacts, materials and representations are used in different settings and talked about in different ways. Translating, understanding and communicating around them are other aspects of Metamorphing. A challenge for the field of interaction design within the domain of patient empowerment is to devise a set of devices, services and content that can, through appropriate interaction, support the health care staff, the patient and his surrounding social network to collaboratively articulate the state of the injury and the necessary steps for successful rehabilitation and patient learning. The experiments from the Everyday Learning project and our experiment with patients producing media shows how a discourse could be built around the use and production around digital media in a way that supports patient learning and empowerment.

But the interaction around the life-cycle of digital media poses several interesting questions.

DEALING WITH HETEROGENEITY

Heterogeneity of formats and representations is inherent in the concept of Metamorphing. They might be digital or material and have different forms. They also reside on different devices and are used differently. As networked digital media is becoming more and more ubiquitious in our environments we can also observe how heterogeneity of devices and interaction is becoming a crucial issue. Chalmers and Galani highlights in a widely referred paper (Chalmers and Galani, 2004, pp.243-252) how a too narrow focus on one tool or medium is contra inductive to how everyday activities involves an interweaving of media and formats, but also devices. As should've become obvious by now I share their view that "*Social people, in their environment, continually mix and couple media in everyday communication: walking, gesturing and pointing while one talks, and referring to places and what people did in them as one writes.*" (Chalmers and Galani, 2004, pp.244). Since Weiser's original vision (Weiser, 1991, pp.94-110) of ubiquitous computing a widespread goal of development has been a notion of seamless interaction and the computer being "invisible" in our environments. This is partly due to an overemphasis of some of Weiser's formulations such as ""literally visible, effectively invisible" (Weiser, 1991). One example of how this has influenced research is the naming of the European research initiative The Disappearing Computer, in which Atelier was one of the projects. An underlying assumption, which also has affected much HCI research, behind the idea of invisibility and disappearance is Heidegger's definition of tools being either "present at hand" or "ready at hand". In many cases "ready at hand" (Heidegger, 1927/1996) has been an ideal because not being distracted by technology users have the possibility of completely focusing on the task at hand. While discussing these concepts Chalmers and Galani suggests that; "*The ongoing 'feedback loop' of interpretation and understanding integrates these two modes, and affords variation in people's understanding as well as consistency in their behaviour. For example, creativity can be considered as the variation of an individual's subjective understanding from his or her prior understanding and from others*" (Chalmers and Galani, 2004, pp.245). They put forth the concept of seamful design as an alternative approach. This would include emphasizing a revealing of differences and limitations of systems as a way of supporting social interaction. One example is how they, in the design of a mobile game to be played in urban environments, reveal areas of bad network connections instead of hiding them (Chalmers et al., 2005). Network connections are otherwise typical examples of system properties that often are hidden, being transparent to users.

The Palcom project (www.ist-palcom.org) tries to explore a new take on ambient computing called palpable computing. That a system is palpable denotes that it is capable of being mentally comprehended by the user. States and processes should, when needed, be made available to the senses to promote control, understanding and appropriation. Six dimensions from the vision of ambient and ubiquitous computing are challenged by opposing concepts such as invisibility/visibility, heterogeneity/coherence, automation/user control etc. (more information about the project is available at www.ist-palcom.org)

Most often users will have to explore their way as to find a position somewhere between these extremes. The project's goal is foremost to develop software architecture for palpable systems and a conceptual framework for such computing, but also to develop a range of application prototypes that illustrates the ideas and benefits from the developed software. As people inhabit shared spaces, they elaborate their means for talking about it and interacting with each other as well as the artifacts populating it. In consequence, an emerging design principle is not to design dedicated spaces but to design for the *appropriation* of space. This calls for reflecting the physical spatial conditions for interaction and for possibilities to *configure* objects and actions within the space. These aspects have been addressed in much HCI research concerning end-user composition. A promising area for these configurations is the possibility to work with assemblies of devices and services. This can be dealt with either by *de-construction* of existing devices/services or through *construction* of new open-ended assemblies either via parts of existing assemblies or via components exhibiting new functionalities. Especially we have been interested in how using personally owned handhelds in combination with central resources such as cameras, servers, sensors, displays and databases and so on. Because we are gaining ability to dynamically construct and deconstruct assemblies from constituent resources. And it becomes a question how users perceive heterogeneous devices appearing as coherent but temporary hybrids.

The problem of invisibility of systems has also been addressed by many other researchers such as for example Rehman et. al. They conclude some problems of invisibility; the lack of a good conceptual model, loss of control, lack of feedback and breakdown of traditional models and put forth the principle of visibility as a possible solution (Rehman et. al, 2002, pp.213-216). Visibility is related to materiality in several ways. Most often artefacts have an intended functionality, but as they are appropriated through use, *border resources* are emerging. Consider the use of doors and how public buildings more and more are using automatic doors. A design ideal seems to be a level of implicit interaction, you do not have to open the door, you just walk through it. An example of a border resource residing in the use of doors, is given by Andreas Lund (Lund, 2003) when he refers to a movie by Jaques Tati. In the movie, which is a silent movie, the lead character, frustrated over some disagreement, wants to express his anger when leaving the room by slamming the door shut, a sound which we all can refer to as embodying the dissatisfaction felt by the person shutting it. It is not a property inherent in the design of doors to express emotions, but none the less it has evolved into a border resource comprehensible for most. In the movie the character bangs the door again and again, but since it's a silent movie nothing is heard, the border resources can't be evoked. And the materiality of artefacts does play a crucial role in our everyday sense making. Albert Borgman (1984) uses the term *commodity* to illustrate how just one of several aspects are maintained when an artefact is replaced by technology. One of his examples is how central-heating well provides opportunities for securing warmth, but how wood-burning fireplaces also related to the amount of wood needed, the work with chopping and drying wood and the need for keeping the fire burning. Those might be border resources in relation to 'warmth', but important ones as they also provided a rhythm of everyday life.

But visibility as such has to be carefully designed if we are not to be overwhelmed by a huge amount of choices to make. It is also not sure of which interaction styles to apply, whether it should be appliances in the real world or graphical representations. Probably we'll see quite an amount of hybrid interfaces, depending on shifting between tangible interaction and graphical interfaces, develop in the forthcoming years. In the following I will highlight a design of ours that try to use the virtues of both – a kind of a mixed interaction space. The design can be seen from the background of Metamorphing as aligning actants, the idea of seamful design, the described Palcom challenges and the idea of short-lived assemblies.

EXPLICIT INTERACTION

Mobile devices with capabilities for handling the whole life-cycle of digital media are becoming widespread. Sarvas et al. observes in an analysis of the mobile photo life-cycle how must include all the involved terminals and devices and not only focus on individual devices and interfaces (Sarvas et al, 2005). They emphasize how the life-cycle of mobile photos, which they describe as capture-transfer-share-view and archive, is distributed over several devices and how some of the transitions require substantial user effort. This became very clear in our observation of how the patient, bringing digital photos to the clinic, had to start his meeting with the occupational therapist by trying to connect his memory stick to the TV at the ward. He knew this was possible and had managed to perform the task before. The therapist had no experience at all of this and it took about twenty minutes before they gave up and used my laptop instead, since there was no computer in this room.

Figure 12: Trying to connect a memory stick to the TV

This issue of connecting refers to a very practical aspect of understanding of how digital media is transferred and how different devices co-operate, but there are also several social aspects involved. Collaborating within the environment, which has an lay out similar to those of open offices where many therapists share the same space, is both patients and therapists in their specific meetings, but also the whole amount of actors in the space. The issues of privacy and perception of the actions of others is a general question for every shared space, in where activities around are staged around the use of digital media. Recently voices of concern have been raised against the possibilities of taking photos with mobile cameras. Recording of videos is one aspect, but also the displaying and sharing of media of a private character is a sensitive situation. While the experiments from the *Everyday Learning* project showed promising results, we found that the CD/DVD format does not fully address the potential of networked digital media and also the asymmetrical relationship between staff and patient remains since it is the therapist or physician unilaterally deciding on when and what to record. To manage video recordings the set-up has so far consisted of a video camera with a built in dvd burner mounted on a tripod. The tripod and camera has been carefully set up in advance by the therapist. To control the recording the therapist uses the remote control for the camera. He usually turns the display of the camera so he can distantly view what’s being recorded, but it’s a limited view, being a small display viewed from some distance.

Figure 13: Video recording being performed in the Everyday Learning project

We took as starting point to use mobile phones as central devices for interacting with an environment that has constituent resources in the form of displays, cameras and sensors and so forth. For practical reasons we used PDAs instead during implementation, since, to our experiences they are easier to program. It was important for us to keep the concept of collaborative articulation in mind, supporting empowerment of the patient while at the same time developing a useful tool for the staff. Another object we introduce in our scenarios is the metaphor of a docking station—a physical object that in combination with a phone or PDA provides a framing for fulfilling some specific intention such as recording, viewing or sharing digital media. It is motivated by desirable use qualities such as augmenting the generic device with activity-specific functionality when needed, and supporting visibility of activity and intentions. The name docking station is not an ideal name and it has also been talked about as a physical proximity descriptor or pairing device. Initially we were inspired by docking stations physical shapes and affordances, it is generally very clear to understand how to put the device in the docking station since the slots fits nicely and it has became an accepted mode of joining devices, for example a PDA to a PC.

Figure 14: The “docking station” with two PDAs

Apart from the slots for holding PDAs/phones the docking station has an RFID reader on the inside and the PDAs are carrying RFID tags that are detected by the reader unit once the PDAs are placed in the slots. This is actually unnecessary since the detection is made by bringing the units (tags and reader) into close distance and we could just as well have used a dedicated area of the table for example. But in this specific situation, as well as in many others, we think that the materiality of artefacts have a role to play. When the tags are detected it is possible to determine the identification of the patient as well as the therapist and it thus becomes possible for a proper way of storing and associating the recording. It is a prerequisite that the phones/PDAs have been registered and augmented with tags and the proper software at some point in this scenario. Our yet unimplemented idea is also that while entering the hospital the device is used for registering the patient's arrival, a procedure which today is performed by "checking in" at the reception desk. Entering the hospital the phone's signal is turned off as not to interfere. The motivation for not allowing phones today at the ward is of a social character that the phones should not ring during consultations and at the ward. It is still common that patients forget to turn them off, but it is really not a big problem and the staff claims that there is no problem of interfering signals such as phone/pacemaker or other equipment.

The docking station has been designed for the sole purpose of making a video recording, but in the future it might well be developed as to have potential for other activities such as displaying or sharing. Instead of an ordinary tripod and video camera we have used a webcam of good quality mounted on a desktop lamp. This gives a quality of "physical zooming", by moving the lamp holding the camera closer to the object of recording you zoom in and vice versa. Once the both PDAs are placed in the docking station they are connected to the camera and the video feed is displayed on the displays of the PDAs. We chose to make it necessary to use both PDAs during this first iteration as to enforce the shared decision making on what to record. As it is possible for the patient to start a recording the nature of interaction is more of a shared interface.

Figure 15: Our new set-up with PDAs, camera lamp and docking station

So, instead of using the remote control for initiating and stopping the recording, the act of placing the PDA in the docking station connects it to the camera. The video feed is displayed in a low-resolution version on the PDA (which eventually also will store the media. This is not yet implemented). The screen of the touch-sensitive display replaces the record and stop buttons and tapping on the display thus controls the recording. When the PDAs are taken out of the docking station, the connection with the video camera is ended.

Figure 16: Placed in the docking station the display turns into a two state interface allowing just for pause/record of recording process

Though not fully evaluated in actual use at the clinic we think the design responds to a notion of very explicit interaction, which might seem unnecessary, but still has some interesting features which have been assessed in sessions with the staff:

- *Placing* is not a physically demanding interaction, which actually is an issue for people with hand disabilities. Neither is it a cognitive demanding task, compared with browsing for the right application and navigating in a typical PDA interface with many choices.
- It is *performative* in the sense that both partners can relate to a ritualistic series of actions that reflects a change of rhythm in the consultation. It is agreed that they now are about to start a recording. It also supports other people present in the room that can peripherally perceive that a recording is taking place, in adjusting how they perform for example deciding not to disturb or make loud noises.
- It is *personal* in as much as viewing the recording on the personally owned display gives a feeling of ownership and access to the digital media.

But what is more important; the collaborative nature of interactions enforces the shared and negotiated nature of the decision on when to record and what to record.

Formal evaluations have been made at the clinic together with staff and patients with good results concerning usability aspects. Still, we must ask ourselves how we evaluate the actual experience of using technological artefacts. Participatory design tradition has developed a variety of methods for involving users in different stages of the design process. It is partially a question of acknowledging users as a resource, gaining insight to tacit dimensions of their everyday settings and setting up a language game that can be shared. Often these language games of design are performed in initial phases for gaining a firm understanding of context as foundational for design, but also in iterative steps in the ongoing development. Much HCI research has concerned situations of use in laboratory settings, and strong methods for evaluating criteria such as efficiency ease of use, robustness etc have been developed. In a widely referred book Paul Dourish writes on the notion of appropriation and meaning making. Designers give form to objects that are placed within environments, but it is the users who create and communicate meaning around the use of the artefacts. The designers have primary responsibility for the artefacts, but not for the use. Instead of designing use we must focus on how users understand an object & apply it to their own activities. As people inhabit shared spaces, they elaborate their means for talking about it and interacting with each other as well as the artefacts populating it. In consequence, an emerging design principle is not to design dedicated spaces but to design for the appropriation of space. Therefore important aspects of evaluation refer to how ideas and interventions into practice are picked up by users beyond the designed artefact.

The staff and patients at the clinic is currently using handheld devices, such as cell phones, to access and control this life-cycle of digital media on an experimental basis. This is perhaps an equally important point of reference that ideas and examples have been assimilated to some extent by staff using whatever technology that actually is available.

Figure 17: A physiotherapist is using a cell phone to make a recording of a rehabilitation exercise. Note the webcam mounted on his lamp, which illustrates the diversity of devices used

This also gives rise to further observations of “what people do to make things work”. In this case the physiotherapist, seen in figure 82, have to deal with patients having different phone models, some Bluetooth enabled and some requiring cables for transferring media. This has urged him to make a variety of devices, some with overlapping functionality, available. One example is how he uses a cell phone with a very good camera for recording when “on the move” while using a better web camera mounted on his desktop lamp while sitting at his ordinary desk. This implies that we also must reflect on the whole ecology of devices being used in different situations and not only evaluate how they are used as they perform the intended functionality.

In several instances issues of jointly sharing and controlling interfaces residing at different devices has arisen. These issues refers to a very practical aspect of understanding how digital media is transferred and how different devices co-operate, but there are also several social aspects involved, such as being sure to whom media, or a jointly used interface, is handed over to. The docking station addressed how proximity based interaction supported jointly controlling the recording at the same time as it gave clear signals to the surrounding environment that a recording is being carried out. This urged us to think further on the use of proximity based interaction.

One situation we have been experimenting with is how when staff and patients watch and review videos together, breakdowns occur in individual devices, such as a low-power condition for instance. This calls for transferring content on one device to another one, in order to maintain the stability of an assembly, which can for example be constituted by several phones or PDAs, a displaying device and a display. This kind of contingency handling can often be handled by autonomous behavior in the device itself, but at other times the control should be handed over to the human users. In the situation of watching video together one person controls the display through an interface on his PDA and as the PDA is about to go down due to a power-low condition, the contingency manager observes the breakdown to be, notifies the user and starts searching for a suitable replacement device among the devices being present. At this situation the transference of the interface controlling the displaying could be performed automatically. However, this instance can also be seen as a suitable moment for letting a human negotiation, which also can account for social circumstances, take place.

Figure 18: Handing over by touching/bringing in proximity

The proximity descriptor provides opportunities for a tangible interaction, which permits “hand over” by touching or bringing close two devices. This provides a clear understanding of whom you are handing over to, instead of the uncertainty of browsing device names on the interface, deciding on the proper name and then performing a virtual “hand over”. This is one example of balancing automation and human control. Tangibility renders the situation as clearly perceivable for both patients and staff in consultations and different meetings.

Considering the embedded character of human action in settings where meaning making is evolved with strong impact of both socio-material mediations and computational resources, we think it makes sense to include aspects of the material world and direct tangible interaction when exploring palpability as a concept. When moving between virtual representations and physical constituents proximity based interaction provides a way of ensuring visibility of actions that supports the human user in understanding what is going on and how computational resources are intertwined with the physical space. It is illustrated in the docking station protoype how this affects notions of connectivity and in the contingency handler prototype how it also can enrich understanding of technological inspectability. We think this aspect is valuable far beyond our current scenarios, which have urged us to develop the proximity descriptor as a software module having its place in the Palcom toolbox.

I hope to have shown here that, an important aspect highlighted here is how there also can be an aspect of transformation of devices and interfaces that has to be understood and perceived in an environment. This has here been dealt with through the concept of explicit interaction and an illustration of how short-lived assemblies can be constructed and interacted with. I have contributed to the design of the docking station which exemplifies how physical forms can serve as mediators in creating assemblies. They can act as physical nodes in a landscape of activity based services. Being physical nodes they also have potential to manifest awareness of intentionality and actions for others present in the space. Continuously performing interaction with a variety of timely introduced, ready-made or invented, representations and the human body is to move ahead. Certainly there are maps but wayfinding and navigation are localized moments of real world interaction.

9. Care Community

9.1 “Performing” Ambient Computing

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Status: Submitted as CHI 2008 Case Study

“Performing” Ambient Computing

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Abstract

Ambient Computing systems challenge the way in which humans interact with technologies by developing technological solutions for new *ensembles* of devices and services distributed in the environment. However the introduction of pervasive, ambient and ubiquitous computing in a multitude of devices and environments may create difficulties. We need to develop appropriate computational models to ensure that the user is able to exploit this technological augmentation. The user needs to be able to make sense of, and control, the composition of different elements (physical, logical, functional) and also be able to make sense of them. Thus we argue for a performative view on ambient computing, one that stresses the ways in which researchers, engineers and practitioners together and *in situ* create an ambient computing environment from assemblies of elements. These challenges of Ambient Computing are exemplified in this case study of a Neonatal Intensive Care environment, a complex socio-technical system populated by a significant number of technologies and devices distributed in the environment that the neonatal team – comprised of doctors, a variety of medical specialists, and nurses use during the treatment of premature babies. The case study presents a particular vision for Ambient Computing realised by the “Palpable Computing” framework [4],[18], [20]. Palpable Computing is a vision for Ambient Computing that addresses the way in which humans meaningfully interact with distributed computational systems. In particular the case study shows how Palpable Computing can support people in inspecting the devices present in the neonatal ward during normal activities as well as in the presence of a breakdown event. Furthermore it presents a concrete example of the creation of novel assemblies of services and devices constructed by the neonatal team in order to better monitor and evaluate conditions of the babies under care.

Keywords

Ambient Computing, Palpable Computing, User Engagement, Inspection, Emergent Use.

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

The concept of Ambient Computing involves the design of distributed, pervasive and reactive systems able to communicate with the users and to continuously adapt to their needs and expectations. The Ambient Computing vision is to build a highly dynamic computing environment where mobile and stationary devices connect and coordinate seamlessly and automatically.

In 2000, a scenario planning exercise was launched to describe what living with ‘Ambient Intelligence’ might be like for ordinary people in 2010 [6]. The IPTS (part of the European Commission’s Joint Research Centre) in collaboration with DG Information Society and with the active involvement of 35 experts from across Europe published a report containing four scenarios that explore how Ambient Computing might be implemented in society. In the report the scenarios were used as a means to uncover the specific steps and challenges in Ambient Computing technology, and suggest qualitative changes in the life of ordinary people living with and using Ambient Computing technologies. The four scenarios describe how Ambient Computing is experienced by people in their daily life. In all four scenarios people are surrounded by intuitive interfaces that are embedded in a variety of objects. They present a vision of Ambient Computing environments which are capable of recognising and responding to the presence of different individuals, and are implemented in a seamless, unobtrusive and often invisible way. The “perfect” world envisioned in the scenarios involves a huge distributed network consisting of thousands of interconnected embedded systems that surround the protagonists and satisfy their needs for information, communication, navigation, and entertainment [6]. However, if any kind of breakdowns or unexpected event occur in the scenarios, the likelihood is that the protagonists will be unable to understand and control the system(s) - leading to further complications not developed in the scenarios. Indeed if any of the systems described do not fit the tasks people are trying to do, or if there is a breakdown, then people need to be able to see the systems, to experiment with them or even to repair them – the opposite of transparent or invisible systems! . This move towards invisibility of computing resources needs to be supplemented with notions of visibility, allowing people access to information about the ambient systems. Indeed in many instances it is very desirable that ambient computing capabilities are invisible and just ‘do the work’, in others it is very important that devices and environments may, somehow, show their status and their affordances: i.e. make ‘visible’ what they are doing, what they potentially may do, and what other devices they might connect with [18]. A spectrum of visibility should be allowed to ensure the aesthetical pleasure of interacting with a pleasant and fun-to-use device, but also to support people in case of recurring breakdowns and errors. Then it is necessary to be able to see into the system, to find out what has gone wrong and how to correct the error, to visualise connections and be given an opportunity for recovering from the problem.

The question of visibility is not the only challenging area in Ambient Computing. In the “Scenarios for Ambient Intelligence in 2010” report many ubiquitous computing systems have a high degree of automation [6]; they take the burden of control away from the user by automating decisions. Again, this is fine so long as the intentions of the user are in agreement with the vision of the designer. But if people want to do or achieve something different, then it is extremely annoying that the system is automated. In such cases, there is a request for more user-control and initiative. People should be able to creatively combine Ambient Computing resources as prompted by immediate circumstance and take them apart and reconstruct them to explore and try out different options.

As Rogers states [25], there is a need for an alternative agenda for Ambient Computing “which focuses on designing UbiComp technologies for engaging user experiences. It argues for a significant shift from proactive computing to proactive people; where UbiComp technologies are designed not to do things for people but to engage them more actively in what they currently do. Rather than calm living it promotes engaged living, where technology is designed to enable people to do what they want, need or never even considered before by acting in and upon the environment. Instead of embedding pervasive computing everywhere in the environment it considers how UbiComp technologies can be created as ensembles or ecologies of resources, that can be mobile and/or fixed, to serve specific purposes and be situated in particular places. Furthermore, it argues that people rather than computers should take the initiative to be constructive, creative and, ultimately, in control of their interactions with the world – in novel and extensive ways" ([25], p.406).

In what follows we describe a case study where the Ambient Computing agenda suggested by Rogers [25] has been realised, implemented and tried out with people. The case study is illuminating in several respects:

- it describes a socio-technical critical-support system populated by people and technologies pervading the environment where the issues of visibility, user control and automation are presented and analysed in their full complexity,
- It presents real accounts of events where the work has been supported by Ambient Computing solutions,
- It describes exemplar activities where people (neonatal team) creatively explore, construct, try out and invent different assemblies of services and devices to manage critical situations in a Neonatal Intensive Care Unit.

We share with Rogers the need for a new research agenda for Ambient Computing which makes people more creative and in control of the surrounding environment. We also believe the realisation of this agenda implies the development of a middleware runtime infrastructure to concretely implement this vision.

In what follows we firstly present a Case Study illustrating the activity occurring in a Neonatal Intensive Care Unit and the issues emerging when people cooperate during the care supported by a variety of technology distributed in the environment. Then we present the Palpable Computing framework, a vision on Ambient Computing that purposely addresses the way in which humans meaningfully interact with distributed computational systems. Palpable Computing is introduced not only as a vision for Ambient Computing but also in terms of the middleware infrastructure developed within the PalCom project (www.ist-palcom.org) [18], [20]. Palpable Computing is also discussed with respect to other frameworks, technologies and infrastructures to form a composite view on the state of the art in Ambient Computing and to appreciate differences and commonalities.

Then we go back to the Case Study to show how the PalCom architecture has been used in the Neonatal Intensive Care Unit in two situations: for inspecting the system during a breakdown event and to create new assemblies of services and devices to better monitor and evaluate the baby's conditions.

THE NEONATAL INTENSIVE CARE CASE STUDY

The care of premature newborns is a complex process involving the use of a variety of machines and collaboration among a number of people with different skills and backgrounds, with different objectives and different expectations (i.e. neonatal doctors, nurses, therapists and families).

The system is characterized by a high level of re-configurability since each incubator should be conceived as an *ad hoc* entity, tailored to the baby's conditions and dynamically changing over time. The Neonatal Intensive Care Unit environment should be able to support the co-existence of these diverse necessities and should afford an easy reconfiguration as these necessities change. The work practice is based on the continuous combination and integration of data coming from different sources. In this perspective, it is crucial how people make sense out of what it is going on, and how the continuous process of understanding is supported and connections are established and maintained. This aspect is fundamental for the medical personnel to promptly intervene in the care process when necessary; but also for the families in order to be able to psychologically sustain such a delicate situation and to play an active role in their child's care, offering their presence and emotional support.

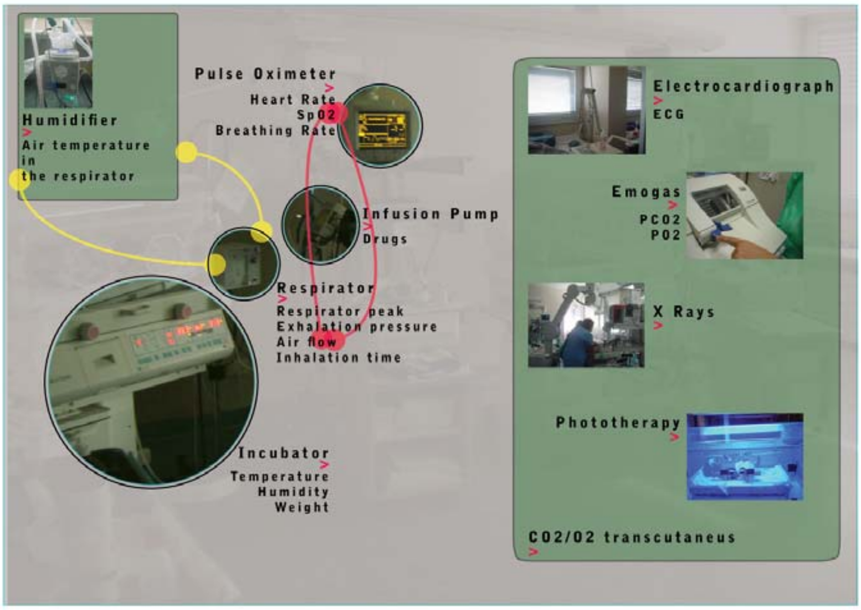


Figure 1: The Incubator System: functional connections among the Pulse Oximeter, the Respirator and the Humidifier

Current incubators do not function as autonomous units. As figure 1 illustrates, each incubator works in conjunction with a number of machines which support the different functions of the newborn. In order to deal with the number and typologies of the sources of information, all the devices are structured in a way that distinguishes each signal from the others. The co-existence of distinct and uncoupled alarm configurations (both visual and acoustic) is problematic and can create potentially dangerous situations for the babies. To better investigate this aspect we will concentrate on the interactions emerging among three fundamental tools at the NICU: the Pulse Oximeter, the Respirator (also called *Ventilator*) and the Humidifier.

The Pulse Oximeter mainly allows the monitoring of the baby's $SpO_2$and heart rate. In medicine, oxygen saturation (SpO_2) measures the percentage of haemoglobin binding sites in the bloodstream that are occupied by oxygen. Put more simply, it is the amount of oxygen being carried by the red blood cells in the blood. The SpO_2 level is measured as a percentage, with a normal value being around 96%. In practice, SpO_2 increases or decreases according to how well the baby is breathing and how well the blood is being pumped around the body. The Pulse Oximeter is equipped with an alarm configuration that provides both visual and acoustic feedback in order to readily alert the medical staff of any problems that may arise. Beside the Pulse Oximeter, the *ventilator* is a fundamental device in the incubator configuration, supporting the breathing functions of the baby. The ventilators are used in combination with a humidifier in order to regulate the temperature of the air flow. The ventilator is equipped with its own acoustic alarms and a visual configuration of alarms that display the different parameters, i.e. the ventilator peak, exhalation pressure, air flow, inhalation time and oxygen percentage. The humidifier is also provided with its own acoustic alarm to detect any increase or decrease in the water temperature. Therefore, each of these machines plays an indispensable role in the care of the child by supporting their vital functions. However, having so many separate, but related, measures can be confusing.

The scenario below presents such a case, and is based on a real situation involving the SpO_2 value. It describes the inspection strategies adopted by the nurse and the neonatal team to understand what is the problem and how to recover the situation.

01

Mismatch detection

The nurse is taking care of a preterm newborn while she detects a mismatch and variation in Sp02 value. She gives a look on the saturimeter display and it shows 80, it is a low value far from the standard range (90 Ð 100).

02

Overcoming the mismatch

Together with the neonatologist, the nurse starts to explore the anomaly. The neonatologist assesses the baby health conditions. The first diagnosis is done basing on the colour of the skin. With a Sp02 value of 80 the corresponding condition should be a blue- grey coloured face in the baby.

03

Hypothesis Testing

The neonatologist verifies that the baby has a rosy face. The nurse and the neonatologist hypothesize possible problems with the Sp02 sound. The nurse tests the hypothesis by checking if the sound is correctly placed on the baby foot. She also tries to move the sound from the hand to the foot.

04

Hypothesis Testing

Once verified that the sound is correctly placed and the saturimeter still shows 80, the nurse decides to substitute it with a new one. In the meanwhile the neonatologist continuously monitors the baby health conditions.

The nurse and the neonatologist check now the new values on the saturimeter. Although the sound has been substituted the saturation value shown is still low (80). On the other hand the empirical assessment of the baby tells she is stable and fine.

05

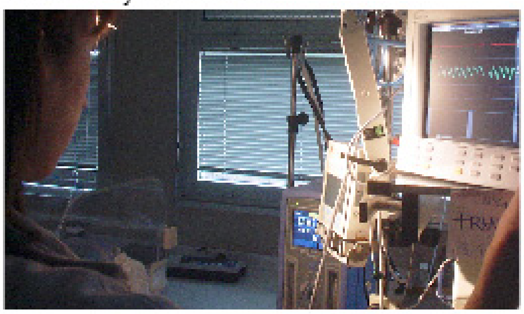
Hypothesis Testing
Since the baby is intubated; the nurse and the neonatologist arrange the hypothesis that the value from the saturimeter is correlated with the function of the ventilator. There's any direct coupling between the two machineries, but of course any anomalies in breathing would directly affect the amount of oxygen in the blood.

06

Overcoming the mismatch
The nurse tries to overcome the mismatch by restarting the respirator while the neonatologist performs manual ventilation with the AMBU bag.

07

Recovery check
The respirator re-starts working properly. The newborn is currently under the neonatologist direct care while the nurse checks the new values provided by the saturimeter shifting her attention from machinery to another.



08

Error Detection
The neonatologist and the nurse assume that the saturimeter was correctly working while the fault was in the respirator.

Figure 2: Inspection Scenario: 'Spo2 Variation'.

When a variation in the SpO_2 value occurs, the medical staff first decide to stabilize the child's situation and then to check if the sensor is correctly positioned on the baby – in order to determine whether to change the sensors' position or replace it. Eventually they control the respirator. The way in which this trial and error strategy is applied depends on the previous experiences of the nurse and of the neonatal team. During the inspection, the medical staff generate different hypotheses about the systems status, continuously checking the condition of the baby and trying to understand where the source of the mismatch is emanating from. This strategy has two main consequences: in the case of mismatch detection, the medical staff must question the overall reliability of the system; no level of degradation is provided: whenever a component stops working the whole system is compromised. In other words, this can be considered an on/off system. Moreover it is not possible to figure out the functional relations among the different equipment necessary for the child's survival - a malfunction on one device (e.g. the respirator) directly effects the functioning of another device (e.g. the Pulse Oximeter) which in turn directly influences the baby status (e.g. change in the SpO_2 value), etc.. Furthermore, there is no direct indication provided by the system to make visible the interconnections between the two devices.

As this case demonstrates, the different equipment at the NICU have a strong, logical connection since all of them have a mutual influence on each other and an impact on the baby. In fact, these components are not functionally connected and each one works independently of the other. This aspect is fundamental for understanding the distributed nature of this setting. Thus, the inter-relation between these measures is determined by the medical staff in the actual situation, without any systems support. It represents the main part of the nursing teams diagnostic process. Of course, when emergences occur, the way in which these interdependencies are noted by the staff can dramatically affect the nature of the work and the well being of the baby. Ambient computing solutions could play a major role in this setting, affecting both the functional and the subjective experience of work and influencing the life of the overall system.

AMBIENT COMPUTING TECHNOLOGIES: STATE OF THE ART

Various research and industrial experiences investigate solutions for making heterogeneous parts (software, hardware and human) participate in new ensembles [25] by exploring novel modalities to conceive the users' role in the interaction with them, i.e. which kind of interaction can be supported and at what level. A number of different software frameworks exist today that try to support these aspects, by mainly providing middleware solutions [9]. Jini [2] is one of the most well-known frameworks, developed by Sun in the late 1990's (although is now driven as a project by the Apache Software Foundation) [29]. Jini is an extension of Java and supports the creation of a distributed computing environment, where devices and software services can be connected to a network and broadcast their presence throughout the network. Other devices and services can then discover these running entities and use their available services. This is supported by an ad-hoc infrastructure, enabling 'plug and play' functionalities [9]. Although Jini enables a spontaneous form of networking [30], the process of discovery, configuration and use of devices and services running within a network is automatic and not visible to the user. In fact, service composition is possible and handled through the use of a proxy object, uploaded to a lookup-service but the composition phase is only handled at development time where the different services learn what connections could be made [29]. In this sense the dynamic properties of Jini's infrastructure results in a focus on automation and system control, while end user control is not supported. The Obje Software project [15] developed by PARC in San Diego explores an analogous vision of services and devices ensembles. The Obje software platform enables a device to 'teach' other devices in the vicinity how it communicates and what functionality it can offer [9]. This is realized by means of an intermediate layer that manages the communication and the interoperability among the different components. In this perspective Obje explores the idea of recombination of devices, applications and services on the fly [7], [8]. Although the Obje project seems very promising, identifying key issues in a pervasive and ubiquitous computing setting, no built-in mechanisms are provided to handle break-down situations [9]. This aspect is crucial to understand the notion of user control that emerges in interaction with these types of technologies. Indeed in order for the users to control the system, the system should make visible the connections available and the functionalities that are supported, especially when problems or breakdown occur. Another example is offered by the Oxygen project at MIT [14], which has been purposely developed with the objective of supporting end user control and re-composition of devices and services. Oxygen provides a platform to support a highly dynamic environment with ad-hoc properties, devices coming and going, as well as human agents interacting with the system. In this sense, the user can control and combine services to coordinate their input and output. Also, service composition is possible and handled by the user by different forms of scripting, for example verbal [9]. In spite of the strong focus on end-user composition that is handled at runtime, the inspection mechanisms are not adequately supported since to sustain a more natural interaction Oxygen automates the inner processes.

As illustrated by this quick overview, although existing ambient computing frameworks (like GAIA, One.World, OSGi) support in many ways the configuration and combination of the resources available in the environment, the modality in which the system status and behavior is perceivable, understandable, inspectable and configurable by the user is less supported and key issues emerge in respect to the interaction qualities that are supported. The investigation of service composition and inspection from both a software and user perspective has not yet been made, mostly due to the lack of an infrastructure supporting this.

PALPABLE COMPUTING

Palpable computing is a vision of Ambient Computing that purposely addresses the ways in which humans meaningfully interact with the distributed computational systems that are available in the environment [11]. However it is not simply a "vision" of Ambient Computing as used, controlled, created and envisioned by ordinary people: it also offers a middleware runtime infrastructure to concretely implement this vision [17]. The word 'palpable' is used since it comes closest to capturing the fact that people need to be able to grasp what technologies are doing and could do for them if they are to use them effectively and creatively [18]. The concept of palpability has been developed in the PalCom project [20] through empirical ethnographic and ethnomethodological studies of how lay persons and professionals (learn to) make complex and dynamic states and processes palpable for themselves and others [4]. Differently from other approaches to Ambient Computing, palpability is not a fixed property of an object. Instead it arises in interaction as an effect; its shape changes with the changing attention, interests, actions that people bring into different situations. This means designers cannot "give" palpability to their objects. Instead they can *design for the production of palpability*.

In order to achieve this vision and allow palpability emerge from use and practice, computational resources must be *visible* to the user and it must be possible to *inspect* and *understand* their states [18]. Moreover the inspection should be *generic* and its availability *not contingent* on the ability of application programmers to foresee what is required to be made visible at any given time. A second important feature of Ambient Computing enabled by palpability is the possibility to *combine* resources as prompted by immediate circumstances, and *take them apart and reconstruct* them to explore their workings in detail, and perhaps try out different options [19]. This has lead to the development of a model of service composition – in the concept of explicitly represented assemblies. Palpable systems are those systems supporting user control by composing and de-composing assemblies of devices and services that communicate and exchange data [12].

Other researchers have been concerned with studying assemblies of artefacts working in concert in socio-technical environments. For example, Bowers et al. [3] defined a design schema for assembling artifacts in the museum setting based on a view of ubiquitous computing where “computing and interaction with computing resources takes place at specific loci with purpose-specific things happening at a particular locus. Computing is made “ubiquitous” by the linkage of these specific loci” ([3], p. 47).

In the Palcom project the assembly is a fundamental mechanism for service coordination [11], [12], [27], central to the project's approach to support palpable systems purposely created to fit the requirements of specific activities in defined places. A system that is constructed by means of assemblies can be inspected in a service browser, making its inner structure visible at a certain level. This gives a better understanding of the system, and is particularly important when a system breaks down. Furthermore, the assembly concept targets construction of systems from services that were not originally created for cooperation with each other. By inspecting the interfaces of a set of services, it is possible to construct an assembly that combines them.

Assemblies in Palcom are defined by assembly scripts that can be loaded at runtime by interacting with an assembly manager. When an assembly is loaded the assembly manager makes the appropriate connections and governs the flow of service invocations [17]. The assemblies may be thought of as physical and logical entities, consisting for instance of a web cam and an EEG sensor that the neonatal team can set up to study any correlation between the baby’s movements and the development of the central nervous system and convulsions [26]. The creation of assemblies implies that each part of the assembly is easy to understand on the logical level (what can be done with this, with what can it be combined and for what purpose), the functional level (how to use it) and on the physical level (it must be possible to see what fits together and to actually build/rebuild the structure). The dynamic construction and deconstruction of assemblies implies that the available services are distributed and able to discover and interact with each other. The discovery process can in principle reside on any of the participating devices [17]. PalCom objects thus recognize each other and their own heterogeneity among the assembled devices. Therefore, the software objects in the Palpable Open Architecture can be run on a variety of different devices, from microprocessors to biosensor monitors. By means of the PalVM, the virtual machine developed within the PalCom project, palpable software objects can potentially be instantiated in everyday technologies as well as in personal objects.

The Palpable system offers a vision on Ambient Computing centred on the practices and concrete uses of digital technologies.

- It supports the dynamic end user composition of services and devices.
- It supports creative construction and deconstruction of ambient technologies both at a physical and logical level. The elements of the de-constructed assembly could be re-used for creating new assemblies.
- It supports user control by making the system visible and inspectable. While using dynamic assemblies, users should be able to discover and detect interrelations among breakdowns and should be allowed to inspect what has been going wrong.

- It manages the graceful degradation of the system functionality. If part of the system fails, still some functionality should be available and be open to inspection. Inspection allows the user to examine the current state of a system or component and to reconfigure the system accordingly. If a system is subject to degradation, it should be able to communicate its new state.

Thus palpable technology can provide users with the opportunity to overcome certain failures of the system by relying on the still-working components. System resilience and re-arrangement of the available resources are key features of palpable computing [4].

In the following we show a concrete application of PalCom Computing in the NICU. Here the modality by which information and the system status become noticeable is fundamental to face ordinary treatment as well as emergency situations.

THE INCUBATOR ASSEMBLY

The Incubator prototype developed in the PalCom project reconceives the NICU setting as an assembly of services and devices that are able to respond to the specific requirements of the setting [26]. The incubator assembly is composed by the incubator itself, the surrounding machinery as well as a number of technologies developed in the PalCom project. These include:

The BioBelt: A wearable device augmented with a set of sensors placed around the infant’s abdomen.

The PalCom-node: This node is an I/O-device functioning as a bridge between non-palpable devices (existing technologies in the ward) and the PalCom technologies. This allows non-palpable equipment to take part in palpable assemblies.

The Assembly Browser: With this browser users can manage assemblies throughout the whole assembly lifecycle [28]. It allows the users to construct assemblies as well as reconfigure and turn off assemblies during the activity. The Assembly browser exists today in one version targeting developers. Another version intended for end-users is now under development. The palpable devices can be assembled with other palpable devices but also in combination with the current, existing equipment at the NICU (e.g. the Pulse Oximeter). This is permitted through the use of the ‘PalCom node’. All these devices (i.e. the devices running the PalCom architecture and the devices connected through the PalCom-node) can be managed (e.g. be attached to different running assemblies or inspected) through the Assembly Browser. A specific user interface allows one to explore the assemblies’ qualities and to permit the user to construct the required assembly according to the needs of the neonatal team [10], [26]. In the incubator system various assemblies can coexist in order to monitor specific parameters and anticipate the occurrence of problems.

The biosensors belt is developed as a first prototype with embedded sensors and transducers for monitoring the heart rate (HR), the breathing rate (BR), the body movements (BM) and the temperature (T) [21], [23]. Concerning the physiological parameters, the belt aims at facilitating the continuous HR, BR, BM and T monitoring with proper signals acquisition and pre-processing systems, ensuring an unobtrusive measure [1], [5]. In order to address the requirements of this particular application domain, the biosensor belt design necessitates specific considerations in relation to the sensor integration in a textile substrate. The belt is about 4 cm wide and can be adapted to fit the size of the baby and fixed in a non invasive way, to avoid direct contact of scratchy material on the baby skin. The BioBelt can interact with the

Assembly browser and other PalCom devices through a PalCom-node. The already existing equipment in the ward, such as the Respirator and the Pulse Oximeter become part of the PalCom network in the same way, by connecting them to PalCom-nodes running services that can wrap them into PalCom devices. The Pulse Oximeter measures the Heart rate and the SpO_2 values from the child while the Respirator assists the childs breathing function [10], [13]. The neonatal team can combine the information coming from the belt in order to get more detailed assessment of the condition of the baby. The assembly not only allows one to connect PalCom devices with existing devices but its networking properties support the inspection of the system by checking the status of the functional connections among the different components of the assembly. To facilitate this task, the belt can transmit also the raw bio-signals ((electrocardiogram (ECG) and the chest dilatation (respiratory movement)) thus facilitating the understanding of possible sensors' failures [13].

PALPABILITY IN USE: SUPPORTING NOVEL INSPECTION STRATEGIES

The Incubator assemblies described above define a system of different components that can allow novel forms of inspection by relying on the networking among the assembly components. This allows the medical staff to respond to the evolution of the baby conditions more flexibly and sensitively. In this system different assemblies can co-exist (e.g. the BioBelt, the Pulse Oximeter and the assembly browser in parallel with the BioBelt, the Pulse Oximeter and the Respirator) integrating palpable applications with the existing equipment in the NICU. This notion of assembly captures a very critical feature of the work at the NICU. The incubator is linked to external equipment to sustain the baby, but no functional coupling is now supported among the different devices. This complicates matters, making it difficult to recognize and discriminate system failures vs. aggravation of the babies condition. The use of assemblies in this setting can significantly modify this situation by establishing novel connections among the incubator equipment and making visible the functional relations among the assembly components.

In the implemented system, it is possible to recognize two complementary strategies to allow inspection of the system behavior [13]. The first one is the classical "redundant error-handling" strategy. In the prototyped version of the assembly the heart rate (HR) detected by the Pulse Oxmeter (HR1) is continuously compared with the heart rate coming from the BioBelt (HR2) that the child wears. In this application an alarm is generated each time the compared values rise above a defined threshold. This represents a classical inspection strategy which compares the same value coming from different sources. Currently this comparison is done by the medical staff without any external support [13].

Redundancy is a well-known strategy for critical systems support and is considered necessary for high-reliability organizations to manage activities that are sufficiently dangerous to cause serious consequences in the event of operational failures (e.g. in the military). In classic organizational theory, redundancy is provided by some combination of duplication (two units performing the same function) and overlap (two units with functional areas in common). The theory is that reliability can be enhanced by parallel configurations—standby components that are in place to operate should the primary components fail [16]. Not all of the critical points of exposure and of vulnerability, however, can be covered, as safety is a compromise between requirements and economic necessity [22]. Indeed inserting additional levels of control is costly and poses problems on the interactive complexity of the system: unexpected interactions can affect supposedly redundant sub-systems. A sufficiently complex system can be expected to have many such unanticipated failure mode interactions, making it vulnerable to normal accidents. For this reason other kinds of inspection strategies are currently investigated in the PalCom project working with the notion of assembly. Different scenarios exploiting network-based inspection have been explored. In these scenarios each component of an assembly is interconnected with the others and in this way is aware of and responsible for the others. If a failure in a component occurs, the other components of the assembly can notify it to the user [13]. Indeed, while using dynamic assemblies, users can discover and detect connection breakdowns and inspect a failure of a component that for some reason does not respond any more to its neighbor in the assembly. Each constituent in the assembly is aware of, and becomes “responsible” for, its neighbors, and can be used to check whether it is receiving signals and data from the others or not. In this way each component of the assembly can refer to the others about the state of its neighbors and the message can be broadcast in the assembly [13]. An example of such an application is the case of breathing-rate monitoring. In one of the scenarios considered, the Respirator provides the child with oxygen, while the breathing rate, which correlates to the respirator function, is monitored by the BioBelt; the SpO_2 values are monitored by the Pulse Oximeter. Whenever any malfunction occurs in the respirator the discovery protocols enabled by the PalCom nodes will propagate the information on the missing signal from the respirator to the whole assembly. This creates a novel inspection opportunity for the user who can understand what is going wrong and at which level of the system.

PALPABILITY IN USE: EMERGENT USE OF SERVICES AND DEVICES

As stated in the introduction, Palpable Computing supports not only the inspection of services and devices but also the creative exploration and construction of novel assemblies to manage critical situations in a neonatal ward. Indeed, the possibility of integrating heterogeneous data and of demonstrating the functional connections that exist at the systemic level is interpreted through the use of specific assemblies, which serve as operative tools for the neonatal team to configure and control the services that they are using and the data that they are monitoring.

In its developmental phase, the incubator assembly combines specific “palpable” technologies (the Biobelt) with instruments that are normally used in Intensive Care (ex: Pulse Oximeter, the respirator, etc.).The relationship between the equipment currently used in the Neonatal Intensive Care Unit and the palpable technologies is synthesized in the “correlation map,” which shows possible linkages between values supported by the creation of specific assemblies. The correlation map was utilized as a simulated interface in brainstorming sessions with the neonatal team with the aim to explore new opportunities for creating assemblies for better monitoring the babies’ conditions.

The map represents all of the equipment that is used for monitoring the children in the Neonatal Intensive Care Unit. Each of the individual pieces of equipment can be considered as one component of a larger system, in which every noteworthy variation can be linked to and can influence another component. Of even greater note is that each of these variations carries with it a consequence and has a direct influence on the conditions of the child; the comprehension of these interactions is therefore one of the most critical factors in the diagnostic process. Of the sensors and equipment that make up this complex system of reciprocal forces and influences, some represent fundamental parameters which must necessarily be rendered visible and accessible in a continuous and constant fashion, in keeping with the strong correlation that exists between them.

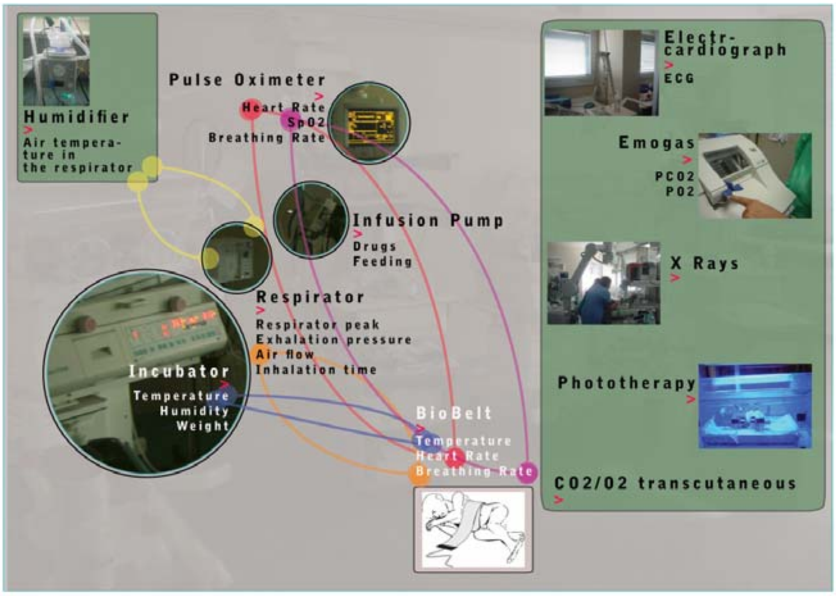


Figure 4: Correlation map in the Neonatal Intensive Care Unit

Other components of the system, on the other hand, constitute effective elements for more specific monitoring, but are not always necessary. Access to these components of the system should therefore be available on a different level of interaction, when the specific conditions of the child would require them as needed. In order to take these functional differences and various necessities into account, the whole of the available information was designed by the neonatal team as a system with different levels of visibility and various access methods.

The *assembly of the vital parameters* that they created represents the whole of the values that describe the conditions of the child, which are the fundamental interpretive tool for the comprehension of the situation. The assembly of the vital parameters comprises the values relative to: $PaCO_2$, PaO_2, SaO_2, Respiratory Rate, Heart Rate, Blood Pressure and Temperature. The parameters are listed in order of their importance, taking into consideration their extremely strong, reciprocal correlation. A single, centralized screen permits the operators to observe the overall progression of these values. In addition, each of these parameters has a specific alarm that can be configured by the user. The alarm systems, aside from being customized to each parameter, can be configured by identifying the *sensitivity thresholds*, the more a variation of one parameter is accompanied by the variation of another. For example, when there is a variation in the SaO_2, CO_2 and temperature values, the “type 1” alarm is activated. When a variation in the blood pressure level is added to the previous variations, the “type 2” alarm is activated, which indicates a more critical situation. The alarms can thus be configured differently according to the risk that is presented. This means that various thresholds of seriousness correspond to a different kind of alarm (from a softer to a more acute sound). In addition, the alarm system that is configured is the direct consequence of a precise semantics defined by the neonatal team according to the type of access they have to the system.

This possibility of the adaptation of output consequent to the variation of one or more values profoundly modifies the quality of the feedback that the system gives. In this way, the feedback becomes more precise and more informative, as it provides not only an indication of having exceeded the values of a certain threshold, but also sustains the possibility of understanding the meaning of that variation according to the more complex logic of the possible correlations between the parameters identified.

As anticipated, the assembly of the vital parameters permits different levels of visibility, according to the type of elaboration necessary for the comprehension of the clinical situation. For example, as in the cases cited by the medical personnel, it is often necessary to complete the clinical framework with the EMOGAS analysis. In this system it is therefore possible to directly access the EMOGAS data from the screen that displays the assembly of the vital parameters in order to identify possible alternative correlations. The interface of the assembly is deliberately designed to be simple and basic in order avoid generating any additional cognitive load for the medical personnel. The values relative to the EMOGAS are thus available via “more internal” levels of information that are accessible from the main interface. In the same way it is possible to visualize and navigate other assemblies dedicated to the monitoring of other, precise correlations. In this way the use of the Biobelt offers new and promising monitoring possibilities that could open new diagnostic opportunities. For example, the neonatal team can compare the values of the SpO_2 with the diaphragmatic movements of the child (which are monitored by the Biobelt), in order to improve the monitoring of hypoxias/apneas. Other examples of possible correlations concern the preliminary identification of pneumatic problems or the obstruction of the endotracheal tube, which is made possible by the option of intersecting the data of the SpO_2, with the respiratory frequency monitored by the respirator and the respiratory frequency recorded by the belt. In the latter case, the combination of these parameters could contribute to an anticipatory diagnosis of respiratory anomalies if these were due to a change in the conditions of the child or equipment malfunctions.

CONCLUSIONS

The paper presents a vision on Ambient Computing that moves away from a mindset considering the environment smart and proactive to one that makes people able to construct and be in control of ubicomp technologies in their everyday and working practices.

This vision has been developed within the Palpable Computing framework, which allows people to dynamically combine resources as prompted by immediate circumstance and take them apart and reconstruct them to explore their workings.

Palpable computing is more than a vision on Ambient Computing since it offers a middleware runtime infrastructure to concretely make invisible technologies visible and available for inspection and reconfiguration, and to support people to make sense of what technologies could do for them if they are to use them creatively.

The case study of the Neonatal Intensive Care Unit represents a concrete implementation of the vision. The preliminary exploratory trials with neonatal team and nurses show that palpable computing allows a goal-oriented, problem solving approach to the use of technologies (supporting inspection and reconfiguration) as well as a more exploratory endeavour based on construction and deconstruction of assemblies of available elements.

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9.2 Assemblies of heterogeneous technologies at the Neonatal Intensive Care Unit

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Assemblies of heterogeneous technologies at the Neonatal Intensive Care Unit

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Abstract

Ambient Intelligence, pervasive and unobtrusive computing research is introducing new perspectives in a wide range of applications. The Neonatal Intensive Care Unit represents a complex and multi-output context aimed at monitoring and controlling biological signals and parameters in premature newborn. This paper details some methodological and design options for developing technologies that allow end-user composition and control. These options enhance consistent user experiences in environments where different devices, services and processes co-exist. In particular we describe the notion of assemblies of monitoring devices, interpreted as the combination of sensors, tools and services in a distributed and unobtrusive computational and monitoring environment. We report on the importance of flexibility and user-control in the use of such technological assemblies in a neonatal intensive care unit, describing an early prototype of such monitoring system.

Keywords

premature newborn, design, open architecture, palpable computing, biosensors, assemblies and user control

1 INTRODUCTION

The introduction of digital technologies into health care scenarios requires specific considerations related to the characteristics of the domain, the activities executed in the environment and the different skills of the actors involved.

The notion of ambient computing has been consolidating with a focus on the design of distributed, pervasive and reactive systems that are able to communicate with the users and to continuously adapt to their needs and expectations. Traditionally, the main goal of ambient or ubiquitous computing applications was to make the technology transparent or invisible to the users. Transparency or invisibility of these systems can enable users to receive help, and get information by the utilization of background cues that sustain their everyday tasks. However, when these applications are more deeply considered, one can recognize that this sort of technological disappearance is not always possible or even desirable [1]. When for example an error occurs within these systems, the user would benefit from the visibility of the current system state, which would permit the inspection of the error and allow the user, if possible, to take the necessary correctional measures. Therefore to effectively use these applications the users must always remain in control [2]. This is especially true in emergency or breakdown situations in critical safety domains, such as for example a Neonatal Intensive Care Unit [3]. Thus, what are the requirements for the ambient devices in such setting? How do they address these potential errors?

A premature birth dramatically alters the stabile situation of a normal pregnancy and the child development in the uterus by destroying the safe configuration of 'filters' between the child and the external world. The premature child can not stand yet the environmental stimuli which he is suddenly exposed to. The newborn shifts from a condition of protection, characterized by postural stabilization and natural stimuli, to a condition within the environment of the incubator that is characterized by excessive and painful stimulations. This in turn can cause a high level of stress that is then reflected into the clinical conditions of the baby.

The Neonatal Intensive Care Unit (NICU) represents an example of a socio-technical fragility that challenges the design of ambient computing technologies intended as a support to the premature babies' necessities and to the collaboration among the individuals acting in the ward. It has been investigated how novel bio-sensors can be introduced in a Neonatal Intensive Care Unit and what are the requirements for introducing such technologies in this kind of environment.

In order to address these research issues we adopted palpable computing as an emerging conceptual framework developed within the EU funded project PalCom (PalCom, http://www.ist-palcom.org). Palpable computing grounds on the notion of ambient computing which is focused on the design of distributed, pervasive and reactive systems able to communicate with the users and to continuously adapt to their needs and expectations. The palpable computing paradigm purposely addresses the way in which humans meaningfully interact with and make sense of distributed computational systems available in the environment.

2 THE CASE STUDY: THE NEONATAL INTENSIVE CARE UNIT

At the NICU, the space built around the incubators represents the main setting of interactions that enable the relationships between different individuals. In fact, it not only embodies the work practice of the medical staff that aims to take care of the baby, it also represents the major setting in which relationships between the child and the external world is constructed. The incubator system is configured according to the baby conditions and it is dynamically re-configured as the newborn status changes and, indeed, the neonatal ward represents a rather changing environment.

Current incubators can not be intended as autonomous units. Each incubator works in conjunction with a number of machineries which support the different functions of the newborn. Moreover each device has its own alarm system that is adjusted according to each baby's status.

The continuous control and monitoring of newborns parameters is obtained through medical personnel collaboration and the cooperation of individuals with specific skills, heterogeneous backgrounds and different organizational values [4]. Medical emergencies require the continuous re-definition of action-plans and re-arrangement of work flows, creating ad hoc solutions for each specific situation. Such a complexity can generate latent situations of conflict that affect the safety of the patients and the security of the work environment [3].

Participatory design sessions [5-8] were organized to understand both the problems and the best practices or successful experiences of the medical staff, which are in turn used as leverage for design processes. This situation engenders different phenomena of interference and a sort of 'side effect' behaviour. In order to deal with the number and typologies of the sources of information, all the devices are set in a way to distinguish each signal from the others. During meeting and interviews with the medical personnel they mentioned that the diverse alarm configurations (both visual and acoustic) sometimes get them confused, creating potentially dangerous situations and contradictory behaviours due to the misunderstandings of the machineries values. The Pulse Oximeter, the ventilator and the humidifier are exemplar stand-alone machineries with their own alarm systems. The Pulse Oximeter mainly allows the monitoring of the baby's SpO_2 and heart rate. In medicine, oxygen saturation (SpO_2) measures the percentage of haemoglobin binding sites in the bloodstream that are occupied by oxygen. The Pulse Oximeter is equipped with an alarm configuration that provides both a visual and an acoustic feedback in order to readily alert the medical staff of any problem that may arise. Beside the Pulse Oximeter the ventilators is used in combination with the humidifier in order to regulate the temperature of the air flow. The ventilator is equipped with its own acoustic alarms and a visual configuration of alarms that display the different parameters, i.e. the ventilator peak, exhalation pressure, air flow, inhalation time and oxygen percentage. The humidifier is also provided with its own acoustic alarm to detect any increase or decrease in the water temperature.

These two machineries, the ventilator and the Pulse Oximeter, are strictly connected and any malfunction in one device would affect the other's function by changing the baby's condition. Nowadays, the neonatologist performs the coupling between the two, by an interpretation of the situation and by combining the information from the different machineries that work in conjunction with the incubator. The different components of the incubator have a strong, logical connection since they share a mutual influence on each other through the baby. Despite this strong correlation, the incubator does not create a system with the other external components: they are not functionally connected and each one works independently from each other. This aspect is fundamental for understanding the distributed nature of this setting.

Furthermore, the only way in which these different parts are interconnected is through the child, i.e. through the reflection of their functions into the child status (by influencing the baby's parameters).

2.1 Making sense of machines

From a direct observation of the activity in the ward, a number of scenarios have been collected to understand the current work practice adopted by the medical personnel and what are the interconnections among the machineries in use. In the following we illustrate a real scenario occurred at the NICU, generated by a variation in the SpO_2 value of the baby [9].

Indeed when a variation in the SpO_2 value occurs, the medical staff first decides to control the newborn and then to check if the SpO_2 sensor is correctly positioned on the baby. This is to decide whether to change the sensors' position or substitute it with a new one. If the mismatch is still present after this first assessment, they control the respirator. Since the baby is intubated; the nurse and the neonatologist arrange the hypothesis that the value from the Pulse Oximeter is correlated with the function of the respirator. There's not any direct coupling between the two machineries, but of course any anomalies in breathing would directly affect the amount of oxygen in the blood. The nurse tries to restart the respirator while the neonatologist performs manual ventilation. After the re-start, the respirator now works properly. The newborn is currently under the neonatologist direct care while the nurse checks the new values provided by the Pulse Oximeter shifting her attention from machinery to another. The neonatologist and the nurse assume that the Pulse Oximeter was correctly working while the fault was in the respirator. The way in which this trial and error strategy is applied depends on the previous experiences of the nurse and the neonatologist. The medical staff generates different hypotheses about the system status, continuously checking the conditions of the baby and trying to understand which is the source of the mismatch. In the current practice it is not possible to figure out the functional relations among the different equipments necessary for the child survival; although a malfunction on one device (e.g. the respirator) directly effects the functioning on another device (e.g. the Pulse Oximeter) which in turn directly influences the baby status (e.g. change in the SpO_2 value).

3 OUR APPROACH: MAKING TECHNOLOGY PALPABLE

The study herein discussed is part of the EU funded PalCom project, which aims at building an innovative research framework within the field of Ambient Computing, denominated Palpable Computing. Balancing heterogeneity and automation with awareness and control is one the goals of Palpable Computing. The paradigm purposely addresses the way in which humans meaningfully interact with the distributed computational systems that are available in the environment [10]. Palpable computing aims at supporting user control by composing and de-composing assemblies of devices and services that communicate and exchange data [11]. The word palpable, in effect, embodies these aspects. “Palpable” has a double folded meaning: in one sense it means ‘tangible’ and ‘perceivable through the senses’; it can also be interpreted as ‘plainly observable’, ‘noticeable’, ‘manifest’, ‘obvious’ ‘clear’. In the Palcom approach, this notion of palpability is integrated by the concept of assembly [2, 10-11]. The assembly is intended as an enabler of palpability by the way in which it permits the logical, functional and physical combination of different services and devices and the dynamic management of these multitude of elements [3]. In fact, the assemblies can be created by the users and modified according to their evolving necessities. The assembly can also be inspected through the use of the network enabled among the assembly components. In this way, the functional connections and the component status can be inspected using the discovery protocols among the assembly parts.

The assemblies are physical and logical entities, at the NICU consisting for instance of a web cam and an EEG sensor that the neonatologist can set up to study any correlation between the baby’s movements and the development of the central nervous system and convulsions [3]. The creation of assemblies implies that each part of the assembly is easy to understand on the logical level (what can be done with this, with what can it be combined and for what purpose), the functional level (how to use it) and on the physical level (it must be possible to see what fits together and to actually build/rebuild the structure).

These characteristics define the notion of assemblies as dynamic collections of devices, services and communication in which palpability emerges as a property-in-use of the systems, such that it responds to the user’s need for flexible and adaptable tools. At this light, the palpability framework explores the manipulation of hardware and soft components in combination with the possibilities to make the computational opportunities noticeable and understandable for the users

The palpable nature of technologies can be further analyzed by three critical issues that challenge the design of ambient/ubiquitous/pervasive systems: *visibility*, *construction/deconstruction* and *automation and user control*. These concepts are part of the ‘palpability framework’ consolidated within the project.

Visibility. The changing needs of mutable contexts of interaction, as well as the emerging necessities that arise when for example a system breakdown occurs, require an update of the notion of computation invisibility. This notion should be complemented with the possibility to notice and understand what is going on at the chosen level. Indeed visibility and invisibility represents the two extremes along an axis and the system should be able to dynamically move from one extreme to the other depending on the situation and on the activity.

Construction/Deconstruction. The possibility of putting together different devices and services and of creating networks that share the available resources and support new or distributed functions, demands that the parts are both easy to understand on a logical level (what can be done with this, what can go together with and for what purpose), a functional level (how is it used) and on a physical level (it must be possible to see what fits together and to be able to actually build/rebuild).

Automation and user control. In ambient computing systems, system automation is one of the main strategies used to manage complex settings and predictable variables. When introduced in our environments, the technological solutions have to find a balance between automatic system processes and the possibility that the user has to make sense of them and of remaining in control. This balance should take place between what the system offers and what are the specific needs of the users.

These aspects are profoundly linked with a set of requirements emerging in the current practice at the Neonatal Intensive Care Unit. In this perspective, palpable computing has been adopted as an emerging conceptual framework developed in order to inform the design of technologies at the Neonatal Intensive Care Unit. As described before, a palpable system relies upon features that are coupled with both the hardware and software architecture on the system where it is implemented. The introduction of dynamic construction and deconstruction of assemblies in a clinical context implies that the participating devices could face to the several constraints proper of such scenario. Despite of generic solutions suitable for common clinical applications, “palpable” biosignals monitoring devices should be capable to create a distributed but homogeneous system. Its core should be able to adapt its configuration and its behaviour continuously in order to follow the modifications and the inspection directives received from other palpable devices and information gathered by the unit itself. This dynamic process can lead to the desired goal of the whole architecture, according to the identified conditions and reducing the possibility of fault.

4 PALCOM ARCHITECTURE

The palpable prototype system we have designed at the Neonatal Intensive Care Unit relies upon features that are coupled with both the hardware and software architecture on the system where it is implemented. Concepts, theories and applications presented in this paragraph depend upon the reference implementation of a palpable software architecture, as implemented by the PalCom project.

The state of the art regarding Palpable Computing software systems is that they are built up by small self-contained units or subsystems that solve user tasks through intercommunication. This approach of treating services and systems can be referred to as a Service-Oriented Architecture (SOA) [12]. The foundation of the Service-Oriented Architecture is that a number of services exists and can communicate among each other. The SOA is a way of designing a software system to provide services to both end-user applications and to other services through published and discoverable interfaces [12]. In 2000, Brown describes SOA in his book as follows: “Applications must be developed as independent sets of interacting services offering well-defined interfaces to their potential users. Similarly, supporting technology must be available to allow application developers to browse collections of services, select those of interest, and assemble them to create the desired functionality” [13].

The services are autonomous and can work in distributed settings, they exists without constrains given by the context or other services. SOA enables the services to run and be located on different platforms in a distributed network. The nature of these distributed services and the SOA provides the mean for connecting these services and allow them to communicate and exchange data. The way in which this is implemented is through the use of Assemblies.

4.1 Palpable Assemblies and Service compositions

An assembly from an implementation or software perspective can be described as a description of how a set of services should be ‘loosely’ grouped together, or how they should interact among them. In the same way, an assembly from the perspective of a user can be described as “some combination of devices or services that is meaningfully considered a cohesive whole by the user.” - M. Ingstrup, K. M. Hansen [11]. This possibility for a user to construct, reconstruct and deconstruct collections of services in a distributed setting (i.e. assemblies) throughout an activity, or over time (i.e. from a software perspective, in runtime), is an important feature to enable user control and visibility.

The assembly concept, from a software perspective is related to software components and their connectors [11]. The different runtime components or services are assembled through the use of a descriptor called an Assembly Script. These scripts can be loaded at runtime, or be applied or altered later by the user.

4.2 Discovery

The dynamic construction and deconstruction of assemblies implies that the available services are distributed and able to discover and interact with each other. The discovery process can in principle reside on any of the participating devices. PalCom objects thus recognize each other and their own heterogeneity among the assembled devices. Therefore, the software objects in the Palpable Open Architecture can be run on a variety of different devices, from microprocessors to biosensors monitors. Within the project many examples of application prototypes are provided to clearly show these software properties [2, 14]. By mean of the PalVM, the virtual machine developed within the PalCom project, palpable software objects can potentially be instantiated in everyday technologies as well as in personal objects.

Each resource can function as an isolated component of the original system in which they were embodied (e.g. a single peripheral of the laptop) and can be purposely collected in newly created assemblies for explicit activities and uses. As assemblies become increasingly dynamic there's an urgent need for handling resources and debugging processes in detailed and useful ways. Managing resources and inspecting processes proves to be dramatically critical in the use of dynamic assemblies. Indeed the quality of the service mainly relies on the different levels of accuracy of the created assemblies [14].

4.3 Resilience

Applications, systems and users might insert faults and prohibited behaviour into modern, distributed computer systems. Technical breakdowns and malfunction might occur as well within a system. Resilience within the palpable architecture aims at suppress or compensate these non-normalized situations by applying the, at the time and situation, most appropriate counter-measures. This can be shifting preferred input and/or output device (e.g. network interfaces and information displays), re-allocating memory or even allocating memory on other devices to compensate heavy system load. These decisions are (if not made by a user, at least) made visible to the user, to empower the user to understand the error situation and drive the activity to overcome the failure [15]. To support this activity and others, three middleware managers exists to control and maintain the lifecycle of the Palcom services and components. These are;

- the Assembly Manager, responsible for the creation and lifecycle management of PalCom Assemblies. [16]
- the Resource Manager, maintains an up-to-date directory of all active (and if required, inactive) 2nd Order Resources. [16]
- the Contingency Manager, maintains resource and assembly resilience by monitoring failure and problem conditions and applying both reactive and proactive compensation policies and mechanisms. [16]

5 THE BIOASSEMBLY DESIGNED FOR NICU

Nowadays many efforts are devoted to design smart monitoring and telemonitoring devices, capable to detect human signals while the subject is at work, during sport activities or simply at home without interfering with his/her spontaneous behavior. This kind of monitoring is based on the concept of using sensors and transducers embedded in the surrounding environment, clothes and other wearable objects. This is generally known as unobtrusive measure of biosignals [17-19], where new sensors and transducers represent the implementation of the physical layer in basic interface between subjects and acquisition systems.

Unobtrusive monitoring devices can become a part of a complete system able to optimize the health-care processes reducing also the failures. It is important to discriminate the problem of realizing wearable and embedded sensors and the problem of the design of systems capable to collect data [18, 21]. PalCom architecture is well suited for a critical monitoring scenario, where the characteristics of the babies are more demanding in respect of adult or elderly people (for whom wearable monitoring devices were primarily developed). Designing biomedical devices for PalCom implies to face problems related to the design of sensors and monitoring devices, the quality of the acquired data, the cost of the systems and the comfort of the user during the usage. In particular unobtrusive monitoring offers new perspectives for the creation of a PalCom architecture in an incubator system, where it is necessary to gather as much information as possible, without interfering with the premature children and interacting with other standard clinical devices.

Novel research within the domain provides interesting solutions for sensors and transducers, but, besides the interesting prototypes realized, they still do not reach a really flexible, smart and embedded solution suitable for the application described in this paper. Furthermore it is difficult to find a complete solution for the many different signals monitored in an incubator. In our work we proposed and demonstrated the possibility to realize an unobtrusive disappearing biosignals monitoring systems fully integrated in a PalCom assembly, which can acquire signals through wearable and environmental sensors and transducers.

The BioAssembly described in details in the following paragraph consists of the BioBelt prototype developed within the project, the use of the current existing Pulse Oximeter, the use of a software Ventilator simulator, the PalCom (communication) Nodes and the Assembly Browser, used to manage the devices and the communication. The above-described Open Architecture is introduced in an incubator setting and integrated, through the BioAssembly, with other standard medical devices in order to provide an adaptable and reliable monitoring station for newborns able to monitor SpO2, electrocardiogram (ECG), Heart rate (HR), breathing rate (BR), movement and skin temperature (SKT).

ECG. The standard measurement of electric biosignals (e.g. ECG) requires a low resistance and stable electrical contact between the skin surface and the electrodes. This requirement is typically met by applying the Ag-AgCl electrodes on the subjects' skin, with a film of conductive gel in order to reduce the artefacts generated at the interface. This traditional solution is suitable for a clinical assessment at the physicians laboratory but, obviously, cannot be used in the frame of an unobtrusive acquisition of the signals. In this latter case the electrodes cannot be directly applied on the subjects body, or better electrodes are in contact to subject body through non standard supports like clothes where they are integrated in.

Aiming at satisfying the specifications originated from this application, the recent progresses in the textile technology which yielded to the availability of conductive fibres. These yarns are being used to create textile sensors directly integrated in a garment, or also in furniture and mostly every other textile-covered object in the environment [18, 20]. In our prototypes, we used conductive yarns to create electrodes and conductive pathways. It is worth noting that the performances of these systems can also depend on the characteristics of the skin and the specific respiration rate, which can alter them.

Movement. The standard technologies for movement analysis are video and optoelectronic motion capture systems, widely used in clinical, domotics and research applications. Unfortunately these technologies can not satisfy our requirements in terms of portability, wearability and integration in the commercial devices. Although there are systems already introduced in the ambient, for our applications it is conceivable to look for smarter and more efficient solutions in the Micro-Electro-Mechanical Systems (MEMS) technology which provides enough precision and cost effective solutions. They can sense acceleration, in order to obtain indirect indication on subjects movement and posture [22].

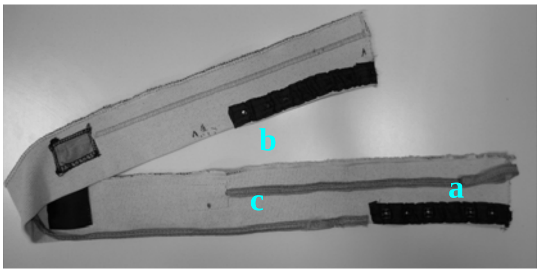
Respiration. There are many techniques which can be used in order to assess respiratory activity. Discarding the optical ones, for the same reasons argued in the previous session, the acquisition can be made with different wearable systems:

- Impedance inductive plethysmography [23];
- Resistive or piezoelectric strain gauges;
- Direct measurement of the impedance of the thorax.
- Accelerometers on upper body
- Thermistor placed at the nostril entrance.

The latter two systems are not suitable for monitoring chest movement, but are suitable for breathing rate measure. The BioBelt system adopted a textile-extensimeter suitable for measuring chest dilatations.

5.1 The BioBelt

What are the technologies available to realize small, integrated and portable solutions in order to implement unobtrusive acquisition? Is it possible to realize processing systems which can disappear in the surrounding environment? Many concrete ideas can be imagined and considered, but practically there are many specifications which have to be addressed [21]. The BioBelt is a wearable device functionally augmented with a set of sensors to be placed between the infant's chest and abdomen. Our prototype is made out of soft fabric (cotton – for bio-compatibility – plus lycra – for a best fitting of the sensors to the body), with biosensors directly integrated in the tissue (Fig. 1).



Biosensor belt prototype: respiratory sensor (a), electrode for ECG (b), pocket for accelerometer/temperature sensor (c)

First of all, we searched the possibility to realize miniaturized systems, with a flexible architecture suitable for palpable applications. The measuring specifications for biosignals (see table 1) in terms of sampling rate, bandwidth, data throughput, filtering) can be met through a proper electronics design.

Table 1. Typical bandwidth of the proposed signals [24].

ECG Holter	0.05-55Hz
RESPIRATION	<1Hz
SKT	DC
MOVEMENT	DC-25Hz

We remind that in unobtrusive measurements are adopted sensors embedded in garments or in environment, and consequently the skin/electrode impedance dramatically increases [25-26]. The first stage of acquisition systems is the most critical for the following reasons:

1. It has to collect the signals from the sensors;

2. It is responsible of the first, most important amplification;

3. It has to reject common mode voltages;

4. It has to provide the rejection of the low frequencies drift and noise.

Moreover the possible instability of the contact between skin and sensors, particularly when the subject moves, becomes more critical. The consequent skin-motion artefacts caused by the subject movement might affect the low frequency components of the signal, increasing the possibility of saturation of the input front-ends [25, 27]. Considering the model of the skin proposed by Fowles [28], with the assumption of perfectly polarisable electrodes, it is possible to deeply understand the problem of electrical coupling. In fact the high resistance presented to the sensors by the cutis induces a poor signal transmission, reducing the coupling between the signal source (that reaches the hypodermal layer) and the input stage of the amplification system. Such sensors increase also the effects related to the instability of the contact, enhancing high frequency noise, which can corrupts the signals.

The high input impedance of the first stage of our biopotential amplifiers, when it is coupled with the use of polarisable electrodes and unstable contact, makes the circuit prone to collect the 50Hz external interferences producing an increase of the risk of output saturation. The adoption of wireless transmission (this solution allows to reduce the EMI coupling of the cable), ad-hoc printed circuits board (PCB) layouts and shielding, when possible, allowed us to provide solutions for the mentioned problems without requiring an hardware notch-filter, but only a first order, high-pass filter and a third order, low-pass filter. A low-cost, industrial microcontroller was used in this device, coupled with a 12-bits analogue to digital converter (ADC).

As wireless solution, we adopted a commercial class II Bluetooth® module (PAN1540, Panasonic: Matsushita Europe) able to transmit all the data with only 30mA of average current absorption. The transmission data rate was set in order to optimize the power consumption without affect signal quality (the higher is the sampling frequency, the lower will be the noise acquired by the ADC). The Bluetooth technology allows the systems to integrate itself with many other different devices. This feature is extremely useful in a dynamic “palpable” assembly: moreover the distributed, pervasive computing of PalCom architectures, allows for the distribution of rules and parameters for decision making and inspection processes can be shared between different devices. An example of data output from the BioBelt, is shown in Fig. 2.

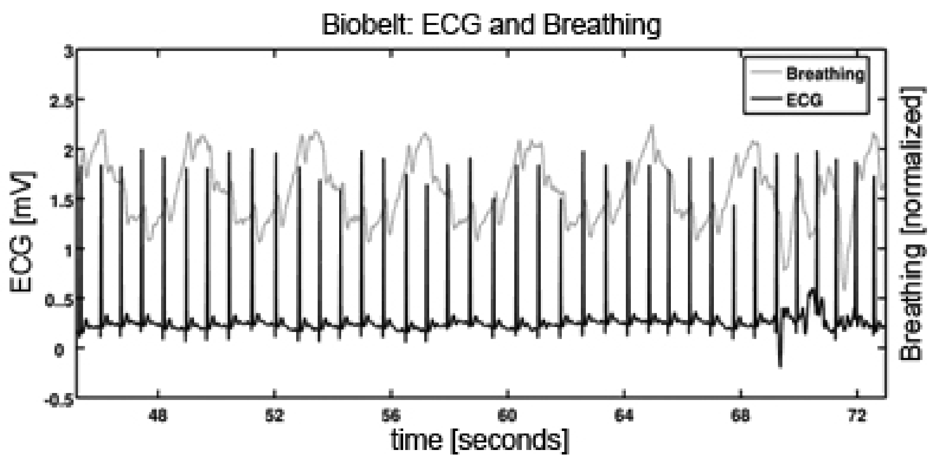


Fig. 2: ECG signal and breathing signal acquired through the Belt (adult people)

5.2 Pulse Oximeter

We have used a Masimo Radical Pulse Oximeter [29]. It permits monitoring of SpO_2 and Heartrate values (with timestamps) over a serial RS-232 line. The Pulse Oximeter is connected to a Palcom node utilizing this serial communication link.

5.3 Simulated Ventilator

As in the current state of development, we can not try this system on a real premature newborn we simulate the Ventilator with an accelerometer placed on the BioBelt. The solution to fully include a real Ventilator in the system is similar to the Pulse Oximeter, as has been described, is already implemented with the real hardware.

5.4 Palcom Nodes

The PalCom node is an I/O-device functioning as a bridge between non-palpable devices (existing technologies in the ward) and the PalCom technologies. This allows non-palpable equipment to take part in palpable assemblies [9].

PalCom architecture can exploit the resources available in “Palpable” devices to establish the connection between them and to manage the flow of information through the assembly. In the working scenario depicted in this paper, the three main devices (BioBelt, Pulse Oximeter and Ventilator) were introduced in the architecture through their available channels (Bluetooth, RS-232, Adapter). This transport allowed us to create different Palcom nodes and services regarding the specific information acquired from the instruments. More in detail, in this preliminary study we created the BioBelt Node, the Pulse Oximeter Node (Saturation) and the Ventilator Node. The signals coming from the first two nodes provide us with raw signals that PalCom services can process and convert in synthetic parameters like Heart rate (BioBelt and Pulse Oximeter), Breathing rate (BioBelt and Ventilator), SpO_2 (Pulse Oximeter) and Posture (BioBelt).

Other nodes can be represented by for example a Webcam and microphones, useful for more reliable inspections of the baby. In order to provide a complete vision of the whole scenario, different services have been deployed in the framework, extracting the parameters required by the clinicians.

The different clusters of information (HR, BR, Movement etc.) can be analyzed through real-time processing, compared with values of the same clusters (e.g. HR of the BioBelt vs. HR of the SpO_2). Through applying different, specific rules the assembly can show and indicate the reliability of the different data. The subsequent presentation of the raw data is another resource that is possible to show in order to help clinicians in the decision-making process of potential fault or babies' critical conditions. Such flexible solution is suitable not only for an inspection scenario, but also for the daily monitoring scenario, especially when coupled with the other technologies that are going to be developed in the PalCom project.

5.5 Assembly Browser

With the browser users can manage assemblies throughout the whole assembly lifecycle [30]. It allows the users to construct, initiate assemblies as well as reconfigure and turning off assemblies along the activity. The Assembly browser exists today as one version targeting developers. One intended for the end-users are now being under development [9]. An example of services running in the Assembly Browser can bee seen in Fig. 3.

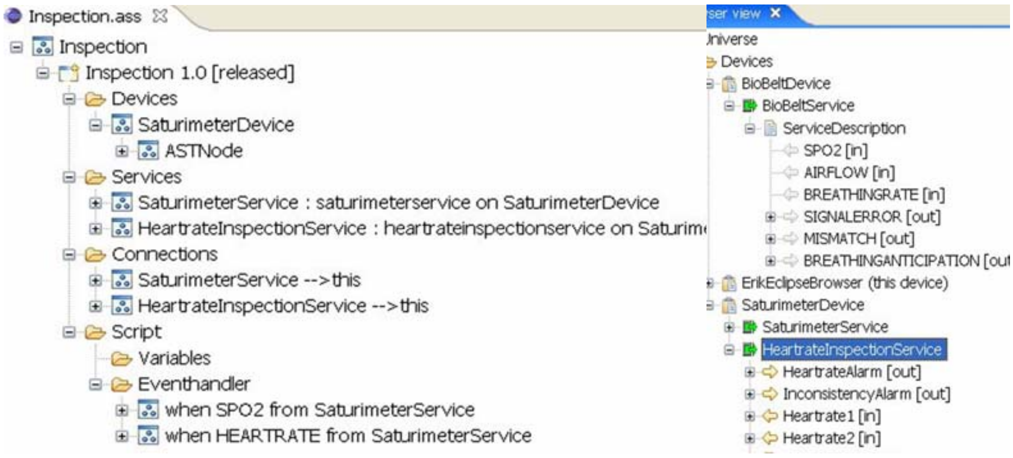


Figure 3: Different Palcom nodes running, visualized in the Assembly Browser

6 INSPECTION THROUGH THE BIOASSEMBLY

The Incubator is a re-configurable system that can be adapted accordingly throughout the different treatments, thus allowing the medical staff to respond to the development of the baby more flexibly and sensitively. The palpable devices (e.g. the BioBelt) can be assembled in combination with the current equipment (e.g. the Pulse Oximeter) through the Assembly Browser and can result in a deeper understanding of the baby's conditions. Indeed in this way any failure in the functional connections among the assembly components can be easily detected, in particular those which directly affect the baby's conditions.

The Incubator assemblies described above define a system of different components that can allow novel forms of inspection by relying on the networking among the assembly components. This allows the medical staff to respond to the evolution of the baby conditions more flexibly and sensitively. In this system different assemblies can co-exist (e.g. the BioBelt, the Pulse Oximeter and the assembly browser in parallel with the BioBelt, the Pulse Oximeter and the Ventilator) integrating palpable applications with the existing equipment in the NICU.

This notion of assembly captures a very critical feature of the work the NICU. The use of the BioAssembly in this setting can significantly modify this situation by establishing novel connections among the incubator equipment and making it visible the functional relations among the assembly components.

6.1 Inspection strategies

We have been designing technologies that can be used to create flexible incubator assemblies that can be adapted on-the-fly for different kinds of treatments and situations. This allows the staff members to manage events related to the baby care more flexibly and sensitively.

The neonatologist can combine the value of SpO_2, Heart Rate and Breathing Rate coming from the BioBelt, with the data from other machinery and sensors, currently in use at the NICU, in order to get more detailed assessment of the baby conditions. A first BioAssembly configuration consists of the Pulse Oximeter and the biosensors Belt for monitoring of the Sp02 values (Fig. 4).

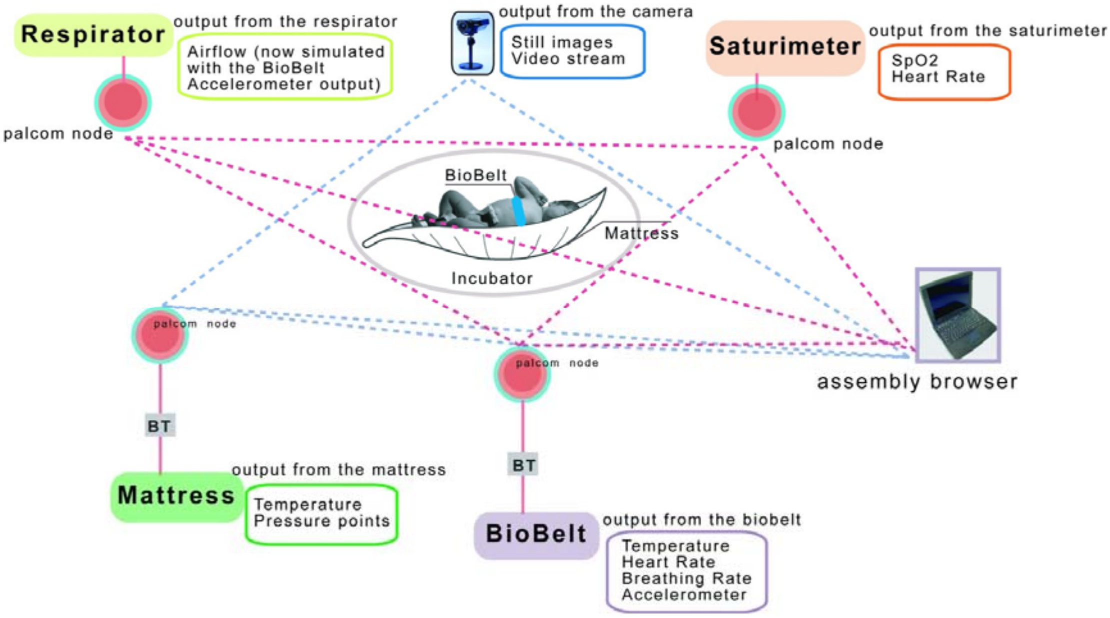


Figure 4: Two possible concurrent assemblies running on the system

In the figure above, an exemplification of the notion of assembly is provided. In this application two assemblies co-exist and integrate data to monitor the baby's conditions, anticipate the occurrence of problems and allow for system's inspection by using the networking properties of the assemblies. In detail, the 'red assembly' reveals the functional interdependencies among the current respirator at the NICU, the Pulse Oximeter and the BioBelt in order to monitor the respiratory abnormalities and heart rate functions of the baby and to allow for the coupling of any failure at the level of one device with the baby's conditions and with the information coming from the other devices. In this way, the standard redundancy inspection method is combined with the networking strategy supported by the assembly [9].

Currently, when a variation in the SpO_2 value occurs, the process of understanding the baby conditions can be long and can generate misinterpretations, due to the difficulties of understanding if the values depend on the newborn condition or is they are generated by any malfunction of the machine.

The use of assemblies not only allow to connect PalCom devices with existing ones but its networking properties support the inspection of the system by checking the status of the functional connections among the different components of the assembly. To facilitate this task, the belt can transmit also the raw biosignals (ECG and the chest dilatation (respiratory movement)) thus facilitating the understanding of possible sensors' failures.

In the implemented system, it is possible to recognize two complementary strategies to allow inspection of the system behaviour. The first one is illustrated in Fig. 5. In this case a classical *redundant error handling strategy* is applied. The heart rate (HR) detected by the Pulse Oximeter (HR1) is continuously compared with the heart rate coming from the BioBelt (HR2) that the child wears. In this application an "inconsistency alarm" is generated each time the compared values overcome a defined threshold, for a predefined number of pulses. This can indicate a fault in the setup providing a classical inspection strategy which compares the same value coming from different sources. Currently this comparison is done by the medical staff without any external support [9].

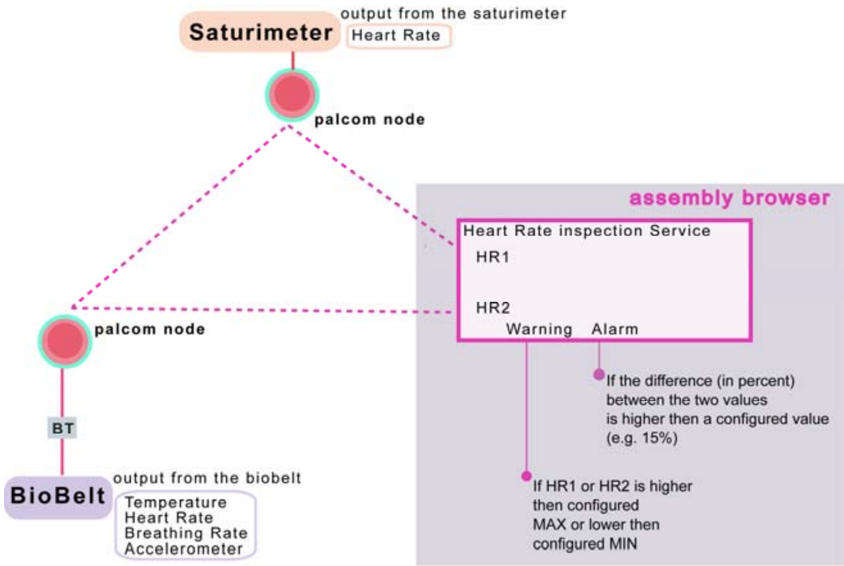


Figure 5: Inspection strategies based on redundancy

The "fault alarm" is different from the alarm regarding biological condition (i.e. HR go over or go under the thresholds set by the clinicians). In the complex scenario here investigated, also the possibility to discriminate between problems in health condition and the less critical instrument error.

In the scenario illustrated in Fig. 4, the Ventilator provides the child with oxygen, while the breathing rate, which correlates to the ventilator function, is monitored by the BioBelt; the SpO_2 values are monitored by the Pulse Oximeter. Whether any malfunction occurs in the ventilator the discovery protocols enabled by the PalCom nodes will propagate the information on the missing signal from the ventilator to the whole assembly. These inspection scenarios are developed to bridge current problems in the medical practice, where the different monitoring devices are not functional connected. Here the flexible, loosely coupled system approach provided by a palpable middleware can prove useful. This creates a novel inspection opportunity for the user who can understand what is going wrong and at which level of the system, showing the potential impact of "palpable" and "unobtrusive" technologies applied in the health care context. The scenario described here represents a first functional device and system implementation. This system has been developed with the actual users and responds to their specific requests. An experimental study conducted with the medical staff at the NICU will provide more insights on the use of assembly in this setting. An initial 1 month test-period of the system is going to be performed in order to assess the use of the BioBelt as an unobtrusive monitoring device and what diagnostic opportunities the notion of assemblies together with the different inspection strategies can offer for the neonatologists' daily practice.

7 CONCLUSION

The research has been strongly influenced by the critical setting of the NICU. An Intensive care situation provides a highly dynamic environment where a number of heterogeneous actors co-exist. This ongoing, dynamically changing situation provides very specific, but in the same time, continuously changing requirements. The BioAssembly prototype and the emerging framework of Palpable computing investigates on a functional, logical and activity level the notion of Ambient computing and what requirements needs to be fulfilled when applying ambient systems within such a critical setting as the NICU. Thus we have described visibility, construction and user control as key components for ambient systems design in dynamic and critical situations. Visibility emerges as an important property for the different users to understand the status of the system and potential error situations. By mean of the PalCom architecture, users can then construct assemblies of heterogeneous technologies as discussed in this paper. Differently from common ambient computing solutions, the palpable framework aim to provide awareness and control over the system for the users. Further studies and field trials have to be made, but these early results are coherent with outcomes from other studies in emergency and intensive care situations [31-32]. However, these changes have to be implemented both from a technical perspective (i.e. support implemented in the software architecture) and from an activity perspective (i.e. the way users do perceive these ambient systems and how they can interact with them). Initial results show the possibility to use redundancy inspection scenarios within this domain. We would now like to further investigate other inspection strategies (e.g. network-based inspection [9]) to understand how the user can make sense and perceive the assemblies, in particular in relation to breakdowns and failures in ambient computing systems.

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9.3 Supporting inspection strategies through palpable assemblies

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Supporting inspection strategies through palpable assemblies

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ABSTRACT

The paper reports an early study on inspection strategies of high-risk systems using ambient computing technologies. Traditionally, the main goal of ambient, pervasive and ubiquitous computing applications is to make the technology transparent or invisible for the users. However this sort of technological disappearance is not always desirable in particular in presence of any failure in the system. In such an event the user would benefit from the visibility of the system state, and from adopting inspection strategies to detect the error and take, if possible, the necessary correctional measures. The paper presents a study performed in a Neonatal Intensive Care Unit where novel ambient computing technologies and related inspection strategies are currently being designed and assessed in the context of the European project PalCom (www.palcom.dk).

Keywords

High-risk systems, ambient computing, inspection, error detection

INTRODUCTION

Traditionally, the main goal of ambient, pervasive and ubiquitous computing applications is to make the technology transparent or invisible [1] for the users. However, when these applications are more deeply considered, it becomes obvious that this sort of technological disappearance is not always possible or even desirable. When, for example, an error occurs within ubiquitous systems, a user would benefit from the visibility of the current system state, which would thus permit the inspection of the error and allow, if possible, the necessary correctional measures to be taken. In other words, this means that in order to effectively use these applications the users must always remain in control [2]. This is especially true in emergency or breakdown situations in safety critical domains, such as, for example, Neonatal Intensive Care [3]. In these kinds of settings where distributed processes and simultaneous overlaps between the situations deeply affect the nature of the work, many potential conflicts and dangerous situations can be generated. In this paper we draw on ethnographic studies and long-term participatory design sessions with the medical staff and the parents of premature children at the Neonatal Intensive Care Unit (NICU) of ‘Le Scotte’ Hospital in Siena (Italy). The study investigates visibility and control of ambient devices in relation to inspection strategies for errors or faults detection and recovery.

Balancing transparency and automation with awareness and control is the goal of PalCom (PalCom, http://www.ist-palcom.org), which aims at developing an innovative design approach called Palpable Computing. Palpable computing complements key features of ambient computing, such as invisibility and end-user composition of devices, with their opposites - e.g., visibility and decomposition – to enable users to independently navigate and influence the computing system [2].

As compositions of devices, or 'assemblies' become increasingly dynamic there is an urgent need for supporting users in handling resources and debugging processes in detailed and useful ways. Indeed, quality of service depends on people's ability to gauge the different capacities of the created assemblies (e.g. levels of accuracy for measurements, location information, or other information provided by elements of an assembly) [4].

ASSEMBLIES AND INSPECTION

Palpable assemblies are characterized by their availability for dynamic composition and use. A major feature of many current ubiquitous and distributed computing applications is the use of fixed (or pre-defined) collections of devices for specific activities. An example in a fairly common environment (home technology) is the automatic service composition developed at Nokia Research Center U.S. where a 'Media Library' device, a 'Video Screen', a 'Media Server', 'Media Receiver and Controller' are collected in a network [5].

Palpable assemblies ought to support user needs regarding flexible and adaptable tools. If composition is automated, users should be able to notice and take control at any step in the process. In addition, completely user controlled composition of assemblies should be supported. A dynamic assembly is made from collections of devices, services and communication capabilities where palpability emerges as property-in-use of these systems. In the dynamic construction and deconstruction of assemblies, services are distributed and able to dynamically discover and interact with each other and the discovery can in principle reside on any of the participating devices. PalCom devices and services thus recognize each other and heterogeneity among the assembled devices is made possible.

As assemblies become dynamic there is an urgent need for handling resources and debugging processes in detailed and useful ways. We are going to debate what happens when connections break among the components and how to notice and understand if the assembly still preserves (some of) its initial capacities. Managing resources and inspecting processes reveals to be dramatically critical in using dynamic assemblies. A component might not always have the same capacities and services, thus it can potentially have different levels of accuracy. It is very important that the users can be made aware of the given accuracy of the assemblies that they are relying upon.

THE NEONATAL INTENSIVE CARE UNIT (NICU)

The NICU presents some peculiar features which challenge the design of ambient computing technologies in many ways, as they can support the premature babies' necessities and the inspection mechanisms of the medical staff. The incubators used in the ward represent a complex system of different components, each one playing a precise role for the child care. More in detail [3], [6]:

The system is characterized by a high level of re-configurability, i.e. each incubator should be conceived as an ad hoc entity, tailored to the baby's conditions and dynamically changing over time.

The incubator is associated to external equipments to sustain the baby necessities, but no functional coupling is now supported among the different devices, this making complicate to recognize and discriminate system failures vs. aggravation of the baby conditions.

The work practice is based on the continuous combination and integration of data coming from different sources.

Different actors have different access to the incubator depending on their role: this implies a different access to the information to be displayed.

This setting should support co-existence of emergence situations as well as daily care.

Such a complexity can generate latent conflict situations that could affect the safety of the patients and the security of the work environment [3]. Indeed, the correct execution of different undergoing processes depends on the medical staff's control of the equipment, the possibility to anticipate breakdowns' occurrences and the inspection of the system behavior.

From a direct observation of the activity in the ward, a number of scenarios have been collected to understand the current inspection strategies adopted by the medical personnel at NICU.

The collected scenarios have been presented using the Model for Error Detection developed by Rizzo, Ferrante and Bagnara in 1995 [7]. The model is based on the idea that a stimulus can be evaluated with respect to the reference system it evokes after the fact, rather than in relation to pre-established expectations. The process includes four main phases: i) mismatch emergence (i.e. a breakdown in the perception-action loop; it consists in a conflict or clash of knowledge in the working memory); ii) detection (i.e. the awareness that an error occurred; in this case the undesired result is properly attributed to the own activity); iii) identification (i.e. individuation of the source of the breakdown); iv) overcoming of the mismatch (i.e. strategies for either reducing the mismatch, or to get rid of it, or to undo its cause). The four steps do not necessarily occur in all the error detection episodes; instead the contrary is often the case.

In the following we illustrate a real scenario occurred at the NICU, generated by a variation in the SpO_2 value of the baby. SpO_2 is a measurement of the amount of oxygen attached to the haemoglobin cell in the circulatory system. Put simpler it is the amount of oxygen being carried by the red blood cell in the blood. SpO_2 is given in as a percentage, normal is around 96%. The "S" stands for saturation and the SpO_2 is monitored by the Saturimeter. In practice, SpO_2 goes up and down according to how well the baby is breathing and how well the blood is being pumped around the body.

The scenario describes the inspection strategies adopted by the nurse and the neonatologist to overcome the mismatch and detect and solve the error occurred in the system.

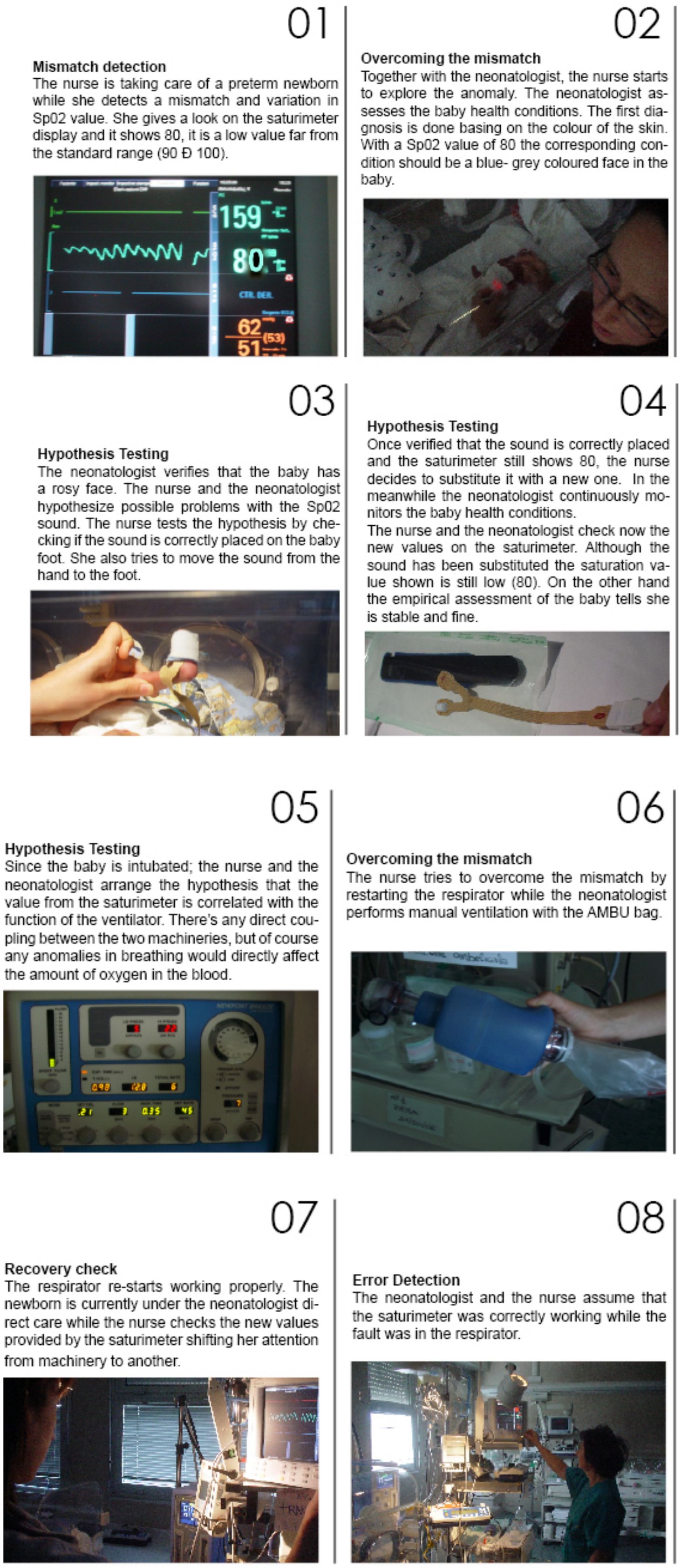

Figure 1: Inspection scenario – SpO_2 variation

As the scenario illustrated in Figure 1 shows, the incubator and the equipments surrounding it define a quite opaque system which in presence of an unexplainable variation does not offer any means to inspect the system and overcome the error. The only way to cope with the mismatch is to apply a trial and error strategy. Indeed when a variation in the SpO_2 value occurs, the medical staff first decides to control the baby and then to check if the sensor is correctly positioned on the baby to decide to change the sensors' position or substitute it. Eventually they control the respirator. The way in which this trial and error strategy is applied depends on the previous experiences of the nurse and of the neonatologist. During the inspection, the medical staff generates different hypotheses about the system status, continuously checking the conditions of the baby and trying to understand which the source of the mismatch is. This strategy has two main consequences: in the case of mismatch detection, the medical staff must question the overall reliability of the system; no level of degradation is provided: whenever a component stops working the whole system is compromised. In other words, this can be considered an on/off system. Moreover it is not possible to figure out the functional relations among the different equipments necessary for the child survival; although a malfunction on one device (e.g. the respirator) directly effects the functioning on another device (e.g. the Saturimeter) which in turn directly influences the baby status (e.g. change in the SpO_2 value).

MAKING EXISTING TECHNOLOGY PALPABLE: THE INCUBATOR ASSEMBLY

We are designing technologies that can be used to create flexible incubator assemblies that can be adapted on-the-fly for different kinds of treatments and situations. This allows the staff members to manage events related to the baby care more flexibly and sensitively. The incubator assembly is composed by the incubator itself, the surrounding machinery as well as a number of technologies we developed in the PalCom project. These include:

The BioBelt: A wearable device augmented with a set of sensors to be placed around the infant's chest on the abdomen.

The PalCom-node: This node is an I/O-device functioning as a bridge between non-palpable devices (existing technologies in the ward) and the PalCom technologies. This allows non-palpable equipment to take part in palpable assemblies.

The Assembly Browser: With the browser users can manage assemblies throughout the whole assembly lifecycle [8]. It allows the users to construct, initiate assemblies as well as reconfigure and turning off assemblies along the activity. The Assembly browser exists today as one version targeting developers. One intended for the end-users are now being under development.

The palpable devices can be assembled with other palpable devices but also in combination with the current, existing equipment at the NICU (e.g. the Saturimeter). This is permitted through the use of the 'PalCom node'. All these devices (i.e. the devices running the PalCom architecture and the devices connected through the PalCom-node) can be managed (e.g. be attached to different running assemblies or inspected) through the Assembly Browser.

The biosensors belt is developed as a first prototype with embedded sensors and transducers for monitoring the heart rate (HR), the breathing rate (BR), the body movements (BM) and the temperature (T) [9], [10]. Concerning the physiological parameters, the belt aims at facilitating the continuous HR, BR, BM and T monitoring with proper signals acquisition and pre-processing systems, ensuring an unobtrusive measure [11], [12]. In order to address the requirements of this particular application domain, the biosensor belt design necessitates specific considerations in relation to the sensor integration in a textile substrate. The belt is about 4 cm wide and can be adapted in respect to the baby size and fixed in a non invasive way, to avoid the direct contact of scratchy material to the baby skin. The BioBelt can interact with the Assembly browser and other PalCom devices through a PalCom-node. The already existing equipment in the ward, such as the Respirator and the Saturimeter become part of the PalCom network in the same way, by connecting them to PalCom-nodes running services that can wrap them into PalCom devices. The Saturimeter measures the Heart rate and the SpO_2 values from the child while the Respirator assists the child breathing function.

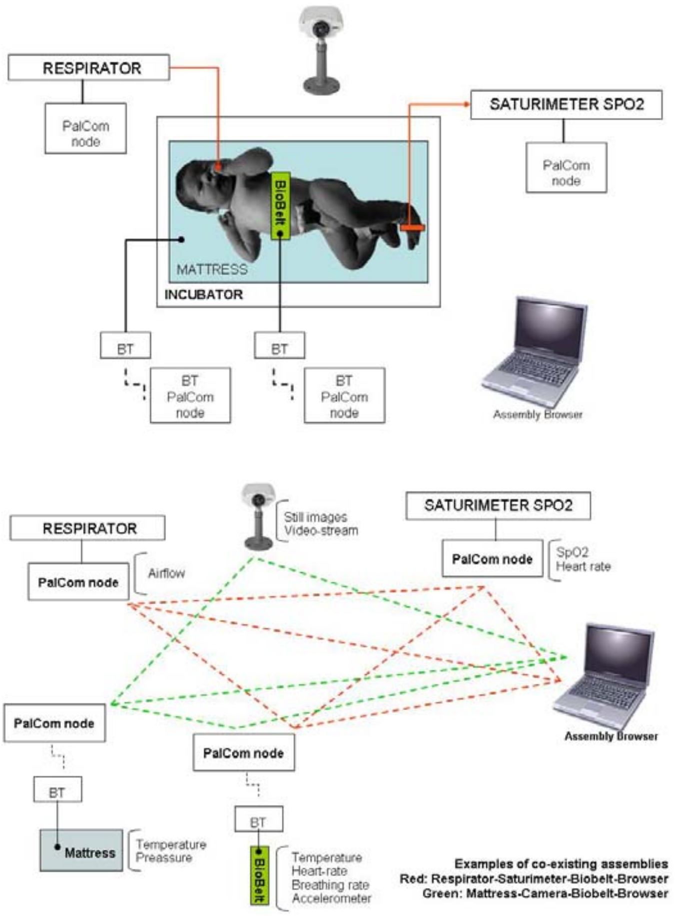

Figure 2: System overview and examples of assemblies (red and green dot lines)

The neonatologist can combine the information coming from the belt in order to get more detailed assessment of the baby conditions. A first assembly consists of the Saturimeter and the biosensors belt for monitoring of the Sp02 values. The assembly not only allows to connect PalCom devices with existing ones but its networking properties support the inspection of the system by checking the status of the functional connections among the different components of the assembly. To facilitate this task, the belt can transmit also the raw bio-signals ((electrocardiogram (ECG) and the chest dilatation (respiratory movement)) thus facilitating the understanding of possible sensors' failures.

The definition and the use of the assemblies result in a deeper understanding of the baby's conditions. Indeed in this way any failure in the functional connections among the assembly components can be easily detected, in particular those which directly affect the baby's conditions.

DISCUSSION: NETWORK-BASED INSPECTION

The Incubator assemblies described above define a system of different components that can allow novel forms of inspection by relying on the networking among the assembly components. This allows the medical staff to respond to the evolution of the baby conditions more flexibly and sensitively. In this system different assemblies can co-exist (e.g. the BioBelt, the Saturimeter and the assembly browser in parallel with the BioBelt, the Saturimeter and the Respirator) integrating palpable applications with the existing equipment in the NICU. This notion of assembly captures a very critical feature of the work the NICU. As the scenarios in Figure 3 and 4 show, the incubator system is the product of various, interrelated components that have a strong, logical connection since all of them have a mutual influence on each other through the baby. Despite this strong correlation, the incubator does not create a system with the other external components. In fact nowadays they are not functionally connected and each one works independently from the others. The use of assemblies in this setting can significantly modify this situation by establishing novel connections among the incubator equipment and making it visible the functional relations among the assembly components.

In the implemented system, it is possible to recognize two complementary strategies to allow inspection of the system behavior. The first one is illustrated in Figure 3. In this case a classical redundant error handling strategy is applied. The heart rate (HR) detected by the Saturimeter (HR1) is continuously compared with the heart rate coming from the BioBelt (HR2) that the child wears. In this application an alarm is generated each time the compared values overcome a defined threshold. This represents a classical inspection strategy which compares the same value coming from different sources. Currently this comparison is done by the medical staff without any external support.

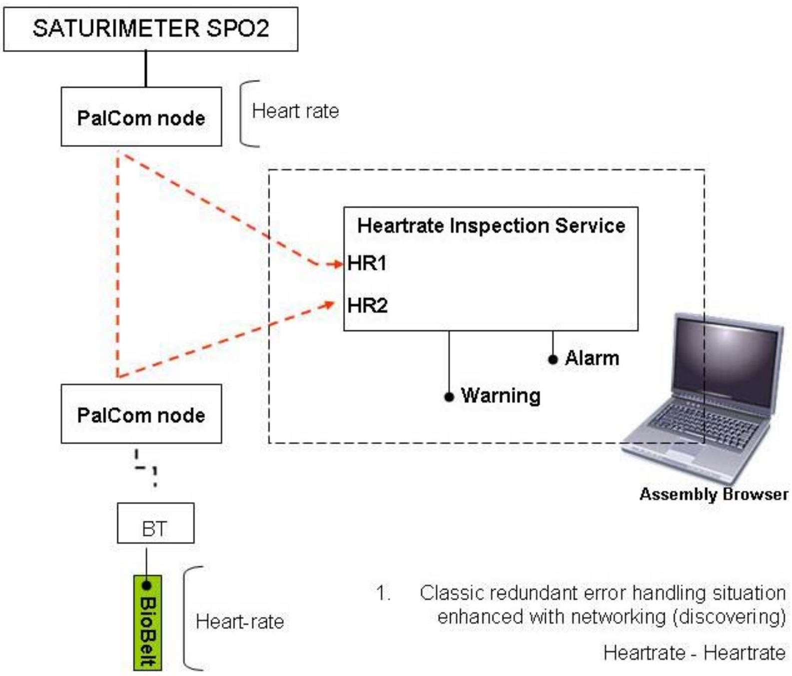

Figure 3: Inspection strategies based on redundancy

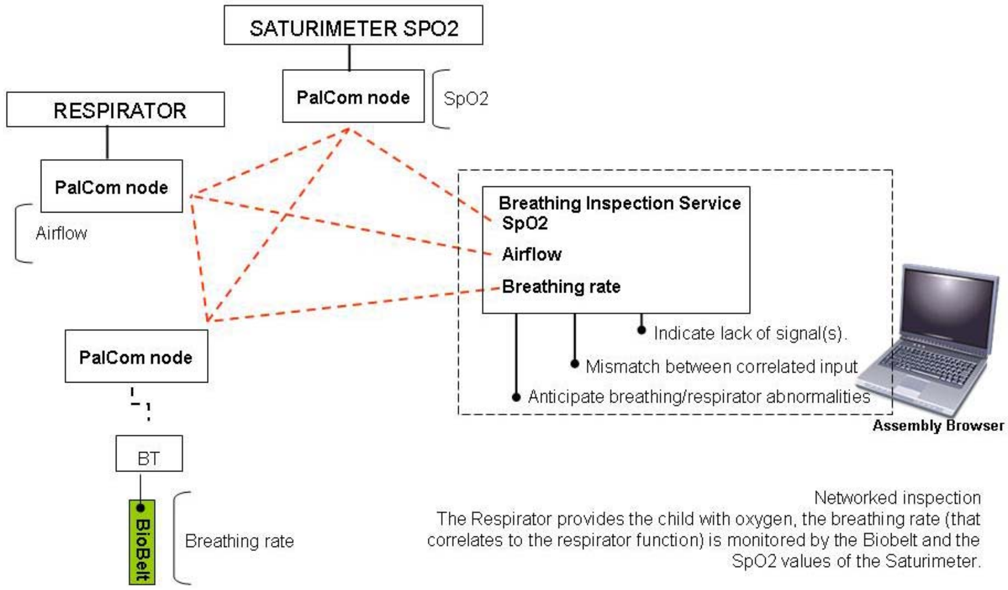

Figure 4: Network-based inspection strategies

Redundancy is a well consolidated strategy and is considered necessary for high-reliability organizations to manage activities that are sufficiently dangerous to cause serious consequences in the event of operational failures. In classic organizational theory, redundancy is provided by some combination of duplication (two units performing the same function) and overlap (two units with functional areas in common). The theory is that reliability can be enhanced by parallel configurations—standby components that are in place to operate should the primary components fail [13]. Not all of the critical points of exposure and of vulnerability, however, can be covered, as safety is a compromise between requirements and economic necessity [14]. Indeed inserting additional levels of control is costly and poses problems on the interactive complexity of the system: unexpected interactions can affect supposedly redundant sub-systems. A sufficiently complex system can be expected to have many such unanticipated failure mode interactions, making it vulnerable to normal accidents.

For this reason other kinds of inspection strategies are currently investigated in the PalCom project working with the notion of assembly. Figure 4 shows a scenario exploiting the network-based inspection: each component of an assembly is interconnected with the others and in this way is aware of and responsible for the others. If a failure in a component occurs, the other components of the assembly can notify it to the user. Indeed, while using dynamic assemblies, users can discover and detect connections' breakdowns and inspect a failure of a component that for some reason does not respond any more to its neighbor in the assembly. Relying on the networking enabled between the assembly's components each constituent is aware and become "responsible" of its neighbors and can be used to check whether it is receiving signals and data from the others or not. In this way each component of the assembly can refer to the others about the state of its neighbors and the message can be broadcasted in the assembly. An example of such application is the case of the breathing rate monitoring. In the scenario illustrated in figure 4, the Respirator provides the child with oxygen, while the breathing rate, which correlates to the respirator function, is monitored by the BioBelt; the SpO2 values are monitored by the Saturimeter. Whether any malfunction occurs in the respirator the discovery protocols enabled by the PalCom nodes will propagate the information on the missing signal from the respirator to the whole assembly. This creates a novel inspection opportunity for the user who can understand what is going wrong and at which level of the system. This allows taking different recovery actions.

As anticipated in the introduction, this study on inspection strategies in high-risk systems is at an early stage. In order to more deeply investigate the opportunities of the network-based inspection, the scenarios described in the paper will be simulated in the NICU with the medical staff with the purpose to raise new requirements from the operators. Initial results show that the possibility to use both redundancy and the network-based inspection strategy may offer new insights about the way in which the user can make sense and perceive the assemblies in particular in relation to breakdowns and failures in ambient computing systems.

Acknowledgments

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9.4 Opening the Design Space: the Soft Set of Requirements

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Opening the Design Space: the Soft Set of Requirements

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ABSTRACT

This paper provides a methodological perspective towards the design of ambient computing system informed by the notion of Aesthetics of Interaction. This approach stemmed from the growing complexity that is offered by interaction when computation is distributed in the environment and embodied in all sorts of objects. Indeed, the life of human-technologies systems settings involves a complex whole of variables not just dependant on the functional aspects. In this work the notion of Aesthetics of Interaction in ambient computing system is challenged by the use of the Soft Requirements as tools to complement the existing design methodologies. The presented perspective is based on the work conducted at the Neonatal Intensive Care Unit at Siena Hospital -Italy as a part of the EU PalCom project. The outcomes provide a heuristic account to inform the design process by fostering the novel complexity of ambient/palpable technologies in delicate and fragile settings.

Categories and Subject Descriptors

H.4[**Information Systems**]: Multimedia Information Systems - *Evaluation/methodology*

H.5 [**Information interfaces and presentation**]: User Interfaces - *Theory and methods, User-centered design,*

General Terms

Design, Human Factors

Keywords

Aesthetics of Interaction, Soft Requirements, Palpable Computing, Neonatal Care.

1. INTRODUCTION

The life of human technological system entails a complex whole of variables, that determine not just how we use such instruments (i.e. functionally), but also how we make sense of them and how their presence in our life manifests itself. Recent researches in the HCI and Interaction design filed would suggest that the design space should be reconceived introducing non just the functional variables that effect and determine our interaction with systems and tools, but also the emotional variables that can triggered by the aesthetic values of the designed solutions [7], [8], [16], [17] The design methodologies can be similarly seen as evolutionary objects, which constantly change to adapt to the emerging needs of design human-technology interaction. The users needs are a complex of expectations, previous usage experiences and emotional variables that should be integrated into the system design. It is, indeed, fundamental to capture the varieties of usages, expectations and experiences that are established between the individuals and throughout their interactions with the tools and the environment.

Designers at the vanguard of Human Computer Interaction (HCI), Participatory Design (PD) and Computer Supported Cooperative Work (CSCW) [23] have established a tradition of using ethnographic studies, participatory design methods and laboratory and naturalistic experiments to inspire, inform and evaluate design. Some of these methods can be adapted for the design of ubiquitous computing technologies [5], [21] and their use is spreading. But while empirical studies and participatory engagement in practice promise large returns for the quality of programming language, middleware and software architecture design, it is difficult to formulate theories regarding how to realize such designs directly and in a clearly focused manner.

2. WHAT IS THE ROLE FOR THE AESTHETICS OF INTERACTION?

A particular focus on the Aesthetics of Interaction [10], [11], [12], [16], [17] has recently been put on the design of exhibition spaces, entertainment technologies, and interactive performance (just to mention the most frequent); but it is quite rare to find examples in the HCI literature of how to capture the aesthetic qualities of interaction and how to transform them into design requirements. For instance, the importance of aesthetics within health care settings has proven to be a key factor, capable of influencing medical treatment and the overall care of patients. A famous examples that demonstrates this fact is the study of the qualities of light in each area of the Alajärvi Hospital carried out by Alvar Aalto (1924 – 1928). Thus, assuming that aesthetics has an important function in this application domain, how can the aesthetic qualities be extracted and made usable for the design? How to they related with the other variables of the design process?

In many senses, the perspective of the Aesthetics of Interaction can be considered as a means of facilitating the way in which computation is manifested in system’s design, and overcoming some of the traditional problems of ubiquitous, ambient and pervasive computing, which cause computation to become invisible with the consequent loss of control on the part of the user [18], [23], [24], [25], [26]. Indeed, any attempt to concretely embody the aesthetic concerns of a design into a sharable approach has been little investigated, and aesthetics has been traditionally seen as a quality delegated to specific design sensibilities. The interaction design discipline should find a delicate balance between the approach that is more design driven, - that is, the approach that focuses on inspiration, concept generation and representations as the triggers of the process, - and the approach that attempts to base the design solutions on a strong methodological foundation. The former delegates the design solutions to the designers’ sensibilities, while the latter entrusts the design reliability to the repeatability of the method. This distinction obviously oversimplifies the underlined phenomena, since in most cases these two tendencies co-exist and cooperate along the design process. This dialogue also enriches the design by taking advantage of both the approaches: the creative stance uses methodologies, such as brainstorming sessions, attribute listing, conceptual maps and inspirational cards, to reinforce the creative process, while the methodological stance sometimes follows pure inspiration to enhance the designed solutions. In any case, the balance between these two tendencies is a fundamental aspect of the interaction design practice.

With respect to the role of Aesthetics in Interaction Design, the way in which an aesthetic account can be embodied in the design methods has been investigated to a very limited extent. One of exception to this rule is exhibited in the work of Djajadiningrat, Gaver and Frens [6]. They suggest that Aesthetics of Interaction must consider the richness of appearance, the actions and role of a design, thus moving beyond the mere idea of usability. This perspective requires new methods for understanding the design possibilities [6].

One of the major concerns of Interaction Design, when adopting the different methodologies, is that of ensuring that the knowledge from one phase of the process to the other is correctly transformed; moreover, as Djajadiningrat, Gaver and Frens discuss, it is important that the latent needs of the existing practices become manifest to the designers, in order to be later elaborated into requirements and design solutions.

In this paper a methodological perspective to address the role of aesthetics of interaction as a complementary strategy for the design of ambient computing system will be proposed. In this way it will be also explored the modalities by which computation in complex ambient computing system can become manifest along interaction.

In this sense, the notion of Palpable Computing, elaborated within the Palcom project, represents an emerging conceptual framework that attempts to investigate the different phenomena that is inherent in the way computation is manifested in complex, socio-technical systems. The word ‘palpable’ embodies the challenges of designing computational solution that can be both tangible, perceivable through the senses, but also, clear, intuitive, noticeable, and manifest. The co-existence of these meanings clearly explains the objective of palpable computing, which seeks material modalities in which computation can dynamically handle the needs of evolving contexts, by balancing the demand for computational invisibility, visibility and inspectability [4],[13]. This creates an equilibrium between the system automation and the need for the user to remain in control, and manages the possibility of constructing meaningful configurations of devices through interaction and iteratively decomposing them in order to create other, different compositions, according to the situation of use. The primary demand that lies behind the challenges of Palpable Computing is the manipulation of the way computation can be expressed in interaction. In fact, the properties of the computational material that is used are particular and specific and should be precisely understood. The aesthetic aspect can, in this context, be intended as *the material process by which the possibilities for interaction can manifest themselves by the creation of meaning through interaction and by balancing the different qualities that effect ambient computing systems* [20].

The idea of aesthetics in the design of digital technologies often appears to be restricted to the product’s appearance [7] but the physical appearance does not subsume the complexity of aesthetic phenomena and the dynamics engendered by the use of tools. Indeed, there are plenty of technological products that appear attractive at first sight, but frustrate us as soon as we start interacting with them [7]. The ‘Aesthetics of use’ [8] is one of the perspectives that promotes a notion of aesthetics that seeks to develop a more nuanced cooperation with the object through the interactivity that is made possible by computing - a cooperation which might enhance social contact and influence everyday experiences.

This work aims at addressing the role of the Aesthetics of Interaction in ambient computing systems with the objective of understanding how the notion of aesthetics can provide indications that can reflect on the existing design methodologies.

The case study presented in this work is taken from the PalCom project, in which a co-evolutionary and participatory perspective is adopted for the design process. The main issue, which is methodologically addressed by the project, is that of elaborating the design methodologies and techniques that are able to inform the design of the software architecture by following a bottom up approach [4]. According to this process the needs and requirements that emerge through the analysis of the users activities and through the involvement of the users in the design process (e.g. in future laboratories, bricolage workshop, data sessions, etc.), can be transformed into requirements, for instance providing hint on the modalities of end user composition; the inspection strategies; the meaning attribution dynamics supported by interaction.

2.1 The Soft Approach To Design

The assumption of the proposed work is that when designing for ambient computing applications the nature of the requirements to be considered should extend to what in traditional architecture has been called soft qualities [3] or Qualities Without a Name [1], [2]. The author's conviction is that the role of these aspects is indispensable to the design of ambient computing systems, in which the interaction does not take place only according to the 'one to one' relationship between the human and the device, but is also distributed within the setting - and across the settings -, pervades everyday objects, and enables new relationships, which arise from the environmental and relational conditions put into place. Of course, these considerations assume a greater importance when designing for settings that present a high level of socio-technical fragility, such as the Neonatal Intensive Care Unit. This methodological proposal adopts the notion of soft qualities of interaction as an operative instrument intended to design for Aesthetics of Interaction in ambient computing systems. The idea of soft qualities of interaction is directly borrowed from the *Design Primario* [3] movement and from the concept of *Qualities Without A Name*, as it is proposed by Alexander [1]. In both of these cases the design demand is that of externalizing the features that define aesthetics and that create the sense of wholeness that characterises our relationship with certain environments. The presence of these qualities can determine what Alexander also calls design patterns: which are the best practices that can be verified in very different domains, gaining for instance a strong importance in object oriented programming [2].

The proposed *soft approach* to design stemmed from the growing complexity that is offered by interaction when computation is distributed in the environment and embodied in all sorts of objects. The perspective of the Aesthetics of Interaction is considered as a means of facilitating the way in which computation is manifested, and overcoming some of the traditional problems of ubiquitous, ambient and pervasive computing, which cause computation to become invisible with the consequent loss of control on the part of the user. This approach is grounded on the use of the *soft properties*, the *soft requirements* and the proposal of a *soft prototype* are as analytical and operative tools in order to actualize the notion of the Aesthetics of Interaction in the design practice.

The case study presented in this work has been carried out following a participatory design approach to design with the aim of integrating the existing techniques with the notion of aesthetics of interaction, with the following objectives:

- highlighting the need to permit the emergence of the latent requirements of interaction in the design approach
- emphasizing, in this way, the importance of the requirements' elicitation and presentation
- complementing the design approach with the notion of aesthetics as they are manifested through the soft properties of interaction and embodied in the soft set of requirements

3. THE NEONATAL INTENSIVE CARE UNITI

The introduction of digital technologies into health care settings requires specific considerations that are related to the characteristics of the domain, the activities that take place therein and the different skills of the actors involved. At the Neonatal Intensive Care Unit, the space built around incubators represents the main setting of interactions that enable the relationships between different individuals. In fact, it not only embodies the work practice of the medical staff that aims to take care the baby, it also represents the major setting in which relationship (i.e. functional and emotional) between the child and the external world is constructed. In this setting, the design of the environment and of the tools is focused on the functionalities that they will support and little account is given to what concerns the qualitative, soft properties of interaction which define the criteria of the aesthetics in this work setting. Conversely, the NICU micro-environment (i.e. the incubator) and macro-environment (i.e. the neonatal ward) are profoundly effected by the typology of these properties which are related to the noise levels, the quality of light, the configuration of the incubators, the presence of displays, etc. These characteristics, even if they are not exclusively functional, can establish a dynamic in the surrounding environment that enables the creation of relationships among the participants, and also supports the collaboration, the emotional exchanges and the understanding of the baby's conditions by both the medical staff and the families . Indeed, the NICU is shaped by diverse, coexisting factors that specify the uses, the activities, the objectives and the expectations of the individuals involved in the care of the child and in this sense it represents a transitional environment that provides the child with the main mediation between its mother's womb and the external world.The fieldwork activities combined to creative workshops with the stakeholders enriched our understanding of the context of use and allowed to collect fundamental requirements for an effective introduction of new technologies in the NICU [9], 15], 20] To summarize, the NICU presents: 1) the system is characterized by a high level of re-configurability, i.e. each incubator should be conceived as an ad hoc entity, tailored to the baby's conditions and dynamically changing over time. 2)The incubator is associated to external equipments to sustain the baby necessities, but no functional coupling is now supported among the different devices, this making complicate to recognize and discriminate system failures vs. aggravation of the baby conditions. 3) The work practice is based on the continuous combination and integration of data coming from different sources. 4) Different actors have different access to the incubator depending on their role: this implies a different access to the information to be displayed. 5)This setting should support co-existence of emergence situations as well as daily care. 6) The design of standard incubators does not allow an easy reconfiguration of the environment. As a consequence even small adjustments compromise the micro-environmental conditions necessary for the child. Indeed, the temperature, the level of light, the level of noise and the postural stabilization are continuously jeopardized by the nature of the environment and by the typologies of the interventions [14][15].

Figure 1: The Incubator System (Nicu, ‘Le Scotte’ Hospital, Siena – Italy

Based on these assumptions, (in collaboration with the Aarhus School of Architecture and Aarhus University, our partners in the PalCom Project) a new conception of the incubator system has been developed addressing the following need collected by observation and fieldwork analysis at the Neonatal Ward.

- To support the creation of an environment that fully embraces the child, and is able to sustain its body and to simulate the kind of stimulation the child was used to receiving in the mother uterus
- To provide a mediation layer to support the transition between the different NICU environments and interventions
- To support the co-existence of the various individuals’ needs, both in terms of understanding the infant’s conditions and for what concerns the perceptual qualities that control all of the interactions in this setting
- To dynamically manage the relationship between the macro and micro environmental levels.

3.1 The initial set of functional requirements

In parallel to the analysis of the activity an envisioning process has been carried out in order to create new concepts for the NICU setting. A initial set of requirements has been enriched and shaped by means of these new concepts. The envisioning process was undertaken with the medical staff in the NICU.

The outcomes of this activity led to the definition of the ‘water lily’ concept. This concept, developed within the design team, embodies most of the properties emerged along the concept generation and activity analysis. The Water Lily represents a soft and protective environment composed of a layered structure of petals and smart materials. The environment alters light and sound, keeps the infant’s body in place, reduces the need for external manipulation, monitors bio-parameters, and provides connectivity with the diverse actors of community built around the child (i.e. the care community). The system consists of two structures, a bottom and a top layer. The top is constructed with a number of petals that can cover the child completely or partially to provide warmth, can maintain the baby's body in place and can collect vital parameters through the use of biosensors. The bottom layer is a structure similar to 'pin art' which supports the positioning, the manipulation and the measurement of the infant. The system enables the dynamic assembly and disassembly of bed pins, petals and the tangible bottom surfaces according to emerging needs. A preliminary assessment of the water lily concept was performed by building a physical mock up. Nurses and physicians used the mock up by pretending to perform ordinary operations on a baby doll.

On the basis of this early assessment of the mock up, the initial requirements of the incubator was redefined in order to develop, in collaboration with the Aarhus School of Architecture, a physical model of an incubator inspired by the water lily concept. Different focus groups have been conducted with our stakeholders (physicians, nurses and therapists) with the intention of exploring the concept potentialities and collaboratively define the requirements of the system. The following table expresses the outcomes of those activities, in which, by starting with the existing incubator, medical staff pointed out the main problematic aspects, and suggested solutions as design proposals.

Table 1. Set of functional requirements

• **GENERAL**	
Opening system •	• Description: The performance of treatments on the babies such as intubations and placing of sensors currently requires the opening of the incubator, which dramatically effects the micro environment conditions inside. It should be possible intervene on the baby both without opening the incubator and in such a way that the medical staff is provided with a sufficient degree of comfort in accomplishing their operations
Environmental pollution - electromagnetic fields •	Description: In the overall environment there exists a high level of electromagnetic fields. Though it has not yet been proven that these electromagnetic fields effect the newborn in a negative fashion, the staff would nonetheless like to limit the baby's exposure to them, both around and inside the incubator.
Acoustic pollution - External noise	Description: The overall environment (the ward as such) has a acoustic pollution that can has a damaging effect or be perceived as harmful for the newborn in the incubator. There is a wish to prevent these noises from reaching the newborn. This is also applicable when the child is undergoing an intervention e.g. in today's case, when the lid of the incubator is open.
Acoustic pollution - Internal noise	Description: The modern day incubator also generates a noise level that disturbs and effects the child in a negative way. To provide just one example of the various types of these noises, current models are powered by an engine that is placed within the incubator, which produces a very high level of sound. The

	new incubator should seek to limit or completely remove such noises.
Internal temperature control	Description: The child should as much as possible be kept in a temperature controlled environment. This temperature should be set and maintained by the staff, even during all kind of interventions. Today the incubator is opened during some interventions, thus directly changing the protective environment that is normally maintained inside the incubator
Sterile environment	Description: The incubator should be kept sterile, This includes the handling of the child's excrements and hygiene.
Two way audio	Description: An emerging need is that of having a 2 way audio link to and from the incubator.
Video/Image	Description: The wish to monitor the child using a streaming video source or images is among the requests from the staff.
THE COVER	
Light control	Description: A prematurely born child is extremely sensitive to light and for this reason it is requested that the amount of light inside the incubator can be controlled and kept constant with disrespect to the external light sources.
Visibility	Description: The staff should in a clear way be able to visibly monitor the child. This is requested even if the light inside the incubator is dimmed.
THE BED	
Soft mattress	Description: The Mattress on which the baby lays is currently made of a hard plastic material; it is not comfortable and not adaptable to the baby's body. A soft, more adjustable mattress is requested that supports the interventions and the needs of the child.
Tilting mattress	Description: To assist the child's respiration it is necessary that the bed can tilt the child and maintain a position in which the head is higher then the feet and vice versa, until such a time that the child is re-manipulated.
Fixed body position/Prevent big body movements	Description: The medical staff would like to be able to keep the child in particular positions for some interventions or to keep the child in a position supporting its current needs.
Flexible body movement/Allow small body movements	Description: The child, even in a fixed position, should be able to make small movements. The mattress should support this necessity even if in a predefined position.
Interaction modalities	Description: Medical staff should be able to intervene without directly manipulating the baby or opening the incubator.
Petals	Description: The Petals should be able to monitor the following vital signs through sensors: the oxygen saturation, the heart rate, the breath rate, the temperature, the skin perspiration.

Taking the requirements list as starting point, the main features of the incubator prototype were discussed with the medical staff. On this basis, it was possible to sketch out the initial physical model of the incubator. The incubator in this prototyped version is seen as a portable environment that is conceived as an assembly of devices and functions to be configured on the basis of the baby's conditions. The incubator has been designed as an autonomous system that doesn't need to be connected to other external devices, such as ventilators or phototherapy lamps, as is the case today. The various units needed in the treatment and care of the premature newborn are plugged into a rack on the back on the incubator. A system of different modules contains the different machineries for the treatment. In the incubator the baby lays on a special mattress that is provided with a system of sensors that detect the pressure points of the baby's body and continuously monitor its movements. Moreover, the mattress allows the manipulation of the baby's body without opening the incubator, and in this way the micro-environmental conditions, which would otherwise be compromised, are preserved. This manipulation is made possible by a pin-wise system whose elements can be moved up and down directly or indirectly [20].

The dome is the basic unit of the incubator. The dome structure is easily moveable mainly because the biosensors wireless communication limits the number of wires attached to the structure, and in this way the dome becomes an autonomous structure. Furthermore, the dome construction allows the incubator bed to swivel, thus increasing the possibility of accessing the incubator from different positions and supporting situations in which different persons intervene on the baby. The circular shape of the dome and the presence of holes are intentional design solutions for supporting the collaboration among the different persons of the community.

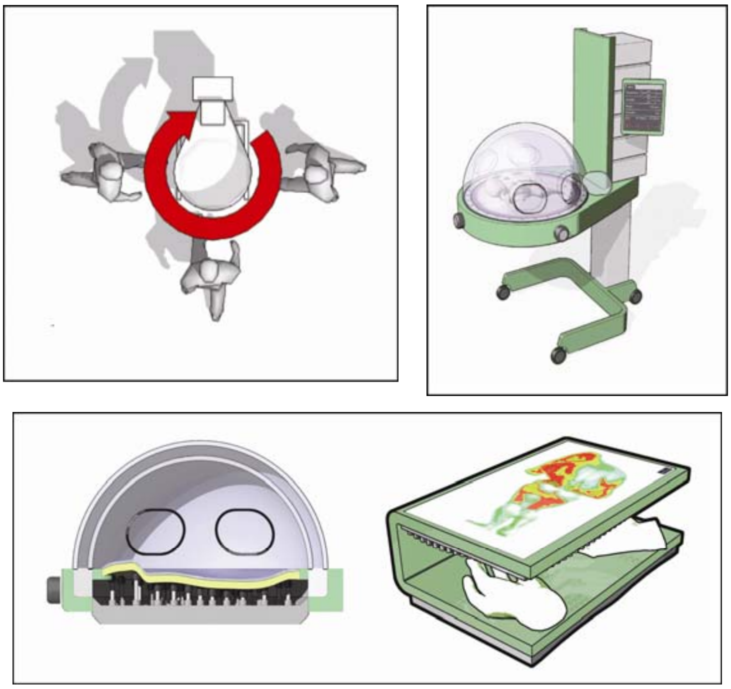


Figure 2: Incubator 3d model and Mattress Pins system and map of pressure sensors developed in collaboration with the Aarhus School of Architecture

The child can be accessed in multiple ways, either through the holes or by completely removing the dome. The possibility of using diverse modules of the incubator in order to support the necessary tasks allows the configuration of the functionalities with respect to the babies' varying conditions. In each incubator it is possible to combine assemblies of different biosensors in order to monitor precise parameters and then by subsequently combining those to obtain more detailed and complete information [20].

Within the micro-environment of the incubator, the baby lies on a mattress containing body pressure sensors that detect the weighted areas of the baby's body on the mattress surface. In order to avoid pressure sores and similar problems a fine grained modular system allows the medical staff to manipulate and change the position of the baby's body without opening the incubator, thus preserving the microenvironment conditions inside. This manipulation is allowed by a pin art type of system whose elements can be moved up and down directly or remotely. The incubator can be set up in different ways by configuring assemblies of devices and services [20].

The development of the first incubator prototype mainly served as an evaluation tool with the objectives of:

- Refining the original concept by embodying its properties into a physical model
- Sharing the design ideas among the stakeholders group
- Evaluating the design solutions by means of user workshops with the medical staff and expert evaluation.

In this way, the work has been carried out through the use of a participatory design perspective in which the users played a fundamental role. Different user workshops have been devoted to evaluating the incubator prototype and its associated functionalities. One of the main topics of discussion was related to the mattress design. Through user workshops, the main outcomes achieved by the medical staff can be summarized as follows:

Manipulation of the baby through the mattress

- The baby should be handled only for therapeutic purposes: medical personnel excluded any possibility of using remote or automatic manipulation for performing training activities or simply for creating a contact between the child and the mother.
- Medical personnel deemed it very useful to have a trace of the pressure points of the baby body on the mattress, in order to simultaneously monitor all the babies and anticipate pressure on high risk areas, or just to avoid pressure sores.

Physical Design

- The mattress itself is still similar to the original model, i.e. a layer of hard plastic material, augmented with new functionalities (pressure point detection and automatic manipulation), but it's not able to contain the baby's body.
- The dome structure can be more easily transported.
- The dome shape facilitates collaboration among the staff members.
- The modules system makes the incubator an autonomous unit, without the need for external equipment.
- The mediation the dome structure provides is still perceived as a separation between the child and the external ward.

These design solutions have been also subjected to an expert evaluation; the prototype and the scenarios have been assessed by professor Westrup, who is the founder of the NIDCAP approach to the care of premature newborns. NIDCAP is an acronym that stands for Newborn Individualized Developmental Care and Assessment Program

[27], which is an approach that uses a range of medical and nursing interventions that aim to decrease the stress of preterm neonates in NICUs [22].

Westrup severely criticized this first prototype. In fact, in this design solution he couldn't recognize the manifestation of the environmental qualities that are fundamental to the care of the child. If the prototype was able to support the child's well being from a functional perspective (i.e. through the maintenance of the environmental conditions inside the dome, the filtering of light and sound and the facilitation of the medical staff intervention), from an interactive perspective, this prototype still embodies the traditional concept of the incubator space, which does not allow the kind of direct contact between the child and the care givers that is necessary to the early development of the child.

4. THE SOFT SET OF REQUIREMENTS

The methodological perspective of this work has been motivated as a complementation to the design process undertaken in the project. As reported, the first set of functional requirements led to the development of the first incubator physical prototype, mainly intended as a communication tool among the design team and to sustain the evaluation with the stakeholders at the hospital. As it was demonstrated throughout the evaluation of different types of user workshops and in interviews with the experts, this first prototype was effective in responding to precise necessities, including the simplification of the opening system, the creation of a space around the child where the medical personnel could more easily collaborate (i.e. the dome structure), the provision a good degree of environmental insulation, and the resolution of the problems of dependence on the external equipment that surround the current incubators through the creation of the system of side modules, each of which contains the necessary machinery for the child care. In contrast, this first prototype was not able to interpret the more delicate variables in the setting of the Neonatal Intensive Care Unit such as the necessary physical contact between the child and the care givers, the postural stabilization of the child's body, the different levels of understanding of the baby's conditions by the diverse individuals of the care community and the shift of perspective that is necessary to psychologically support the different emotional needs of the people involved. In this sense the central questions are: can the design of ambient computing system respond to such a complex whole of variables? What is the role of the Aesthetics of Interaction?

Of course, the first incubator prototype can not be indented as a finished work, but merely as a first attempt of embodying some of the design issues, and it should be considered in light of the process of subsequent iterative design cycles. Notwithstanding, it has been decided to begin a parallel and complementary design phase with more focus on some of the soft aspects of the interaction in order to better externalize the latent needs of this application domain and to retrieve the richness of the activity analysis and of the inspiration provided by the water lily concept. This methodological proposal adopts the notion of soft qualities of interaction as an operative instrument intended to design for Aesthetics of Interaction in ambient computing systems. For a complete discussion on the nature of the soft properties of interaction in the Neonatal Intensive Care Unit see [10]. The elicitation of the soft properties at the NICU by comparing different NICU setting and by isolating the soft aspects from the others allowed a more in depth elaboration on the nature of these qualities [19], thus revealing how they are strictly intertwined with the functional aspects, but also showing how their consideration could significantly influence the life of this setting by engendering a real shift of perspective. In the methodological proposal of this work, the soft properties, will transform into soft requirements of the design in this setting.

The soft set of requirements herein proposed aim at complementing the list of functional requirements that guided the design of the first incubator prototype and with the objective of making more sharable within the design process the latent qualities of this setting that, while they are implicit inside the functional aspects, can play a fundamental role in the introduction of ambient technologies. Indeed, some of the soft requirements embody specific soft properties elicited during the analysis; while the others rather re-formulate pre-existing functional requirements, enriched at light of the soft properties of interaction.

SOFT SET OF REQUIREMENTS

Filtering: different level of opacity

Description: opacity shall become a design quality of this environment that acts in two different ways: firstly by creating a light insulation for the child and also by supporting a smoother and softer view of the child for the families.

Soft Quality: interferences; background/foreground effects.

Open/closed environment

Description: the incubator environment shall be able to be freely opened or closed to allow direct contact or protection according to the different needs and situations.

Soft Quality: background/foreground effects; separation/interpenetration; access.

Perceivable output

Description: the incubator environment shall make even small traces of the child's life visible. These will represent an indication of the child's well being for the medical personnel, but will also be a sign that is understandable for the parents.

Soft Quality: background /foreground effects; different visibilities

Granularity

Description: the introduction of technology shall be visible at different levels, thus generating an aggregated view of diverse data as well as an in depth view of particular value, with the primary objective of supporting inspection, revealing functional connections and integrating information.

Soft Quality: background/foreground effects; different visibilities; interferences.

REFORMULATED FUNCTIONAL REQUIREMENTS

Postural stabilization/embracement

Description: the incubator environment shall be considered as a delicate layer which (embrace) embraces the child, sustains the baby's body and preserves the environmental conditions.

Soft Quality: overlapping; access

Layering

Description: the incubator environment shall manage different layers of interactions. The multilayered property of this environment shall allow the end user configurability and simultaneous courses of action.

Soft Quality: layering; access.

Rigid structure/foldable material

Description: the incubator environment shall balance a rigid structure that creates a safe environment during the interventions with a soft and foldable material that can be easily transported and configured.

Soft Quality: separation/interpenetration

The proposed soft set of requirements can intervene at micro, macro and interactive levels and are directly grounded on the soft properties of interaction. Furthermore, these requirements are not seen as exhaustive as such, on the contrary they should complement and re-formulate the functional requirements of a setting or a system based on specific technological innovations and user needs.

In line with this, a key aspect yet to be considered is the way in which these requirements can be transformed into design solutions.

4.1 Making the soft set of requirements explicit: a representational concern

The treatment of the soft set of requirements within the design process described here requires a further discussion related to the representational aspects of the requirements. If one would compare for a second time the first list of design requirements elicited for the incubator prototype with the soft requirements proposed in this analysis, one could argue that in reality these two lists present a different level of accuracy in addressing specific aspects of the setting. This is, of course, correct since the soft set of requirements are subsequent to the first iterative design cycle, thus implying a more consolidated view on the area of intervention. On the other hand, the soft set of requirements, (i.e. *Filtering: different level of opacity, Postural stabilization/embracement, Rigid structure/foldable material, Layering, Open/closed environment, Visual output, Granularity*) offer a complementary view on the design that is already embodied in the current practice, mainly focusing on the soft aspects, and which represent successful strategies of interaction that emerged after isolating the aesthetic aspects from the others. In this sense, the objective of this soft set of requirements is also to transform these aspects into solutions to be interpreted by the design of ambient computing systems.

It is here that the importance of the representations in the design process becomes relevant; in fact, these profoundly effect the way in which knowledge - extracted from fieldwork activities, state of the art technology and concept generation - is transformed and made available to the different members of the design team. In many cases of interdisciplinary design teams, the way in which requirements become solutions is a complex process, in which information undergoes different interpretations, such that the embodiment of the requirements into the system design can discount important aspects or contribute to the process by which some features remain latent. This of course depends on the diverse sensibilities of the designers who can mutually concentrate on some aspects rather than others.

An effective countermeasure to this potential loss of information is provided by the way in which the requirements come to be illustrated and represented. This is based on a very strong practice especially in the area of Interaction Design, which is more influenced by the aesthetic tradition and where concept generation plays a central role. In accordance with this stance, this methodological proposal sought to make the soft set of requirements explicit by the use of graphical representations that primarily aimed at guaranteeing the correct transformation of information throughout the design process. In fact, these proposals embody the soft but also the functional requirements in different ways. Furthermore, they are used to elaborate and prototype the design solutions for the incubator micro environment with the focus on the baby mattress. In fact, as emerged through the evaluation with the expert and the members of the medical staff at Siena Hospital the mattress artefact should be re-designed as *a dynamic layer which protects the child, keeps the baby's body in place, facilitates the transportation of the newborn, allows the detection of the pressure points of the baby's body and the micro-stimulation of the baby*.

In addition, the production of the graphical representations can be seen as the consequence of a close collaboration between interaction and graphic designers. The engendered dialogue offered new cues to the design and provided a novel synthesis of the envisaged solutions. The result of this activity has been shared in a design workshop among the design team members, and supported by the creation of a soft prototype to test the soft requirements with the users at the hospital. The key features of the soft prototype are:

- High configurability, i.e. composition of the different modules by the staff members
- Design the material properties, i.e. different levels of thickness and softness; metamorphic quality
- Define probable solutions: i.e. the sizes, the weight
- Make visible the output of the technological solutions, i.e. use of coloured dots to make the sensors position on the mattress's base visible.

4.2 Toward a Mattress Prototype

The function of the mattress soft prototype is strategic, in fact it allows the direct exploration of the soft qualities by isolating the soft requirements in its design and providing a good balance between the supported functionalities and certain aspects of the look and feel. The specific characteristics of Mattress Soft Prototype goes toward the ideal of embodying the soft requirements into intermediate solutions to be tested and evaluated with the users. In this prototype three elements play a critical role, the *softness* of the material, the *thickness* and the *metamorphic possibilities*. As the evaluation with users revealed, these elements supported the way the medical staff could experiment the filtering properties of the mattress, the possibility to embrace the child, and the possibility to configure the space. Furthermore, the way the 'foldable' requirement has been supported demonstrate to sustain the ways the parents could in different ways 'open' the child micro environment, passing from the mediated contact to the direct contact. Another important aspect is related to the use of sensors in this prototype. In fact, the presence of the sensors on the mattress base is made visible to the different individual acting in this setting. This provides interaction cues for both the medical personnel and the parents. Medical staff can indeed have an indication on the functioning of the sensors and on their correct placement in respect to the baby postural regulation. The parents can use the visualization of the sensors as a trace of the baby life, and can learn on the baby conditions by making sense of this information. The nature of the material that is able to filter the environmental input would create the kind of layered mediation the child needs, and it would also support the creation of a modular and reconfigurable space adaptable to each baby. These outcomes led to a further elaboration of the mattress prototype.

The premature newborn can be placed in this special mattress immediately after the delivery when the physicians check the fundamental vital parameters. In this way the child may be moved from the delivery room to the neonatal ward on the mattress, in order to preserve the optimal conditions as much as possible. Furthermore, the mattress can facilitate all of the operations that may be performed on the baby; by filtering the light and preserving the temperature, the mattress will allow an easier access to the baby from different positions and will support situations in which different actors intervene on the baby.

An important feature implicit to this idea of mediation is the way in which this artefact will change the nature of the access to the baby. The possibility of using wireless sensors and of using the mattress material to detect certain parameters will simplify medical staff interventions and will offer more opportunities for collaboration; in this way the mother can be more easily integrated into the care process.

Thus the mattress micro-environment intervenes at two different levels. It modifies the nature of the access to the baby. Therefore it re-shapes the interaction unit built around the child by introducing the mother’s presence and by facilitating the co-existence of different courses of actions.

It creates an intermediate point in the tension between separation and interpenetration that characterizes the life in the NICU.

The protocols usually adopted for the care of the newborn strongly address the need to re-establish a direct contact between the mother and the infant by promoting as much as possible the direct care of the mother. In this perspective the mattress environment is able to mediate the environmental conditions in order to adapt to the baby’s needs, and able to mediate the relationship between the infant and the different actors. Here the meaning of mediation reflects directly on the possibilities for creating contacts, for establishing relationships and for supporting collaborations.

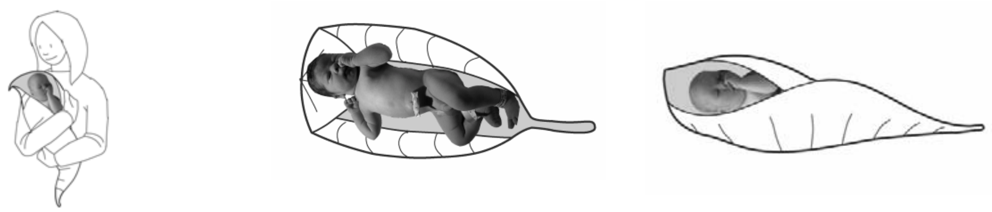
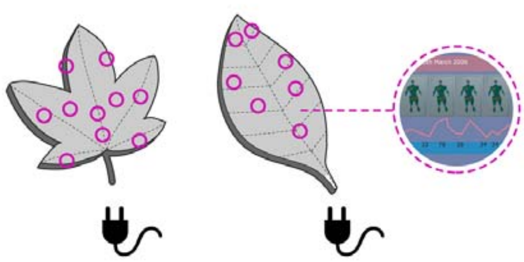
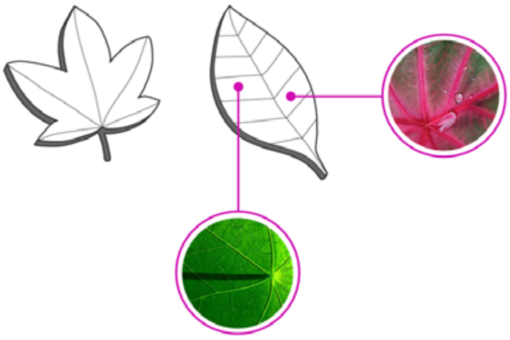


Figure 3: the mattress design proposals: the leaf metaphor

Table 1. Design proposals for the mattress prototype

	**The inner surface of the mattress** This side of the mattress is the one on which the bay lies. A number of pressure sensors are placed in a pattern inside the mattress which detect and communicate the pressure on each unique point on the mattress surface. Depending on the data detected by the sensors, the mattress can be reconfigured to prevent postural problems and pressure sores.

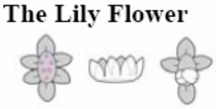


The outer surface of the mattress

This side of the mattress visualizes for the different actors the pressure points of the baby. Indeed small leds correspond to the different pressure sensors and indicate their position and the intensity of the pressure on each point, i.e. by changing led intensity.

The values of the baby pressure points are also available on a remote display.

Table 2. The functional requirements, the soft requirements, the design qualities

Proposal	Functional Requirements	Soft Requirements	Design qualities
The Leaf 	Opening system Environmental pollution Internal temperature control Sterile environment Light control Visibility Soft Mattress Fixed body position/Prevent big body movements Flexible body movement/Allow small body movements Interaction modalities	Granularity Rigid structure/foldabl e material Embracement Open/closed environment Filtering Visual output	Nature as a metaphor Physical configuration Autonomous unit
The Lily Flower 	Internal temperature control Sterile environment Light control Visibility Opening system Petals Soft Mattress Fixed body position/Prevent big body movements Flexible body movement/Allow small body movements Interaction modalities	Layering Granularity Rigid structure/foldabl e material Open/closed environment Filtering Visual output	Nature as a metaphor Physical configuration Autonomous unit
The Baby Bag 	Internal temperature control Sterile environment Light control Opening system Fixed body position/Prevent big body movements Flexible body movement/Allow small body movements	Rigid structure/foldabl e material Visual output Open/closed environment Filtering	Everyday object Minimal Autonomous unit Portable

5. DISCUSSION

The approach to the design presented herein aims at integrating the co-evolutionary design process by accounting for the role of Aesthetics of Interaction. Of course, Aesthetics can not be intended as a driving force for the design of complex systems where computation is made available in a distributed, networked, embedded way. Notwithstanding, the persuasion of the research is that a consideration of the aesthetic properties can complement the design of these systems and can better interpret the complex whole of variables that effect the life of human-technology systems. The operative tool by which aesthetics can emerge and can be designed for are described by the soft approach: the identification of the soft properties, the elicitation of the soft requirements and the creation of a soft prototype. The methodological perspective presented here is inspired by the nature of soft qualities in architectural domains. In greater detail, the Design Primario movement [3] in the Italian Vanguard throughout the Seventies and the Eighties, and the investigation of the Qualities Without a Name [1] and of the Design Pattern [2] in the Christopher Alexander research, supported the intuition that the role of aesthetics in the design of interaction could be similarly accounted for by looking at the soft properties of interaction. These properties, although they do not have a direct, functional purpose, also effect the interaction modalities by defining the expressional level at which computation can be manifested.

In effect, the consideration of these soft variables of interaction can revise the process both in analytical and in design terms,

- by making explicit some latent aspects of interaction that are also fundamental in the explanation of the complex dynamics of this setting
- by externalizing the knowledge gained throughout the design process by the use of prototypes and different representations to share and evaluate the properties, the requirements and the design solutions.

As the proposed argumentation has demonstrated, these aspects lead to concrete advantages. One is external to the design process; making the latent variables explicit can in fact anticipate problems that may arise in the interaction with the designed system and can help with the construction of acceptance when introducing new technological equipment in this delicate setting; this means that the consideration of the soft aspects can minimize the learning process usually necessary in the use of new technologies.

The other advantage is internal to the design process. The work reported in this research mainly demonstrates how the modality by which information passes from one phase to the other of the design process is in reality a critical variable, since the loss of information can occur between diverse phases, and since the modality of presentation can create misunderstandings in the design object. The systematic use of different typologies of representation (i.e. the interaction patterns form, the requirements representations, the soft prototype) sustained the design process in order to identify, share and evaluate the role of the soft qualities as they were progressively shaped into design solutions.

Design methodology, as Landin clearly suggests [13], is one way to elaborate knowledge about the properties of expression of computational technologies. This can be achieved in two ways: by following an approach by design [13], [6] that explores the aesthetics of the intended use [10] in design solutions; and by an aesthetical analysis of actual use, that poses the delicate issue of transforming an analytical knowledge into a design knowledge [13]. The soft approach presented herein is an attempt to combine an analytical and a design perspective for integrating the Aesthetics of Interaction in the design of Ambient Computing Systems. Furthermore, the soft approach does not represent any consolidated framework; rather, it represents an early reflection on the existing design practices and seeks to pose the question of how to open the design space establishing a new dialogue between the functional and the emotional aspects of the interaction. The possibility to continuously find new points of balance between these two coexisting dimensions -manipulating functional and soft aspects- allow the designers exploring novel implications of their work, such as the possibilities to influence human attitude toward a certain situation. These reflections clearly gain a particular value when designing for application domains in which the emotional and psychological aspects involved express a specific socio-technical fragility and in which people's attitude plays a critical role. This is the case of the Neonatal Intensive Care Unit.

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9.5 Entering the life of Human-Technologies systems: Soft Properties of Interaction at the Neonatal Intensive Care Unit

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Entering the life of Human-Technologies systems: Soft Properties of Interaction at the Neonatal Intensive Care Unit

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Abstract

The life of human-technologies systems in fragile settings involves a complex whole of variables not just dependant on the functional aspects. In this work the notion of Aesthetics of Interaction in ambient computing system is challenged by the design proposal of the Soft Properties of Interaction as a tool to complement the design methodology. The case study discussed refers to a delicate setting such as the Neonatal Intensive Care Unit (Grönvall et al., 2005). Especially in a context as this, interaction can not be merely indented as the functional relation between humans and devices, instead it should become manifest from the environmental conditions enabled (Branzi, 1986; Navoni et al., 1974). Such conditions can be expressed by the aesthetics of use (Petersen et al., 2004; Dunne, 1999) as they can support novel opportunities of interaction and sustain the inspection mechanism in an intuitive way. The perspective presented is based on the work conducted at the Neonatal Intensive Care Unit at Siena Hospital -Italy (Rullo et al., 2006) as a part of the EU PalCom project. The outcomes provide a heuristic account to inform the design process by fostering the novel complexity (Shultz et al., 2005; Chalmers, 2004; Weiser,1991) of ambient/palpable technologies in delicate and fragile settings.

Categories and Subject Descriptors:

Information Systems – Information Systems Applications – General (H.4.0); Information Systems – Information Interfaces and Presentation – User Interfaces (H.5.2)

General Terms:

Design, Human Factors, Theory

Additional Key Words and Phrases:

Aesthetics of Interaction, soft properties, palpable computing, neonatal care

1. INTRODUCTION

The idea of invisibility in use has been interpreted in many ways in the Ambient Computing field, aiming at exploring the various modalities in which computation can become manifest, and noticeable for the user. In Weiser's (1991, 1994) conceptualization, 'invisible' means that individuals can become so familiar with the use of technologies that they don't have to think that they are interacting with those. Technologies are ready to hand, and people can focus on the task on which they are involved without concentrating on the interaction with the device that mediates that. In this perspective this meaning of invisibility suggests a reflection on the typology of mediation offered by technology, i.e. how they can support this transparent use.

The proposal of making technology invisible in use has been further elaborated (Weiser and Brown, 1996; Tolmie, 2002; Petersen, 2004) by focusing on the real meaning of computation invisibility, e.g., the notion of unremarkable computing, the idea of calm technologies, the proposal of remarkable computing, to mention only a part of this research. In general, the idea of computation invisibility runs into trouble when something stops working, when any failure in the system occurs and the user should disambiguate what is going on and take decision accordingly. These cases underline the difference between the notion of technology *'ready to hand'* that mediate our activities without (almost) being aware of, and technologies that must become present at hand, to allow the awareness and the understanding of the processes undergoing (Winograd and Flores, 1986). In this case, computation shall manifest itself, by making visible, at the chosen level, what is going on, and likely allow the user to enter the system and re-configure the application in order to overcome the system failure or to use the residual capacities of the system. These aspects are very much related to the possibility of making sense of what the system sense being inspired, for instance, on how these processes are embodied in human-human interaction (Bellotti et al., 2002). Bellotti et al. challenge these topics by addressing a novel class of systems that obtain user inputs through sensing user actions, rather than through standard input device such as the keyboard, mouse or stylus (Bellotti et al., 2002).

Palpable Computing represents an emerging conceptual framework in this research's field, that makes an attempt to investigate these different phenomena inherent the way computation can manifest in complex socio-technical systems. The word *palpable* itself embodies the challenges of the object of analysis. In fact, palpable means both tangible, perceivable through the senses, but also, clear, intuitive, noticeable, manifest. The co-existence of these meanings well explains the objective of palpable computing that seeks for the material modalities in which computation can dynamically handle the needs of evolving contexts, by balancing the demand for computation invisibility, as it has been described above, visibility and inspectability; creating an equilibrium between the system automation and the need for the user to remaining in control, managing the possibility to construct meaningful configurations of devices through interaction and iteratively decompose them in order to create other different composition, according to the situation of use[1]. The demand that is behind the challenges of Palpable Computing, is to handle the way computation can express in interaction. In fact, the properties of the computational material that is used are particular and specific and should be precisely understood. In the domain of ambient computing applications the computational technology manifest as a new typology of design material with its expressional necessities.

[1] For an overview see: www.palcom-ist.org

Computational material present an inherent complexity since computation take places as simultaneous and abstract processes which work on a logical level and it is difficult for the non-expert users to figure out what is going on and at which level.

Computation is immaterial, in fact much of the computational processes and resource management occurs in a modality that is out of the users perceptual range, being in this way unnoticeable.

Changeable conditions. The number of opportunities offered by ambient computing requires a continuous learning process on the side of the users due to the constantly increasing rhythm in which computation possibilities change.

Ambient computing system can be immensely powerful offering a wide range of flexible solutions for the use and the interaction, but they are not able to make sense of the huge quantity of information that they compute in ways acceptable for the humans along interactions.

Computational material shares with other human manifestations such as music, dance or film, the possibility to express along time. The temporal dimension indeed characterises the way computation can manifest (Hällnas and Redström, 2002) and define some material properties that can affect the acts of use (Landin, 2005) and that determine the expression of interaction.

The aesthetics of interaction can, in this context, be intended as the material process by which the interaction possibilities can manifest themselves by creating meaning through interaction and by balancing the different qualities which effects ambient computing systems.

The idea of aesthetics in the design of digital technologies often appears to be restricted to products appearance (Djajadiningrat, 2000). But the physical appearance does not subsume the complexity of aesthetic phenomena and the dynamics engendered by using tools. Indeed, we are plenty of technological products which look good at first sight, but frustrate us as soon as we start interacting with them (Djajadiningrat, 2000). The 'Aesthetics of use' (Dunne, 1999) is one of the perspectives toward a notion of aesthetics which seeks developing a more nuanced cooperation with the object through the interactivity made possible by computing - a cooperation which might enhance social contact and influence everyday experience. Petersen proposes the notion of Aesthetics of Interaction as a design strategy to make computation remarkable:

'Aesthetic interaction is not about conveying meaning and direction through uniform models; it is about triggering imagination, it is thought provoking and encourages people to think differently about interactive systems, what they do and how they might be used differently to serve differentiated goals' (Petersen et al., 2004b).

In this proposal Aesthetics represent the modality by which interaction can be playful and allows to explore inedited modalities of interaction, investigating novel ways in which computation can become visible and noticeable.

This paper aims at addressing the role of Aesthetics of Interaction in ambient computing systems to understand how the notion of aesthetics can provide hints to reflect on the existing design methodologies. The methodological perspective presented here is inspired by the nature of the soft qualities in the architecture domains. More in detail, the Design Primario movement in the Italian Vanguard along the Seventies and the Eighties - on one hand, and the investigation of the Qualities Without a Name and of Design Pattern in the Christopher Alexander research - on the other, supported the intuition that the role of aesthetics in the design of interaction could be accounted in the same way by looking at the soft properties of interaction. These properties although not having a direct functional extent, as well effect the interaction modalities, by defining the expressional level by which computation can be manifested.

Of course Aesthetics cannot be intended as a driving force for the design of complex systems where computation is made available in a distributed, networked, embedded way. Notwithstanding, the persuasion of the research is that an account for the aesthetics properties can complement the design of these systems and can better interpret the complex whole of variables which effect the life of human-technology systems.

The concrete enablers of this methodological proposal are the *soft properties of interaction*, the elicitation and representation of *soft requirements* and the development of a *soft prototype* to complement the existing methods in the design research and inform the design process as well as the design solutions.

These considerations gain a particular significance if considering application domains that present a particular systemic fragility. Health care setting exemplify a particular typology of these systems. The use of information technologies directly impacts the way in which the different tasks are carried out in these contexts, enabling new behaviours, supporting new practices, but also generating new problems, i.e. what happens during a system breakdown or when any failure occurs? The possibility to anticipate the occurrence of breakdowns and to allow inspection of digital devices is a key issue when introducing information technologies in this setting. Indeed, managing the health care complexity means allowing the different users to get in control of the simultaneous processes undertaken (Shultz et al., 2005; Rodden and Blair, 1991). On the other hand, it is necessary to balance these functional necessities with the non functional (e.g. emotional and psychological) needs of these settings. The case study presented in this work represents an example of how this sort of socio-technical fragility is the result of the combination of both functional and non functional properties.

2. THE NEONATAL INTENSIVE CARE UNIT

The Neonatal Intensive Care Unit, at ‘Le Scotte’ Hospital, Siena (Italy) presents very specific features which challenge the design of ambient computing technologies in many ways, as they can support the premature babies necessities and the collaboration among the diverse individuals who act in the ward. At the NICU, the space built around incubators represents the main setting of interactions that enable the relationships between different individuals. In fact, it not only embodies the work practice of the medical staff that aims to take care the baby, it also represents the major setting in which relationship (i.e. functional and emotional) between the child and the external world is constructed. In this setting, the design of the environment and of the tools is focused on the functionalities that they will support and little account is given to what concerns the qualitative, soft properties of interaction which define the criteria of the aesthetics in this work setting. Conversely, the NICU micro-environment (i.e. the incubator) and macro-environment (i.e. the neonatal ward) are profoundly effected by the typology of these properties which are related to the noise levels, the quality of light, the configuration of the incubators, the presence of displays, etc. Indeed, the NICU is shaped by diverse, coexisting factors that specify the uses, the activities, the objectives and the expectations of the individuals involved in the care of the child and in this sense it represents a transitional environment that provides the child with the main mediation between its mother's womb and the external world.

In effect, the current incubator represents a complex system of different components in which each plays a precise role and the relationship among them has a strong impact on the child care. This setting presents (Rullo et al., 2006; Marti, Rullo, 2006):

1. a high level of re-configurability, i.e. each incubator should be conceived as an ad hoc entity, tailored on the baby's conditions and dynamically changing over time.
2. The incubator is associated to external equipments to sustain the baby necessities, but no functional coupling is now supported among the different devices, this making complicate to recognize and discriminate system failure vs. aggravation of the baby conditions.
3. The work practice is based on the continuous combination and integration of data coming from different sources.
4. Different actors have different access to the incubator depending on their role: this implying a different access to the information to be displayed.
5. This setting should support co-existence of emergence situations as well as daily care.
6. The macro and micro environmental conditions play a fundamental role in establishing the interaction supported, i.e. physical contact between the baby and the caregivers, participation of the families to the child care, collaboration among different professionals.

In this light, the Neonatal Intensive Care Unit is characterized by a type of fragility. Indeed, it is possible to recognize a unique socio-technical fragility that is generated by the premature babies' conditions, the need for a continuous monitoring of the child, the use of complicate machineries and the nature of the work that is often carried out under emergency conditions. From another perspective emerges a psychological fragility, which is engendered by the strong emotional impact of the premature birth on all of the individuals involved, including professionals (neonatologists, nurses and therapists) and non-professionals (mainly parents and families) (Als et al., 1986, Pignotti, 2000). As emerged from the analysis presented in chapter 2, these two fragilities (socio-technical and psychological) co-exist, each one respectively influencing the other.

Ambient computing solutions designed for this setting could raise several issues, effecting both the functional and the subjective experience of work and influencing the life of the overall system (Marti and Rullo, 2006).

3. THE METHODOLOGICAL PERSPECTIVE

Understanding the role of aesthetic qualities in ambient computing settings of course poses particular difficulties that arise for two main reasons; the first of which is related to the subjectivity of the aesthetic experience which is grounded on individual variables that are difficult to conceptualize in an objective way, and the second of which concerns the difficulty of externalizing aesthetics in such a way that the 'configurations' that demonstrate an aesthetic value can be reused. Designers at the vanguard of Human Computer Interaction (HCI), Participatory Design (PD) and Computer Supported Cooperative Work (CSCW), have established a tradition of using ethnographic studies, participatory design methods, laboratory and naturalistic experiments to inspire, inform and evaluate design. Some of these methods can be adapted for the design of ubiquitous computing technologies (Stringer et al. 2005; Diggins & Tolmie, 2003) and their use is spreading. In this perspective the role of Participatory Design as had been profoundly debated. Participatory Design (PD) is one of the most important movements within HCI-development, having influenced most of the standard methods that are used today in interaction design (Schuler and Namioka, Eds., 1993). This tradition is based on the assumption that it is the users who will best be able to express what kinds of functionality are needed, rather than managers or sales people (Höök, 2006). The ideals of PD were in reality difficult to realize. Indeed, the original PD movement was something more than a process that simply involved users in the design process as a guarantee that the interaction and functionality were correct and usable (Marti, 2006). The real legacy of PD for the contemporary design practice is that of raising the issue of the role of the users in the design of human-technology systems, which should continuously adapt to the design contexts and to the design demands. The primary point of discussion here is not participatory design processes and their merits as such, but that of questioning the design process in order to understand how and if it can address - by means of its existing methods - the role of aesthetics. The modality by which, on an interdisciplinary design team inspired by a participatory design approach, the knowledge that comes from the user involvement can be transformed into design solutions, the limitations of this perspective and the role that aesthetics can play through the soft properties of interaction will be herein discussed in greater detail.

3.1 Soft properties and Qualities Without A Name

The continuous exploration of the relationship between form and function in architecture and industrial design brought into fruition the design movement 'Design Primario'. This movement was born from an open discussion on architecture between some of the main representatives of Italian vanguard in the Seventies; In Florence, Archizoom, U.F.O., Superstudio and Gianni Pettena; in Milan Gaetenao Pesce, Alessandro Mendini, Ugo la Pietra, Ettore Sottsass; in Naple Riccardo Dalisi. They aimed at radically changing the rationalist and functionalist conventions in design, and emphasized the need for the design of primary instruments capable of recalling the simplicity of primitive objects in which natural and artificial was identified, and by doing this, they searched for the specific meaning of an aesthetic thought. These initial attempts lead to the formation around the middle of the seventies of a design experience called Design Primario or Soft design. This research assumed that Industrial Design has traditionally been based on the idea that the fundamental qualities of an environment or an object is constituted by its structural correctness, i.e.: the balanced correspondence between form, structure and functional necessities (Branzi, 1986). The creation of this balance would directly effect the product's expressiveness, its social value and its habitability (in case of an architectural space). Design Primario, as Branzi explains (1986), offered a sort of eccentric perspective on such a vision. Indeed, it brought the attention toward other structural properties which can be defined as *soft properties*. These qualities - generally considered as secondary by both Classical and Modern Architectural movement - consist of colour, light, micro-climate, decoration, odours and environmental music and should be intended as spatial experiences linked to the physical perception of a space. In Design Primario the immaterial qualities have been identified as the core aspect of design, and assume an aesthetic and cultural value. A famous example of such an approach is the installation prepared by Andrea Branzi and Ettore Sottsass jr. entitled ‘Italian New Renaissance’ (Rotterdam, 1980). In this work the architects decided to introduce a strong mint smell as the only architectural element, which as a soft property could support the interaction and work as a commentary on the artworks exposed.

Design Primario wasn’t the only perspective that considered the qualities perceived in a space that couldn’t be accounted for in purely functional terms. The architect Christopher Alexander uses the term Qualities Without A Name to describe the characteristics of a space that are difficult to name or to classify but that still affect our experiences. In The Timeless Way of Building (1979), Alexander introduces the idea of “the quality without a name,” the possession of which is the ultimate goal of any design product. It is impossible to provide a concise example of this concept. Alexander presents a number of partial synonyms: freedom, life, wholeness, comfortability, and harmony, but no single term or example can fully convey the meaning or capture the force of Alexander's notion and its impact on design.

In A Pattern Language (1977) Alexander further introduces the notion of design pattern. The term “pattern” is a preformal construct (Alexander does not ever provide a formal definition) that describes sets of forces in the world and relations among them. In Timeless, Alexander describes common, sometimes even universal patterns of space, of events, of human existence, that range across all levels of granularity.

Patterns contains 253 pattern entries. Each entry might be seen as a “mini” handbook on a common, concrete architectural domain. Each entry create relationships among a set of forces, a configuration or family of artefacts, and a process for constructing a particular realization .

In this way, the entries intertwine the ``problem space'', the ``solution space'', and the ``construction space'' issues, so that each may evolve concurrently when patterns are used in development.

Alexander’s work can be synthesized by the need of creating a lingua franca in the design that is able to guide the design team through the different design choices.

An exemplary case of how Alexander’s thoughts can inform and direct the design is provided by a study from the urban designer Randy Hester: the "re-design" of the town of Manteo, North Carolina, in the 1980's (Hester, 1993). Also as Erickson (2000) has explained, in the last decade, pattern languages have attracted increasing attention from technologists, both in the object oriented programming community and in the HCI community. For HCI, in general, and interaction design, in particular, patterns are an idea which can usefully update the design of the interaction. Erickson (2000) provides two of the most oft-cited reasons for this:

- • Quality. Design patterns will support the creation of systems that have what Alexander and his colleagues (Alexander, 1979, 1977) call "The Quality Without a Name" (and which, computer scientists, in their inimitable way, have reduced to the acronym QWAN) — this is a shorthand for systems which really 'work' for people, in all of the many meanings of that phrase, and
- • Re-Use. Design patterns permit the re-use of the hard-won wisdom of designers, allowing the accumulation and generalization of successful solutions to commonly encountered problems.

3.2 Difficulties of a methodological approach

The attempt of this research is to consider the Aesthetics of the Interaction from a methodological perspective, in order to discuss the challenges and the limitations of the proposed approach. In other words, is it worthwhile to complement the current techniques of Interaction Design by using the idea of Aesthetics of Interaction as a leverage for the design?

Of course, this approach may provoke different hesitations; indeed if we consider the case study presented in this work, the functional component of interaction represents a strong necessity that cannot be ignored. However, as will be demonstrated by this first iterative cycle of prototyping, focusing only on the functional aspects doesn't allow the transformation of the thoroughness of the activity analysis into design solutions capable of accounting for the fragility of this domain. This may have happened because of the way in which the requirements have been presented throughout the different stages of the design process, progressively losing the initial complexity of the analysis and of the inspiration part of design. Of course, this occurrence cannot be generalized, as it is the result of the particular design process herein reported; but, it can be argued, it is representative of the need to more explicitly capture the existence of these soft properties of interaction in the design methodology, in order to better understand their actual value in influencing the daily work practice and the life of human-technology systems, as well as their potential value when interpreted into the design solutions. In short, these brief considerations aim:

- at highlighting the need to permit the emergence of these latent requirements of interaction in the design approach
- at emphasizing, in this way, the importance of the requirements' elicitation and presentation
- at complementing the design approach with the notion of aesthetics as they are manifested through the soft properties of interaction.

To better exemplify these aspects in what follows a comparison will be offered among two different phases of the design process followed in the Palcom project to design a novel concept of the incubator for premature babies. More specifically, two different designs of the mattress on which the baby lies will be compared: one is the result of a traditional approach to the design grounded on a participatory design perspective; the other integrates the soft properties as a strategy to complement the design for this setting. The two mattress design captures two different phases of the same design process undertaken within the Palcom project in strict collaboration between the University of Siena, the Aarhus School of Architecture, and the University of Aarhus.

The activity analysis performed at NICU combined with an inspiration process which involved both the design team and the users at the Neonatal Intensive Care Unit of Siena Hospital allowed to individuate as a critical area of intervention the possibility to create a micro environment to embrace the child in order to maintain its temperature, to weigh the its body and to keep the body in place, avoiding pressure sores and other postural problems. The modality in which these users needs have been interpreted and transformed into design solutions is the topic addressed in the next part of this work.

3.2.1 The first mattress design

The Water Lily guided the first iterative phase of the design process leading to the first mattress early prototype. The Water Lily represents a soft and protective environment composed of a layered structure of petals and smart materials. The environment alters light and sound, keeps the infant's body in place, reduces the need for external manipulation, monitors bio-parameters, and provides connectivity with the diverse actors of community built around the child (i.e., the care community). The system consists of two structures, a bottom and a top layer. The top is constructed with a number of petals that can cover the child completely or partially to provide warmth, can maintain the baby's body in place and can collect vital parameters through the use of biosensors. The bottom layer is a structure similar to 'pin art' which supports the positioning, the manipulation and the measurement of the infant. The system enables the dynamic assembly and disassembly of bed pins, petals and the tangible bottom surfaces according to emerging needs.

Fig. 1. first mock up of the water lily incubator: the mattress

A preliminary assessment of the water lily concept was performed by building a physical mock up. Nurses and physicians used the mock up by pretending to perform ordinary operations on a baby doll. The concept seemed promising for use in normal situations as well as more critical situations when an emergency protocol should be followed. The possibility of adapting the Water Lily to the individual needs of each infant was recognized as a valuable aspect. For what more directly concern the mattress, the flexibility of the 'pin art' like mattress was recognized to be a valid alternative to the direct and intrusive manipulation of the child's body. Moreover, the system is easily transportable from the neonatal early resuscitation room to the NICU, thus following the infant through the different steps of treatment. In doing this, it mediates the relationship of the baby with the external environment. On the basis of this early assessment of the mock up, the initial requirements of the mattress were redefined in order to develop, in collaboration with the Aarhus School of Architecture, a physical model of the mattress inspired by the water lily concept. Different focus groups have been conducted with our stakeholders (physicians, nurses and therapists) with the intention of exploring the concept potentialities and collaboratively define the requirements of the system. The following table expresses the outcomes of those activities, in which, by starting with the existing mattress in the incubator, medical staff pointed out the main problematic aspects, and suggested solutions as design proposals.

Table 1: Mattress, first set of requirements

THE MATTRESS
Soft mattress Owner: Medical staff Description: The Mattress on which the baby lays is currently made of a hard plastic material; it is not comfortable and not adaptable to the baby's body. A soft, more adjustable mattress is requested that supports the interventions and the needs of the child.
Tilting mattress Owner: Medical staff Description: To assist the child's respiration it is necessary that the bed can tilt the child and maintain a position in which the head is higher then the feet and vice versa, until such a time that the child is re-manipulated.

Fixed body position / Prevent big body movements Owner: Medical staff Description: The medical staff would like to be able to keep the child in particular positions for some interventions or to keep the child in a position supporting its current needs.
Flexible body movement / Allow small body movements Owner: Medical staff Description: The child, even in a fixed position, should be able to make small movements. The mattress should support this necessity even if in a predefined position.
Interaction modalities Owner: Siena Design Team Description: Medical staff should be able to intervene without directly manipulating the baby or opening the incubator.
Petals Owner: Siena Design Team Description: The Petals should be able to monitor the following vital signs through sensors: the oxygen saturation, the heart rate, the breath rate, the temperature, the skin perspiration.

The development of the first mattress prototype mainly served as an evaluation tool with the objectives of:

1. Refining the original concept by embodying its properties into a physical model
2. Sharing the design ideas among the stakeholders group
3. Evaluating the design solutions by means of user workshops with the medical staff and expert evaluation.

In this way, the work has been carried out through the use of a participatory design perspective in which the user played a fundamental role.

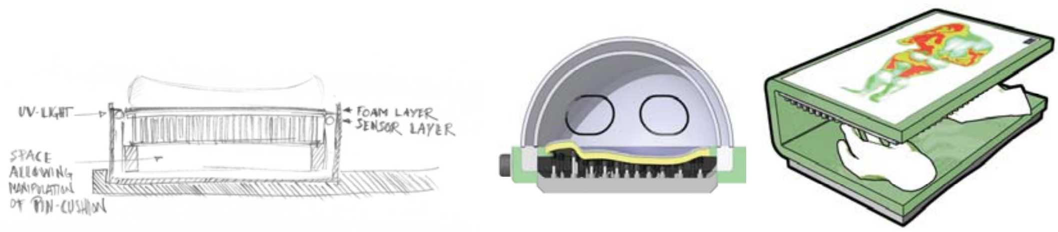


Fig. 2. Mattress Pins system and map of pressure sensors

On this basis, the mattress emerging by this approach can be described as follows: a mattress containing body pressure sensors that detect the weighted areas of the baby's body on the mattress surface. In order to avoid pressure sores and similar problems a fine grained modular system allows the medical staff to manipulate and change the position of the baby's body without opening the incubator, thus preserving the microenvironment conditions inside. This manipulation is allowed by a pin art type of system whose elements can be moved up and down directly or remotely.

Different user workshops have been devoted to evaluating the incubator prototype and its associated functionalities related to the mattress design. Through user workshops, the main outcomes achieved by the medical staff can be summarized as follows:

Manipulation of the baby through the mattress

The baby should be handled only for therapeutic purposes: medical personnel excluded any possibility of using remote or automatic manipulation for performing training activities or (just) simply for creating a contact between the child and the mother.

Medical personnel deemed it very useful to have a trace of the pressure points of the baby body on the mattress, in order to simultaneously monitor all the babies and anticipate pressure on high risk areas, or just to avoid pressure sores.

Physical Design

The mattress itself is still similar to the original model, i.e. a layer of hard plastic material, augmented with new functionalities (pressure point detection and automatic manipulation), but it's not able to contain the (baby) baby's body.

These design solutions have been also subjected to an expert evaluation; the 3D model of the early prototype have been assessed by professor Westrup, who is the founder of the NIDCAP approach to the care of premature newborns. NIDCAP is an acronym that stands for Newborn Individualized Developmental Care and Assessment Program (Westrup, 2005), which is an approach that uses a range of medical and nursing interventions that aim to decrease the stress of preterm neonates in NICUs (Symington & Pinelli, 2003). Westrup severely criticized this first prototype. In fact, in this design solution he couldn't recognize the manifestation of the environmental qualities that are fundamental to the care of the child. If the prototype was able to support the child's well being from a functional perspective (i.e., through the maintenance of the environmental conditions inside the dome, the filtering of light and sound and the facilitation of the medical staff intervention), from an interactive perspective, this prototype still embodies the traditional concept of the incubator space, which does not allow the kind of direct contact between the child and the care givers that is necessary to the early development of the child.

From this perspective, the first mattress prototype presents several limitations:

- it doesn't support the creation of an environment that fully embraces the child, and is able to sustain its body and to simulate the kind of stimulation the child was used to receiving in the mother uterus
- It doesn't provide a mediation layer to support the transition between the different NICU environments and interventions
- It doesn't support the co-existence of the various individuals' needs, both in terms of understanding the infant's conditions and for what concerns the perceptual qualities that control all of the interactions in this setting
- it doesn't dynamically manage the relationship between the macro and micro environmental levels.

These aspects, although seemingly easily recognisable as fundamental users requirements, in reality, remained latent in the design process to such an extent that they weren't transformed into design solutions. This perhaps happened because these features have a less functional use and can be treated in much the same way as the Branzi's Soft Properties or Alexander's Qualities Without a Name, which represent variables that are difficult to categorize but have demonstrated to play an important role in people's experience of space, of objects and, it can be suggested, of interaction

4. THE SOFT APPROACH

The integration of aesthetics into the design of ambient computing systems poses a number of methodological questions. From a participatory design perspective, the issue of aesthetics raises the question of how much the users are aware of their aesthetic experiences and consequently how the possible outcomes can be used in the design process. This happens for two different reasons. Traditionally, the aesthetic value of an object is seen as a superficial layer to be considered at the last moment of the design process and it is the designers who are usually entrusted with this work. It is also very difficult to perceive the aesthetic experiences in an objective way. A methodological perspective on the aesthetic properties of interaction should find a compromise between the need for the adoption of a sharable methodology and the necessity of preserving a design sensibility that is able to interpret the soft properties and make them available for the design. In this sense, it is important to clarify that the aesthetic evaluations provided in this work are not based on the stakeholders' quantitative measurements of arousal levels when in the NICU, rather, the patterns of interactions have been investigated and their impact explored. Thus, the primary challenge will be that of using the current techniques (e.g., focus, group, user workshop, bricolage workshop, future laboratories, data sessions, observation, cultural probes) utilized in Interaction Design research to investigate what properties of interaction play a role in this setting, and to question to what extent these current techniques are capable of addressing the novel aesthetics challenges.

4.1 The map of aesthetics experiences

With the aim of framing the problem, an initial user workshop was conducted with representatives of the staff members of the Neonatal Ward at Siena Hospital. This workshop was organized with the objective of creating an initial map of the aesthetic experiences at the NICU. Another fundamental consideration was that of distinguishing the interactions that could potentially have an aesthetic value. The workshop was thus conducted with a predominant focus on the aspects that characterize the relationships at NICU from which various aesthetic manifestations could emerge. Here it is important to underline that the meaning of aesthetics couldn't be limited to the notion of beauty of appearance, rather, in this work aesthetic value is intended as a continuous and dynamic phenomenon that is based on a process of interaction (Dewey, 1934). The user workshop involved three members of the medical staff: two neonatologists and one physiotherapist. They were asked to describe experiences related to the following topics: Conflicts, Participation, Surprise, Stimulating Experiences, Upsetting Experiences, Moving moments, Provocation and Reactions. The rationale was that of exploring the whole spectrum of emotions- from negative to positive experiences - that were felt in this environment, with the aim of understanding the key dynamics that affected their attitude toward their work as they occurred.

The data coming from this preliminary activity have been mapped in Figure 3.

This map represents an attempt to represent the various facets of the aesthetic experience in this setting by means of a description of the subjective values that are those working within the system associated with the experience. The user workshop also served to highlight the difficulty of using the users' attitude as a way of identifying the aesthetic properties of the interaction. Indeed, the users are not capable of externalizing this kind of information, since the aesthetic concerns prove to be too strictly linked to the emotional values engendered and the users are not aware of the information (i.e., the soft properties of interaction) that is so deeply intertwined with their everyday experience. However, it is still possible to illustrate the outcomes of the activity.

Figure 3: Map of the aesthetics experiences at the NICU
('Le Scotte' Hospital, Siena, Italy)

What initially emerges from these data is that the work in the NICU has a very strong impact on the emotional and psychological life of the subjects, affecting their motivations, their involvement, their level of satisfaction and their frustration. Furthermore, this aspect seems to be more related to the nature of the relationships existent between the various individuals present in the ward than to the stress that is caused by the management of such a complex system of functions related to the infants care. Throughout the different dimensions considered, a reoccurring topic is that of a frustration felt in the relationships with the other colleagues. This happens for many reasons, the most important is the lack of a common vision on the approach to the care of the child, which makes mutual collaboration and coordination very difficult. The primary basis for all of these relationships is the child and the space around her. Herein, the most meaningful events take place and the different attitudes toward the baby's care are manifested, among which two common approaches are: 1) the approach by which the baby is treated as an 'object' and little attention is provided to the emotional significance of the situation; and 2) the approach that conversely tries to respect the various necessities of the baby and of the families. This conflict results in a number of contradictory behaviours and creates many tensions among the staff members:

'I feel lonely amidst everybody', and 'I'm trying to find the motivation to go on'. Despite this, the contact between the mother and the baby, whenever it occurs, represents the main stimulation and the focal point of the aesthetic manifestation in this setting. This is the core of all the interactions, from which all the different courses of actions can be carried out. In other words, the physical relationship between the family and the child is the motivating factor behind the organization of various actions that are taken in the NICU environment. The data presented in the aesthetic map have been compared with the data coming from previous observations at NICU and with the interviews with families and medical personnel. The following diagram illustrates the spectrum of the interaction that takes place in the neonatal ward, as it was demonstrated by the comparison of the various data that had been gathered.

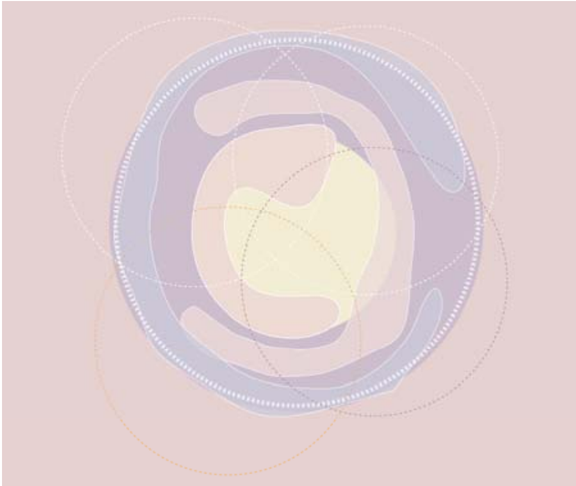


Figure 4: The micro, macro and interaction model at the Neonatal Ward

This diagram illustrates three levels of analysis: the micro environment, the macro environment and the interactions . Each defines an area of influence on the baby in which different types of phenomena are generated. The micro environment is represented by the yellow area, which is mainly occupied by the child, the macro environment is symbolized by the violet area, which frequently overlaps the microenvironment, and the coloured circles identify the (relationships that occur in both the micro and macro levels and among the various individuals present in the ward. Here, too, many overlapping situations can be observed. This diagram is based on the assumption that the interaction in ambient computing systems cannot be intended as the relationship between humans and devices, but rather the interaction that emerges from the environmental conditions in place. The dynamics illustrated by this diagram have been further elaborated upon in order to discern the way in which they can reveal what properties are relevant in this setting. The elicitation of the soft properties of interaction represents a fundamental step in this approach. They will then be used to update the requirements for the design.

4.2 The soft properties of interaction at NICU

In order to better illustrate the soft qualities in this work two different strategies have been adopted: 1) the comparison between various settings with the aim of finding reoccurrences and dissimilarities that can be intended as an inspirational activity, and 2) what can be called 'aesthetical isolation', an analytical process by which the soft properties of interaction of this setting are isolated from the functional aspects. In this work this process has been carried out with the help of the architect and designer Andrea Branzi. However, what does it mean to utilize aesthetics as an analytical tool? In section 4.1 it has been recognised that the users are usually not aware of the soft properties of interaction or the way in which they converge into their practice of work and effect the life of such a delicate setting. Yet, it is necessary to distinguish these properties in order to inform the design process, as the hypothesis of this work is that latent requirements of this setting could be manifested through these properties.

With this objective in mind a parallel analytical process is proposed in this work, according to which the aesthetics are isolated and investigated separately from the complex set of variables that intervene in this setting. Once again, aesthetics will be considered as properties that occur in throughout the process of interaction. The whole spectrum of phenomena - ranging from the more pleasant to the more disharmonic - will also be considered.

The outcomes of this analysis will be presented as interaction pattern emerging at the NICU; for this reason, the form proposed by Alexander to describe what he called ‘design pattern’ will be adopted. According to Alexander (1977), a single pattern should be described in three parts:

1. "context" - under what conditions will this solution address this problem?
2. "system of forces" - in many ways it is natural to think of this as the "problem" or "goal"
3. "solution" - a configuration that brings the forces into balance or solves the problems presented

When observing which qualities would effect the interaction, without considering the purely functional aspects, an understanding/awareness emerges of the alternation that takes place between patterned behaviours and random occurrences. This kind of alternation is clearly recognizable in the NICU setting, as it is in other situations dealing with routinely performed activities. The work of the medical staff develops along patterns of standardized operation with the intention of nursing the babies. These operations require the precise positioning of the staff members, and the precise placement of the various tools and devices. The recurrence of these patterns is especially strong throughout the diagnostic process, during which the importance of the different equipment should be compared with other significant parameters. Unanticipated situations and sudden changes in the condition of the baby can alter an established path of interaction and can transform the configuration of the micro and macro environments. The presence of the parents evolves in a similar way; for instance, the mother’s presence is profoundly codified in precise patterns, which enable her relationship with the baby. The distance from the incubator, the possibility of entering the internal space, the alternative consideration of the different displays and of the medical staff with the hope of understanding any additional information about the child, are all examples of patterns that were regularly observed in the behaviour of the mothers. This alternation between pattern and random behaviours has a value in and of itself, in that it renders this setting highly manageable across layered contexts of actions, which is a necessary condition in an Intensive Care Unit. On the other hand, the interruption and dominance of random effects over patterned routines creates new layers of action for the figures involved in the care of the child by enabling new understandings of the situation, changing the roles of those involved and supporting new sensibilities in the care of the baby.

4.1.1 Micro-environment: interferences, overlapping, separation and interpenetration

Context: The quality of light, the noise level, the temperature and the air quality in the incubator play a functional role in the creation of an environment that is suitable to the baby needs. Current technologies at the NICU allow for the adaptation of these micro-environmental parameters according to the varying statuses of the babies. However, as a result of the analysis of this setting - in particular from a consideration of the way in which various individuals involved in the care of the baby interact within this space - an understanding emerges of how the micro-environmental conditions of the NICU effect other, more complex dynamics, which go beyond the functional benefits that are provided by a stable environment. The qualities of light, the level of noise, even the temperature of a room effect the way in which the space and the baby's condition are perceived.

System of forces: The qualities of light, the level of noise, and the temperature intervene in three stages at the level of the incubator: the baby; the medical personnel and the families. Currently the quality of light, the noise level and the temperature immaterially defines the different layers of interaction: the limits of the operational space of the medical staff and the limits of the emotional space of the families.

Solution: The interferences are generated by the co-presence of such different and complex environmental stimuli. The manifestations of the interference phenomena that occurs at the micro-environmental level can be simplified by the creation of overlapping, and separations/interpenetration.

Overlapping occurs each time light, sound and temperature conditions of the incubator are filtered, in order to sustain the baby, which is the predominant strategy that is used to protect the baby from the outside environment. Examples include the use of sheets that cover the transparent glass of the incubator to filter the light inside or the blanket that embrace the baby that is used to maintain the body temperature.

Separation: is another outcome that arises from the necessity of preserving the micro-environment of the baby (e.g. the baby is separated by the incubator glass; the micro environment of the baby is separated by the macro environment of the ward). Separation is the rule of interaction that is enabled by the environment. It is interesting to note the way in which the interpenetration between the external and the internal environment of the incubator is the interactional countermeasure of the separation in this setting. It is also interesting the fact that the design for separation can actually be surpassed by the interpenetration between the mother and the child; this factor generates the strongest aesthetic phenomena in this setting.

These dynamics illustrate the way in which the fragility of this setting manifests itself, by engendering different and contradictory opportunities for the interactions creating (or not) the necessary intimate space for the child care. These dynamics also represent solutions that are emerging through usage, which define the space for interaction with the incubator; they are deeply intertwined with the functional aspects but can generate independent phenomena which would effect the micro- environment of the incubator, even in the case that it was deprived of functional implications. In fact, if the engine of the incubator were to hypothetically stop working, the capability of maintaining and preserving the specific qualities of the micro-environmental would also effect the likelihood that the baby would survive.

4.1.2 Macro-environment: layering, foreground/background effects

Context: This setting is characterized by the presence of various individuals who collaborate to make diagnoses and to manage the intervention on the baby. The machineries that constitute the setting - which are multiplexed for the different incubators (at Siena's NICU there can be up to six incubators) - generate a complex configuration of variables that, due to the delicate condition of each baby, must be continuously monitored. This creates a contradictory situation: on the one hand there is the need for specific interventions on each newborn whose conditions are unique and require unique treatments, on the other hand, the co-existence of different incubator configurations requires a sort of standardization in the procedures that are performed, as this is the only way to sustain the overload of information that must be processed in each moment.

System of forces: This is a setting in which the data are highly distributed and a continuous integration is needed in order to obtain an appropriate understanding of the situation. Each member of the medical staff (the neonatologists, the nurses and the therapists) builds their own mental framework based on the instruments used in the daily work practice and their behaviour. Their respective mental frameworks are in turn supported by both the instruments' design and the aesthetics of use.

Solution: The NICU setting enables different levels of visibility of the status of the babies and of the different equipment, depending on the competence of the diverse individuals involved, the emotional attitude supported in the interaction, and on the physical and behavioural design of the system. *Background - foreground* effects are engendered. What remains in the background and what dominates the scene represent a dynamic process that changes as the condition of each baby changes . A dynamic and complex setting such as the NICU enables a similar kind of phenomena in which different layers of perception can be activated, thus altering the role and the relationship between the elements involved. This effect concerns the immaterial conditions of the environment previously discussed; light, sound and temperature determine the aesthetic effects that are engendered by shaping the perception of the events taking place in the space. The Figure-ground effect is recurrent in our continuous, everyday experience, but the nature of this setting leads to a particular realization of this effect. Indeed the foregrounds and backgrounds are many and simultaneous; they depend on the role of the individuals involved and effect the understanding of the baby conditions. This fact implies that they play a role in the diagnostic process but also in the way the parents can relate to the child. The status of the child, the visual displays, the visual feedback, and the noise in the ward create a space of redundancy, in which priority is given to the way information can emerge from the background and be perceived by the various personnel, both professional and non professional. Each incubator system, intended as the combination of incubator and medical equipment, would enable diverse foregrounds and backgrounds that would be differently perceived by the personnel. This process is embodied in every exchange, but it acquires a particular importance when it occurs in an emerging situation, in which everything should be orchestrated in order to optimize the efficacy of the intervention taking place on the children. The simultaneous coexistence of these different layers reflects on the various levels of interaction present in the ward and the possible courses of actions available in the care of the child. Indeed, this type of layering represents a key quality of design.

4.1.3 Relationship: the access, separation and interpenetration

Context: The neonatal ward is perceived as a separated world that is difficult to enter. Separation occurs at different levels: between the incubator and the external environment, between the mother and the child and between the different figures (neonatologists, nurses, therapists and parents) who act individually in the care process.

System of forces: The system does not purposely support communication or collaboration and hence does not cultivate the relationships between the different individuals taking part in the care of the baby. The need for sharing with the 'external world' the situation inside can also generate emergent (mis)behaviour, such as taking pictures of the baby with a mobile phone.

Solution: It is possible to discern a sort of continuum in the passage from the idea of separation to that of interpenetration among different layers of the environment (micro and macro) and among the presence of the various individuals in the ward primarily between the mother and the child. The system supports the movement from one extreme to the other by managing the possibility of accessing the micro/macro-environment. The different environmental solutions define the equilibrium points at which a unique balance between separation and interpenetration is determined.

The separation is a necessary measure that is often taken to protect the baby and to safeguard the work of the medical staff, in such a way that the level of stress and the interference phenomena are controlled.

The interpenetration is possible because of the nature of the access that is enabled by the design of the spaces and by the tools that are available. Currently this access is hindered by many problems that are mainly related to the maintenance of the micro-environmental conditions (i.e.: temperature, light, noise and quality of air). This is the primary reason for which the interpenetration of the micro environment is an infrequent and brief occurrence.

The nature of the access may profoundly effect the subsequent interaction with this environment. The Incubator in its current conception presents numerous barriers for both the medical staff and parents, who cannot easily enter the baby's micro-environment without completely removing the glass that covers the device. This aspect of the design of the incubator not only prevents physical contact between the parents and the newborns, but also influences the way in which the incubator can be reconfigured, according to the occurrence of emergency situations or for routine procedures. Points of prospect are quite rare at the NICU. Non professionals feel disoriented at both the macro-environment level and at the micro-environmental level. As discussed, the incubator and the different medical equipment used in the care of the baby do not permit an easy comprehension of what it is going on for the parents, and the ward personnel, too, can get disoriented by the amount of data and information that must be continually processed, which can result in errors and contradictory behaviours. Therefore, the access design directly shapes the way in which relationships are enabled among the various personnel in the ward and what the possibilities are for the interaction with the baby in its micro-environment. More importantly, the access design demonstrates how the different interaction units (mother-child; child-nurse; child-nurse-neonatologist; child therapists; mothers-child-therapist; mother-child-nurse; mother child neonatologist) emerge and can be created around the incubator space.

Indeed, the occurrence of these interaction units are grounded on the diversity of the needs and expectations of the different individuals, and are enabled by the nature of the environment and by the behavioural possibilities of the system.

4.3 The soft set of requirements

As discussed 3.2.1, the first prototyping phase that lead to the first mattress proposal wasn't able to interpret some of the necessities of this work setting. Indeed, while it solved most of the related functional aspects, the first mattress design wasn't able to fully consider the fragility that is an inherent quality of the Neonatal Ward. The prototype especially failed in creating an embracing layer which envelops the baby from the delivery room to the Intensive Care Unit, and also provides data and information on the baby's condition and in defining a real transitional space for the child, adequately considering the users' different needs and different levels of understanding by supporting different and simultaneous visibilities. Thus, in light of the soft properties of interaction elicited for the NICU setting, a soft set of requirements is herein proposed, which aim at complementing the list of functional requirements that guided the design of the first incubator prototype and with the objective of making more sharable within the design process the latent qualities of this setting that, while they are implicit inside the functional aspects, can play a fundamental role in the introduction of ambient technologies.

Filtering: different level of opacity

Description: opacity shall become a design quality of this environment that acts in two different ways: firstly by creating a light insulation for the child and also by supporting a smoother and softer view of the child for the families.

Soft Quality: interferences; background /foreground effects.

Postural stabilization/embracement

Description: the incubator environment shall be considered as a delicate layer which embraces the child, sustains the baby's body and preserves the environmental conditions.

Soft Quality: overlapping; access

Rigid structure/foldable material

Description: the incubator environment shall balance a rigid structure that creates a safe environment during the interventions with a soft and foldable material that can be easily transported and configured.

Soft Quality: separation/interpenetration

Layering

Description: the incubator environment shall manage different layers of interactions. The multilayered property of this environment shall allow the end user configurability and simultaneous courses of action.

Soft Quality: layering; access.

Open/closed environment

Description: the incubator environment shall be able to be freely opened or closed to allow direct contact or protection according to the different needs and situations.

Soft Quality: background /foreground effects; separation/interpenetration; access.

Perceivable output

Description: the incubator environment shall make even small traces of the child's life visible. These will represent an indication of the child's well being for the medical personnel, but will also be a sign that is understandable for the parents.

Soft Quality: background /foreground effects

Granularity

Description: the introduction of technology shall be visible at different levels, thus generating an aggregated view of diverse data as well as an in depth view of particular value, with the primary objective of supporting inspection, revealing functional connections and integrating information.

Soft Quality: background /foreground effects; interferences.

4.4 A representational concern

The treatment of the soft set of requirements within the design process described here, requires a further discussion related to the representational aspects of the requirements. If one would compare for a second time the first list of design requirements with the soft requirements proposed in this analysis, this person could argue that in reality these two lists mainly present a different level of accuracy in addressing specific aspects of the setting. This is of course correct since the soft set of requirements are subsequent the first iterative design cycle, thus implying a more consolidated view on the area of intervention. On the other hand, the soft set of requirements, (i.e. Filtering: different level of opacity, Postural stabilization/embracement, Rigid structure/foldable material, Layering, Open/closed environment, Visual output, Granularity) offer a complementary view on the design, mainly focusing on the soft aspects, already embodied in the current practice, and which represent successful strategies of interaction emerged isolating the aesthetic aspects from the others. In this sense, the objective of this soft set of requirements is also to transform these aspects into solutions to be interpreted by the design of ambient computing systems.

Here comes the importance of the representations in the design process. In fact, these profoundly effect the way the knowledge - extracted from fieldwork activities, technology state of the art and concepts generation- is transformed and made available in a shared way to the different design team’s members. In many cases of interdisciplinary design team, the way in which requirements become solutions is a complex process, in which information passes across different interpretations, such that the embodiment of the requirements into the system design can leave a part important aspects or contribute to the process by which some features remain latent. This of course depends on the diverse sensibilities of the designers who mutually can concentrate on some aspects rather than others.

An effective countermeasure to this potential loss of information is provided by the way the requirements are illustrated and represented. This is based on a very strong practice especially in the area of Interaction Design more influenced by the aesthetic tradition and where the concepts generation play a central role. Accordingly to this stance, this methodological proposal decided to make explicit the soft set of requirements by the use of graphical representations that primarily aimed at guaranteeing the correct transformation of information along the design process. In fact, these proposals in different way embody the soft but also the functional requirements. Furthermore, they are used to elaborate and prototype the design solutions for the incubator micro environment with the focus on the baby mattress.

As shown in Table II, each graphic proposal has been mapped onto the soft requirements, the functional requirements and presents its own design qualities that further enrich the design research. This clearly demonstrate the relation occurring among functional and soft requirements, where the former express feature grounded on particular problems or existing practice, and the latter primarily express what has been called soft properties of interaction. Based on an internal assessment, the leaf proposal was chosen to interpret the mattress requirements, integrating also key features present in the other proposals.

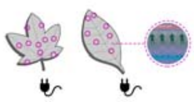
Table II. Design proposals for the mattress: the functional requirements, the soft requirements and the design qualities

Proposal	Functional Requirements	Soft Requirements	Design qualities
The Leaf 	Soft Mattress Fixed body position / Prevent big body movements Flexible body movement / Allow small body movements Interaction modalities	Granularity Rigid structure/foldable material Embracement Open/closed environment Filtering Visual output	Nature as a metaphor Physical configuration Autonomous unit
The Lily Flower 	Petals Soft Mattress Fixed body position / Prevent big body movements Flexible body movement / Allow small body movements Interaction modalities	Layering Granularity Rigid structure/foldable material Open/closed environment Filtering Visual output	Nature as a metaphor Physical configuration Autonomous unit
The Baby Bag 	Fixed body position / Prevent big body movements Flexible body movement / Allow small body movements	Rigid structure/foldable material Visual output Open/closed environment Filtering	Everyday object Minimal Autonomous unit Portable

Table III: the leaf proposal

The inner surface of the leaf

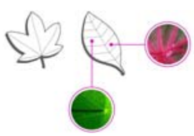
This side of the leaf is the one on which the bay lies. A number of pressure sensors are placed in a pattern inside the mattress which detect and communicate the pressure on each unique point on the mattress surface. Depending on the data detected by the sensors, the mattress can be reconfigured to prevent postural problems and pressure sores.



The outer surface of the leaf

This side of the leaf visualizes for the different actors the pressure points of the baby. Indeed small leds correspond to the different pressure sensors and indicate their position and the intensity of the pressure on each point, i.e. by changing led intensity.

The values of the baby pressure points are also available on a remote display.



The incubator and the leaf

The dome of the incubator works as a docking station for the mattress. The mattress can be positioned in the docking station when a specific intervention requires more stabilization. When placed in the dome, the leaf can receive a micro-stimulation for favouring child sleep.

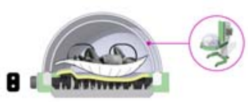
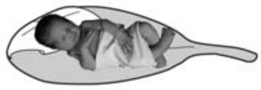


Table IV: leaf proposals scenarios of use

Mattress early configuration	Day-by Day Care	Transportable Environment
  The mattress can be configured in shapes and functions according to the infant necessities (i.e. monitoring of specific parameters and dedicated postural stabilization). The peculiar reconfigurable properties of the mattress are obtained by the specific use of sensors and smart material.	 The mattress environment can support postural stabilization of the baby while monitoring precise parameters, i.e. pressure of the body on the mattress surface and temperature of the environment. The mattress can be combined with the other services and devices in the palpable incubator system. 	  By using the foldable properties of the material the mattress can become a layer embracing the child and preserving the environmental conditions and mediating the relation with the external world.

4.4.1 Toward a soft prototype

The dialogue between the soft and functional set of requirements motivated a second mattress physical prototype to explore the role of the soft properties in use. Accordingly, the second mattress mock up has the specific objective of embodying the soft requirements into initial design solution, especially investigating to which extent the physical properties of the mock up augmented by the use of technologies could sustain the soft requirements. The mattress soft prototype has been developed to purposely assess with the medical personnel:

- the most suitable shape of the mattress
- the thickness of the structure
- the softness of the material
- the flexibility of the material
- the modalities of configuration
- the placement of sensors
- the perceptual output of sensors

The mattress soft prototype has been designed as a system of different modules to be assembled and configured depending on the baby needs and on the typology of interventions. The measures are expressed in centimetres and are elaborated on the assumption that a premature infant is around 35 cm high. Based on these drawings the mock-up was developed so that the medical personnel could configure – in a ‘bricolage’ approach - the different possible modules of the mattress. The aim was that of assessing the soft properties by understanding the sensations of physical manipulation and direct contact. Indeed the workshop was performed simulating the presence of a preterm born child, by using a baby doll. In this mock up, each module is provided with a Velcro stripe to be easily attached or removed. The different shapes of the mock –up have been designed to allow as much configurability as possible when interacting with this artefact. One of the main aspect was related to the design of the side modules. In fact, we presented different solutions in terms of size and shape. We also showed the possibility to split the lateral module into two parts, in order to allow a more flexible usage of the configurations. The base of the mock-up is more stable than the side module. In fact two layers of foam rubber (thickness 10 mm each) stuck together were used. Between these two layers a matrix structure, - using copper threads-, has been placed to give the metamorphic properties to the material. This aspect played a key role for establishing the modality of interaction in the use of the mattress. The side modules were constructed using two layers of foam rubber (thickness 10 mm + thickness 5 mm). This makes the side modules softer than the base. Also the inner part of the modules was made as a matrix with copper threads. The accurate balance of different levels of thickness and softness was a fundamental factor in this prototype. In fact, in this way it was possible not only to evaluate precise requirements for the next prototyping phase, but also to enable new modalities of interaction, before not possible.

The details of these outcomes are expressed in the table below, where the different configurations and possible interactions are illustrated, in relation also to the way in which to present the information available by the mattress sensorization.

Table V: exploration of the configuration by using the properties of the physical mock-up

 Support for the head	 Postural Stabilization	 Lateral postural Stabilization
 Positioning the body for intubation	 Re-configuration of lateral module for intervening in specific area of the baby body	 Use of the external blanket for embracing the child
 Mattress as a transportable environment	 Visual output: placement of sensor	 Use of the visual information for positioning the child

The specific characteristics of this second prototype goes toward the ideal of embodying the soft requirements into intermediate solutions to be tested and evaluated with the users. In this prototype three elements play a critical role, the softness of the material, the thickness and the metamorphic possibilities. These indeed supported the way the medical staff could experiment the filtering properties of the mattress, the possibility to embrace the child, and the possibility to configure the space. Furthermore, the way the ‘foldable’ requirement has been supported demonstrate to sustain the ways the parents, for instance can in different ways open the child micro environment, passing from the mediated contact to the direct contact. Another important aspect is related to the use of sensors in this prototype. In fact, the presence of the sensors on the mattress base is made visible to the different individual acting in this setting. This provides interaction cues for both the medical personnel and the parents. Medical staff can indeed have an indication on the functioning of the sensors and on their correct placement in respect to the baby postural regulation. The parents can use the visualization of the sensors as a trace of the baby life, and can learn on the baby conditions by making sense of this information.

In this way, it emerges as the status of the soft properties create a link between what is functional and what can be called aesthetics and this is explained by the soft prototype presented in this research. Indeed the Mattress Soft Prototype embodies part of the soft requirements to explore the novel ways in which computation can manifest itself, although in a simulation, i.e. softness and thickness of the material, metamorphic qualities of the structure, the set of modules to play with, in order to pretend different care situations.

The further development of this early soft prototype into the final prototype will better exemplify the role of the soft properties of interaction. In this sense, the work presented herein, represent an intermediate result along the design development of the mattress prototype for a premature baby. In order to interpret the outcomes of these activities into the final prototype, the peculiar properties of the mattress will be obtained by the specific use of sensors and smart material. A special material has been selected as the potential candidate for the implementation of the prototype. This material is called Technogel® and presents the following characteristics:

- when pressed by the body, technogel moulds itself to each individual shape by deforming along the three axes (up-down, right-left, frontward, backward).
- It is free from plastizing agents and other volatile agents
- It keeps its elastic mechanical properties for a considerable time
- Its polyurethane base is completely non toxic
- It can be injected like foam inside moulds with large degrees of freedom
- It does not expand and remains compact
- Long life and stability without plastic deformation
- Maximum pressure distribution capacity and excellent weight distribution
- Great ability to absorb shocks and vibration

The gel structure of the mattress shall be augmented with the use of sensors. In the envisioned system a matrix of pressure sensors will be placed in a pattern inside the mattress which detect and communicate what is the pressure on each unique point on the mattress surface. Depending on the data detected by the sensors, the mattress shall be reconfigured to prevent postural problems and pressure sores. The mattress shall be also equipped with sensors to detect the mattress temperature. This information shall be combined with the value of the temperature sensor detected on the baby body in order to dynamically adapt the micro-climate of the baby.

5. INSPECTION AND USE OF SMART MATERIALS

To this point, it has been presented a methodological approach towards the design of ambient computing system. This approach stemmed out from the growing complexity offered by interaction when computation is distributed in the environment and embodied in all sort of objects. The perspective of Aesthetics of Interaction is considered as a means to facilitate the way computation manifests, overcoming some of the traditional problems of ubiquitous, ambient and pervasive computing, i.e. computation becomes invisible with the consequent loss of control on the side of the user. The soft properties, the soft requirements and the proposal of a soft prototype are presented as operative tools in order to actualize the notion of the Aesthetics of Interaction in the design practice. Indeed, the work presented here has two different objectives; one is methodological and will be further discussed in the next section. The other is orientated to design and aims at exploring the role of the soft properties as they can be expressed into design solutions for ambient computing systems. The perspective offered herein individuates the use of smart material augmented with sensors as an fascinating possibility in order to embody the computational possibilities in the physical design of the systems, and by supporting, at the same time, a more nuanced way of interaction. The use of smart material is spreading in many application domains, from bio-engineering to architecture and chemistry. By definition smart materials are materials that have one or more properties that can be significantly altered in a controlled way, by very different external stimuli, such as stress, temperature, moisture, pH, electric or magnetic fields, pressure. From the interaction perspective, the smart materials open a wide range of new interaction possibilities especially when augmented with the use of sensors and actuators which determine new behavioural possibility, by exploring the basic elements in which computation can be manifested, i.e. through its materiality, by manipulating the typology of input and output. Indeed, what can happen when the materials which give form to our objects and environments become the real enablers of the interaction? These new possibilities have been only started to be explored. In this sense this work wants mainly to raise questions rather than provide answers.

Of course, a very challenging aspect related to these themes is how by use of smart material the system inspectability can be manifested. The use of material as the concrete means in which computation can be expressed can define new levels of visibility and can support the creation of soft values in the interaction. These might be interpreted as an aesthetic attention in the design; on the other hand they can open new way in which is it possible to inspect at a functional level the status of the system. An example of such application is the case presented in this work. The mattress prototype is envisioned as a system in which the specific use of smart material augmented by sensors is the actual means to manage different interaction in the NICU setting. In fact, it provides a novel modality for the baby monitoring not supported in the current equipment (i.e. the detection of the pressure point); it preserves the microenvironment conditions and allow to dynamically manage the passing through the different environment of the NICU space and to adapt to the different necessities related to the interventions (i.e., the possibility to fold the material, to close the baby micro-environment, and to open the structure, the possibility to maintain and filter the micro-environmental conditions inside - light, noise, and temperature). Furthermore, the placement of sensors is made visible to the different individuals. This level of enabled visibility can be interpreted as a meaningful clue of interaction for the families, since it can 'reveal' a little part of the life of the child; but also represents an inspection mechanism for the medical staff, by showing the functioning of the sensors and the status of the connections among them. In this sense, the possibility to manipulate the inputs and the outputs by the use of smart material can create new modalities of making sense of the cause and effect relationships in interaction with ambient computing system, in this way addressing some of the challenges of the computation expressiveness: manage simultaneous and different levels of visibilities; and make sense of heterogeneous information in dynamic contexts.

6. DISCUSSIONS: ON THE METHODOLOGICAL APPROACH

Design methodology, as Landin clearly suggests (2005), is one way to elaborate knowledge about expressional properties of computational technologies. This can be achieved in two ways: by following an approach by design (Landin, 2005, Djajadiningrat, Gaver and Frens, 2000) that explores the aesthetic of the intended use (Hällnas, 2004) into design solutions; and by an aesthetical analysis of actual use, that poses the delicate issue of transforming an analytical knowledge into a design knowledge (Landin, 2005)

The soft approach presented herein, is an attempt to combine an analytical and a design perspective to integrate Aesthetics of Interaction in the design of Ambient Computing System. This is achieved by questioning the current methods of interaction design research and when necessary updating them to better respond to the new design demands. Furthermore, the soft approach does not represent any consolidated framework, rather it represents an early reflection on the existing design practice and want to raise the question of how can the design process be aware of the soft properties of interaction and starting a discussion on the way in which and whether it is possible to design for them.

The assumption of the proposed work is that when designing for ambient computing applications the typology of requirements to be considered should extend to what in traditional architecture has been called soft qualities (Branzi, 1986) or Qualities Without a Name (Alexander, 1979, 1977). The author's conviction is that the role of these aspects is preponderant in the design of ambient computing system, where the interaction does not take place only in the 'one to one' relation between the human and the device, but is distributed in the setting - and across the settings -, pervade everyday objects, enable new relationships, thus coming out from the environmental and relational conditions enabled.

Of course aesthetics is not able to address all the variables involved in the design of such complex socio-technical system for this reason it is used as a instrument to complement the design approach in order to better capture more impalpable aspects of interaction. In effect, the consideration of these soft variable of interaction can revise the process both in analytical and in design terms,

- by making explicit some latent aspects of interaction that as well are fundamental to explain the complex dynamics of this setting by externalizing the knowledge gained along the design process
- by the use of prototypes and different representations to share and evaluate the properties, the requirements and the design solutions.

These aspects could lead to concrete advantages. One is external to the design process. In fact, making explicit the latent variables can anticipate problems occurring in the interaction with the designed system and can help the construction of acceptance when introducing new technological equipment in delicate setting as the one considered, i.e. the NICU.

The other advantage is internal to the design process. The work reported in this research mainly demonstrates as the modality in which information passes from one phase to the other of the design process is in reality a critical variable. Because loss of information can occur between diverse phases, and because the modality of presentation can create misunderstandings in the design object. The systematic use of different typologies of representation (i.e. the interaction patterns form, the requirements representations, the soft prototype) sustained the design process in order to identify, share and evaluate the role of the soft qualities as they were progressively shaped into design solutions.

As a final remark, the design methodologies are evolutionary object which constantly change to adapt to the emerging needs of design human-technology interaction. The users needs - especially in context with a strong functional value and a significant psychological involvement- are a complex of expectations, previous usage experiences, emotional variables that shall be interpreted into the system design. It is, indeed, fundamental capturing the varieties of these usages, expectations and experiences that are established between the individuals and along their interactions with the tools and the environment; and it is important to create dialogue between these elements and the way they can be interpreted into design. The proposal of the soft approach to complement the design process is an attempt to capturing more delicate and sensitive variables emerging in interaction when designing for ambient computing systems.

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9.6 Designing for Palpability

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Status: Draft

Designing for palpability

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ABSTRACT

Starting out with a concrete example of some of the problems people encounter in realizing the potential of pervasive computing, I present a detail from ethnographic observations in a neonatal intensive care unit to explore important causes for these difficulties. Inspired by, but also critical of, notions of interactive and accountable computing, I propose to use studies of human-matter 'intra-action' to inform design for palpability.

Author Keywords

Pervasive computing, accountability, palpability.

INTRODUCTION

Pervasive computing could offer attractive, in some cases critical, support in a range of settings. The work of emergency response personnel is one such setting **Error! Reference source not found.**, and one important issue that could benefit from pervasive computing support is illustrated by emergency medical personnel thus:

> *after an accident with many people injured, we try to attend to those most in need of treatment while monitoring the status of others. Noise, darkness, rain and smoke limit what we can see and hear, and many victims are covered with blankets. This makes it difficult to notice changes in patients' condition, when failure to notice critical changes could be fatal.*

These difficulties were described during discussions between researchers and emergency professionals embarking on a joint project to explore the architectural requirements for 'palpable' pervasive computing in emergency response (PalCom: A new perspective on ambient computing http://www.ist-palcom.org, **Error! Reference source not found.**). When asked – somewhat naively – why they do not use biosensors and alarms to assist in the monitoring of victims, the professionals pointed out that biosensors and displays might improve visibility and audibility of vital signs from a distance, but they would require additional time and work to set up. Moreover, wired displays and power sources would impede the transport of victims, and alarms would add to the chaos of the situation, overwhelming staff. While there is a possibility that biosensors and alarms might alleviate the risks of missing significant changes in patient conditions, there are too many disadvantages to even try.

The researchers described how wireless biosensors and wearable displays could be used to direct alarms more effectively. This would be compatible with the mobility of patients, equipment and staff and would allow the professionals to selectively tailor and expand their range of attention. However, subsequent discussion revealed more deep-rooted difficulties. First, although alarms seem to demand urgent action, they can often be ignored safely. Ignoring alarms is skillful work **Error! Reference source not found.** and it depends on knowing the relevance of thresholds built into the alarm system to the specific situation. For emergency trauma injuries few of the standard thresholds are useful. Even if they could be adjusted, it would be difficult for the medics to judge the relevance of one alarm, its frequency and timing in relation to other alarms and a specific patient's condition in a noisy emergency situation Second, responding to, or skillfully ignoring, alarms are accountable and collaborative rather than individual, private responsibilities **Error! Reference source not found.**. People make inferences about the meaning of action or inaction in response to alarms. While this can be negotiated in hospital settings, where patients, doctors, nurses, and visitors have opportunity to talk and learn, in an emergency situation selectively attended alarms could increase the trauma for victims. Third, wireless connectivity makes the connections between people's injured bodies, the sensors and the displays where sensor readings are shown invisible. For medical personnel it then becomes difficult to engage in localization, orientation and recognition of significant sensor alarms **Error! Reference source not found.**. If an alarm sounded, showing critical readings on a medic's wearable display, how would s/he find the victim in question? How could s/he be sure that erratic readings are due to changed patient condition and not a failure of power or network? Even worse – how could s/he avoid the risk of false positives – where good signals are received when the victim's actual condition is deteriorating? Personnel argue that they cannot accept these uncertainties and that although problematic, their current practice of monitoring embodied symptoms through physical examination is best.

This example highlights a key cause for the difficulty of realizing the potential of pervasive technologies: The complexity and invisibility of their processes, states, resources and connections make it difficult for people to monitor, notice, and inspect what is going on and understand it **Error! Reference source not found.**. Breakdown is usually seen as the result of malfunction or failure. However, breakdown is also a constructive, in fact, crucial activity in using technologies confidently and creatively. Drawing on phenomenological philosophy, Winograd and Flores describe breakdown as 'the interrupted moment of our habitual, standard, comfortable 'being-in-the-world' (**Error! Reference source not found.** p. 77). Flows of activities in which equipment is taken for granted or 'ready-to-hand' can be interrupted by malfunction, but also by a change of perspective. People become interested in the components, states, processes, affordances of, and connections between, materials, technologies or environments and make them 'present at hand' or 'palpable' when they experiment, analyze or explore other uses. The word 'palpable', in its sense of 'plainly observable', 'noticeable, manifest, clear' (http://dictionary.oed.com) captures key aspects of what happens during breakdown. Moreover, as I will show, how materials support people in making aspects of their current as well as likely or potential future behaviour palpable is also vital for confident, creative use and the ready-to-hand-ness of flow.

Balancing complexity and invisibility with 'break-down-ability' or support for making computing palpable poses great challenges for designers. Everyday users come to these technologies with different computer 'literacies', a variety of purposes, and in diverse physical and social situations. In addition, component based, mobile, pervasive computing allows people to use geographically distributed, embedded and autonomic devices and services, sustained by invisible, 'grid'-like infrastructures of connectivity, location information, or data services. Not all services are benign and there is a risk of – again often invisible – breaches of security and privacy.

RELATED WORK

The response within the pervasive computing design community has two main strands.

First, one can seek to design systems that anticipate or sense people's needs and eliminate as far as possible the possibility of failure. This should make pervasive computing effective, sturdy and efficient. Approaches include autonomy **Error! Reference source not found.**, context-awareness **Error! Reference source not found.**, self-healing **Error! Reference source not found.**, information appliances **Error! Reference source not found.**. All share the motivation of protecting people from complexity and countless choices whose consequences only few would be able to fathom. Furthermore, designers may aim to make interaction intuitive, e.g. through tangible interfaces **Error! Reference source not found.**. These strategies are attractive. However, they underestimate the challenges and opportunities complexity and invisibility pose.

The second strategy seeks to identify and address these challenges and opportunities. Belotti et al. **Error! Reference source not found.**, for example, insightfully highlight the challenges of 'making sense of sensors' in the absence of GUI-supported interaction tools. Drawing inspiration from the analysis of interaction between people, they focus on problems of addressing embedded systems, of understanding and taking action, coordinating mutual attention and alignment, noticing and addressing accidents. They seek to inform design by sensitizing designers to the challenges of human-computer interaction in environments saturated with interoperating and interdependent devices and services that sense human action. In a similar vein, but drawing on Weiser's work for concrete design inspiration, Chalmers **Error! Reference source not found.** addresses these issues through 'seamful design', revealing system 'sutures' (for example, between areas where location information is or is not available). Dourish, who calls for 'accountable' computing, pioneering the use of reflection to support human-computer interaction **Error! Reference source not found.** is working with a group of researchers to explore, for example, how people might be supported in understanding security **Error! Reference source not found.** and privacy **Error! Reference source not found.** in pervasive computing environments. Anderson et al. **Error! Reference source not found.** explore the need to make autonomic computing accountable. They articulate how autonomy undermines the little 'natural' accountability that systems have (by way of deterministic behaviours), and show how difficult it is to build useful accounting procedures into autonomic computing. Most notably they argue that appropriate or 'recipient designed' accounts are required to answer everyday users' key question of 'why that now?' in ways that are relevant and understandable in specific use situations. Anderson et al. show that contemporary advances – e.g. agent based reasoning or context information – deliver only paltry progress towards enabling appropriate, recipient designed accounts in computational systems. They recommend in-depth participatory engagement with prospective end users to allow designers to better prepare satisficingly appropriate accounts.

My work builds on this research. As a member of an interdisciplinary team I carry out studies of everyday practice to inform the design of an open architecture that supports people in making computing palpable **Error! Reference source not found.**. Like many in this field of research, my colleagues and I come to it through ethnographically informed participatory design projects, in our case with, amongst others, healthcare and emergency response personnel, who express a strong desire for pervasive computing. However, for reasons I elaborate in Parts 3 and 4, we shy away from notions of human-computer ‘interaction’ and ‘accountable’ computing. Instead, we focus on human and material agency and ‘matereal’ methods of ‘intra-action’ **Error! Reference source not found.** – deliberately mis-spelt to highlight that people shape and break down reality through engagement with material agencies in a continuous intertwining of cause-effect, action-reaction, documentation-interpretation. Matereal methods are ways of noticing, but also of acting in line with, and of creating order in human-matter intra-action. Part 3 shows that palpability is an effect of intra-action, not something designers could design *into* technologies. However, I argue that we can design *for* it in Part 4.

NOTICING

As an ethnographer working with professionals in healthcare and emergency response I am able to observe and document intra-action in some detail and I will seek to exhibit what is mean these neologisms through and example from video-ethnographic studies carried out in collaboration with colleagues at Siena University (all names have been changed). The studies take the readers into a neonatal care unit. (why neonatal care is a perspicuous setting)

Figure 1: Chiara, Carla, Donna and Rosa notice and diagnose the cause for David’s erratic heart rate and take remedial action

> *Wearing hygienic aprons and slippers we enter the Neonatal Intensive Care Unit (NICU) at Siena Le Scotte Hospital. Five incubators are occupied. David, delivered several weeks pre-term three weeks ago seems to be developing well. His mother Donna arrives for the visiting period. After a brief chat to Chiara, the neonatologist who is sitting at a table that forms an island in the centre of the ward, noting down diagnoses of her*

> *patients' progress, Donna turns to her son's incubator. Several heart rate alarms sound. The busy soundscape of the ward where a radio, talk, telephone calls, and different kinds of alarms (signaling for example, the completion of a syringe-feeding, a drop in the oxygenation of a newborn's blood, a rise or fall in heart rate, problems with a respirator, and many other issues relevant to the care for premature babies) bay for people's attention, have become a familiar feature for Donna. She opens one of the incubator hatches, passes her hand through and adjusts David's bedding. As she strokes his tiny hand, tears roll down her face and she wipes them away with her arm. One of the heart rate alarms recurrently audible in the room seems to sound with increased frequency and Carla, the nurse at the table, turns to look at David's heart rate monitor (Figure 1.1). She turns back to her paperwork. However, when the alarm sounds again she gets up to look at the monitor (Figure 1.3), where the heart fluctuates between 30 and 153 (Figure 1.2 and 1.5), with somewhere around 140-150 being a normal value. The alarm sounds again, alerting both Carla and Donna (Figure 1.4). Donna, who does not know how alarms and displays are connected, looks at the wrong display at the bottom of the incubator. In the bottom right corner of Figure 1.6 we see Rosa, David's personal nurse during this shift, who has returned from an errant. The muffled cries of a baby are audible: David. The alarm sounds again and both nurses look at the monitor (Figure 1.6). Rosa gets up, dragging her chair to David's incubator. As she does so, the neonataologist joins her, and while Rosa fetches a cushion, Chiara explains that Donna is to hold David (for the first time in their lives), to calm him down (Figure 1.7). Rosa opens the incubator, making David's cries audible loud and clear across the room. The alarm sounds again and both Donna and the neonatologist look at it (Figure 1.8), but as Donna holds David, his heart rate stabilizes and the alarm does not sound again.*

This abridged description of a few minutes in the NICU teems with 'noticings', and our observations highlight a critical professional accomplishment: the ability to notice, diagnose and act on significant, complexly interconnected events to provide a high level of care. Noticing – key to all forms of making things palpable – is clearly not just a moment of cognitive mismatch registration. Mismatch registration is important, for example, in error detection and a number of cognitive activities can be identified **Error! Reference source not found.**. However, noticing is also, crucially, a practical achievement that fits human action into sequences of material action, giving meaning and direction to the intertwined flow. This is important because … The contribution the analysis below makes to design is conceptual. This work with the parents and neonatologists has also informed the design of biosensor technologies for neonatal care (Marti et al …), and it is being used to inform the design for technologies for use in emergency care. …

ASYMMETRIES

The example makes it clear that we cannot talk of accountability and interaction in human-machine interaction. … (also refer to eriksen on accountability)

To fit actions into the intertwined flows of other people's and material agents' actions (and thereby shape and direct the flow), people have methods for noticing, understanding, and creating order. These human methods differ from those that material agencies bring to the encounter **Error! Reference source not found.**. The example above allows me to juxtapose human capabilities and methods with those of material agencies and identify important principles for design.

Human Action

People act accountably **Error! Reference source not found.Error! Reference source not found.**, in three ways: deliberately, physically and inferentially. When Rosa and Chiara offer Donna a chair, for example, they deliberately account for doing so: They tell her that she is to soothe David by holding him. Such accounts are carefully and economically designed. Physical accounts, in contrast, are a pervasive, automatic, inescapable fact of embodied human action in material environments. For example:

- Carla, Donna, Rosa and Chiara document their noticing of the alarm through their looking at its display
- Donna and David cry, documenting emotional states (or, in David's case, possibly physical discomfort). David also documents physical strength through his sustained crying.
- Carla and Chiara document unfolding interpretations of the alarm (as not requiring immediate response, as not Carla's, but Rosa's responsibility) by disattending
- Rosa documents her interpretation of the alarm as indicative of a physical and emotional status that could be bettered by Donna holding her son, and Rosa shows that it is her intention to intervene by rolling her chair to David's incubator
- Chiara shows that she understands and agrees with Chiara's plans by joining her as soon as she moves the chair.

But such accounts are ambiguous. Looking, crying, disattending, getting up and moving a chair, verbal explanations – could mean many things. People can pinpoint meaning relatively precisely not just because they can elicit (more) deliberate accounts, but also because people's actions are tied into, and buoyed up, by sequentially and spatially organized flows of human and material actions/reactions, documentations/interpretations. I will now highlight some particularly important aspects of the sequential and spatial organization of unfolding of ordered socio-material situations and the methods it affords, because they underpin the inferential dimension of human accountable action.

First, people treat appearances – e.g. deliberate and physical human accounts – 'as "the document of," as "pointing to," as "standing on behalf of" a presupposed underlying pattern' (K. Mannheim, quoted in **Error! Reference source not found.**). For example, Rosa takes the fact that Chiara gets up and joins her as soon as she moves her chair in response to the alarm as confirmation of her plan. Were Chiara to remain seated and look up, alarmed, Rosa would probably stop and try to account for moving the chair through an excuse. This general 'documentary method of interpretation' relies on a number of more fine-grained characteristics of the sequential and spatial organization of unfolding ordered socio-material situations. Second, most moves within the flow of activities are 'conditionally relevant', that is they are implicated as appropriate 'nexts' by the previous move **Error! Reference source not found.**. An alarm, for example, demands a response. Methodologically, conditional relevance allows people to treat temporally and spatially proximate moves as 'meant as' the conditionally relevant type of next move. Thus, for example, Carla's turning her head is interpreted as triggered by David's alarm (and not meant to enable her to see out of the window), and her return to her paperwork can safely be seen to mean that no immediate action is required (especially if one knows, as Chiara does, that David is Rosa's responsibility and that she will be back shortly). In turn, the fact that throughout, Chiara remains focused on her notes, indicates that she (who is ultimately responsible for the neonates' care) approves of Carla's conduct. Such inferences are, in themselves, accountable actions which also tie people into moral orders. [How?] Third, both human and material actions can sometimes be, or be perceived to be, inappropriate or unexpected. People can recognize when their actions are (perceived to be) inappropriate, while producing them or subsequent to the completion of a move. Where human conversation is concerned, there is a 'preference for self-repair', that is, people expect that the producer of a flawed move will initiate and, if possible, carry out repair. Even though no words are exchanged as Rosa rolls her chair towards Donna with Chiara following behind, the events that follow attest to similar methods being applied in coordinating the work of caring for neonates and parents in the NICU. Donna clearly does not understand the import of Rosa and Chiara's move. They realize this and explain with a carefully 'recipient designed' translation, that is, an account that is sensitive to Donna's knowledge and situation. If Chiara and Rosa saw a fellow neonatologist looking at them quizzically, they might say: 'he's been stable all week' to explain why they think David is strong enough to be taken out of the incubator. A fellow neonatologist could be expected to anticipate their plan from seeing what they are doing and be entitled to query it. Donna, in contrast, cannot know this, so here they explain that she should sit down and calm David by holding him.

In summary, human or material moves are suspended in the sequential and spatial order of things (that is, 'situated' or 'indexed' by it). This allows people to make sense of socio-material orders. Moreover, actions within socio-material orders are reflexive. Most are fast, almost automatic 'reflex' next moves rather than carefully considered and subsequently executed steps in a comprehensive plan (although such plans may play an important role in facilitating human reflex actions **Error! Reference source not found.**). Second, each move is tied into the unfolding context in a way that is situationally reflexive. Situational reflexivity means that every action is shaped by, but also actively shapes, the situation. People are aware of this and, if things go wrong or take an unexpected turn, they can usually locate the origin of the problem and initiate repair. In this process, people use a documentary method of interpretation, that is, they treat appearances as standing on behalf of underlying (invisible) processes and patterns. Orienting towards this indexical, reflexive, sequentially and spatially organized production of cause-effect, action-reaction, documentation-interpretation, people can produce 'appropriate' accounts, translations, actions and repairs

Material Action

[pending]

PALPABILITY

[Is palpability an effect or a property? If something facilitates the effect it has to be a property? Is I a property that can be designed? Are there properties that cannot be designed? Does 'design add too much meaning inbetween us and the object. Do we need a 'direct' access?]

CONCLUSION

[pending]

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10. Transient Locations

10.1 The RASCAL system for managing autonomic communication in disruptive environments

Authors: Roberto Ghizzioli, Dominic Greenwood

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The RASCAL System for Managing Autonomic Communication in Disruptive Environments

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***Abstract*—This paper presents RASCAL, a contingency manager system with autonomic capabilities which enables collaboration among a set of ubiquitous services deployed in the infrastructure and/or in the ad-hoc network. Autonomicity is shown in the context of disruptive environments, that is, a series of locations that may be subject to intermittent or complete disruption to communications equipment. In this paper we show how the RASCAL autonomic architecture and its adaptable policies determine the types of actions to be taken in order to exhibit stability to the end user.**

I. Introduction

For many, mobility is now a central aspect of everyday life to the extent where mobile users expect to be *always-best-connected*, i.e., they expect anywhere and anytime access with the maximum capacity on offer. As providers rush to deploy the network infrastructure required to deliver high-quality on-demand services, mobile devices including laptops, PDAs, and cellphones can begin to deploy their own ubiquitous services. Just a sample of emerging services used within the health-care and emergency response domains include collaborative technologies such as map/location services, interactive shared whiteboards and wireless health monitors [12].

Empowering the anywhere/anytime access aspect of such ubiquitous services we can now observe the emergence of multi-technology systems and software supporting flexible communication [7]. That is, using any available network technology to communicate, whether infrastructure based (e.g., WLAN, WiMAX or Cellular), or ad-hoc based (e.g., Bluetooth, Ultra-Wideband, or even Infrared).

Naturally such communicative flexibility becomes increasingly important as the operating environment becomes more dynamic or disruptive in nature, and the availability of different network technologies can change rapidly. This is yet more critical in emergency scenarios such as disaster zones and major incidents.

This paper reports on a technology prototype based on concepts drawn from *autonomic communication* research [1], [14], to allow mobile devices to autonomically self-manage connection endpoints and data transmission over available network technologies.

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The prototype is termed the RASCAL system, where RASCAL is an acronym meaning *Resilience and Adaptivity System for Connectivity over Ad-hoc Links*. RASCAL is a novel middleware communication mechanism that automatically ensures (to such degrees as are possible within the operating environment) the continued operation of ubiquitous application services where communication may be subject to disruption. RASCAL has been designed and implemented as a deliverable of the EU-funded PalCom (Palpable Computing) project[1].

To achieve this goal the RASCAL system shifts the burden of tasks such as configuration, maintenance and fault management from users to a specialised self-management subsystem. Each RASCAL system uses a local policy engine for *self-configuration* purposes allowing it to adjust its behaviour in accordance with environmental changes. RASCAL is also *self-optimizing* because it monitors network resources and adapts its behaviour to meet the end-user and application service needs, i.e., automatically switching between WLAN and Cellular connections to maximise the always-best-connected goal. Furthermore, RASCAL is also *self-healing* when managing multiple bearer technologies, such as WLAN, 3G or Bluetooth; for example, switching to an ad-hoc connection in the temporary absence of an infrastructure connection. Finally, RASCAL also offers an intuitive interface allowing the user to inspect ongoing activities, decisions and internal state of the system.

Currently, the RASCAL system operates in conjunction with *palpable devices*, defined by the PalCom project as discoverable user devices that offer one or more services that may serve as constituents of an *assembly*. An assembly is a dynamically composed collection of devices and services delivering on a transient task defined by the user [10]. Although in this respect the RASCAL system uses the PalCom-defined communication stack, it has no specific dependency and can thus operate as an independent autonomic control subsystem on multiple devices and platforms.

The remainder of this paper is organized as follows: Section II provides some background on disruptive environments highlighting the communication complexity and requirements

[1] IST-002057

it places on RASCAL. Section III discusses some relevant previous work on autonomic communication dealing with disruptive environments. Section IV then presents the autonomic features of RASCAL and Section V presents the RASCAL architecture. Section VI shows a scenario where RASCAL was evaluated before concluding in Section VII.

II. Disruptive Environments

Our definition of a disruptive environment is a physical location wherein there is a high probability that some disruption will occur diverging from normal, expected behaviour. In this paper we are, in particular, concerned with disruption to channels of electronic communication in environments such as those impacted by *natural disasters* (e.g., tsunamis, hurricanes, earthquakes, floods, forest fires, etc.), sites of *major incidents* [12], [13] (e.g., plane crashes, multi-vehicle road traffic accidents, building fires, etc.), *theatres of military operations* and also other more *everyday situations* such as healthcare telemedicine [15] and remote working.

In all of these environments there is often a pressing need to communicate information from one locale to another, both within, from and to the environment. A straightforward example is the communication of information between rescue workers operating in disaster zones. The devastation caused by recent global events such as 911, the Asian tsunami, and hurricane Katrina, to name but a few, demonstrate that emergency services must coordinate at multiple levels and with absolute guarantees of information finding its way from sender to receiver via one means or another. Emergency response services must, for example, build ad-hoc rescue teams before acting at an incident site, continuously communicating with one another to exchange orders, share findings, request help, etc. (see Figure 1(a)).

Assured means of communication in such scenarios is highly important because it helps save lives. This can also be the case with telemedicine where health workers must receive patient monitoring information at all times (see Figure 1(b)). And even the remote business worker attempting to remain connected to a company network may be subject to transient availability of access network connections in certain locations.

Due to the potentially disruptive nature of such environments, communication is often subject to unpredictable network conditions. Radios may fail due to electromagnetic interference, infrastructure networks may be inoperative due to physical damage, cellular and satellite communication may be impossible due to poor or intermittent signal strength and ad-hoc connections may be limited due to the availability of local nodes. In general terms, we consider a disruptive communications behaviour as an event occurring in a disruptive environment that alters, modifies, or interferes with data transmission as it travels through interconnected channels between a source and a receiver.

To maximize the probability for successful transmission we require an intelligent, autonomic messaging platform that allows real-time, secure, bi-directional communication of any information from source to destination(s) while remaining agnostic to the devices, networks or carriers required to transfer the information. This requires migrating communication (e.g., message handling) intelligence into the cooperating user devices to allow iterative delivery decision-making throughout the communication route. This is manifested by *recipient pursuit* where intended receivers are tracked down by attempting to move a message closer to their estimated location with each hop (see Figure 1(c)).

The architectures of today's infrastructure networks assume that physical connectivity exists on an end-to-end basis between sources and destinations for extended periods of time. For networks operating in a disruptive environment, these assumptions are no longer valid, and new approaches to routing, congestion and flow control are required. The RASCAL project proposes an architecture and policies supporting end-to-end reliable communication in environments with such intermittent connectivity.

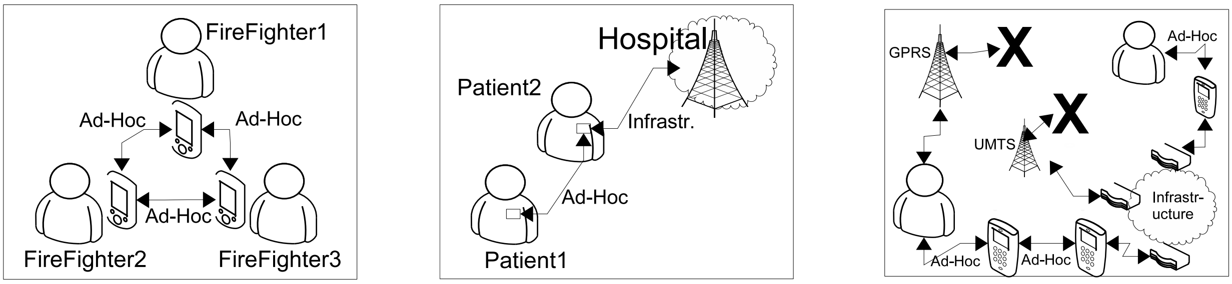
III. Related Work

There are several published studies available regarding the deployment of autonomic communication and network management systems in disruptive environments. However, we find that the majority consider only specific aspects of the domain. For example, when addressing network aspects many papers focus only on either infrastructure or on ad-hoc networks (MANET) without considering the synergy of using the two type of networks concurrently, and in support of one-another. A specific case in point is the work of Chadha *et al.* [3] who present an autonomic system developed under the U.S. Army CERDEC DRAMA (Dynamic Re-Addressing and Management for the Army) program deployed in military scenarios. This system in particular only addresses mobile ad-hoc networks without consideration of potentially available infrastructure networks.

Those papers that deal with hybrid networks (infrastructure and mobile ad-hoc), few consider either the requirements of the end user applications running on top of the presented autonomic systems, or the roles of end-users in various deployment scenarios.

An example of hybrid network management is provided in Hauge *et al.* [8] who present an interesting approach to the combination of 3G cellular and ad-hoc networks. They conclude that hybrid networks provide the opportunity to transmit service data to a higher percentage of interested mobile terminals than when using only an infrastructure network. Nevertheless, the role of their user-level service (multicast) within hybrid networks is not considered. The same can be said of the work of the Delay Tolerant Networking Research Group [5]: they mainly focus on network aspects providing end-to-end connectivity in disruptive environments without considering how application contexts influence the achievement of connection/delivery goals. We address this issue as a component of the RASCAL usage-aware approach (see section IV).

Another work in this area is by Kappler *et al.* [11] who use a policy-engine to address hybrid network composition.



(a) Major incident scenario.

(b) Telemedicine scenario.

(c) Recipient Pursuit.

Fig. 1. Disruptive environments.

Although this aspect is in line with our approach, the authors do not consider the discovery of relevant network nodes and policies are only used for the composition of network devices, whereas our approach also considers user-level service composition.

On the other hand, previous work on ambient and pervasive computing used in disruptive environments or disaster management tends to focus more on service composition or other application-oriented aspects without considering the underline networks issues. Such an example is the reported work of Kristensen *et al.* [13] who focus on IT support in major incidents, such as the use of bio-monitors, person identification and collaboration tools for response units, without considering how these application should behave when faced with network disruptions.

The RASCAL system reduces this gap between specific autonomic aspects purely based on the network management and the autonomic aspects based on the user-level services deployed in disruptive environments.

IV. RASCAL Autonomic Features

RASCAL is a middleware communication layer which resides between the user applications and the underlying networks enhancing the user experience when these applications are used in disruptive environments. When RASCAL is used by a device the device becomes *"RASCALized"* and from that moment on, all messages sent by applications are given to RASCAL which decides, based on a set of policies, the most appropriate actions to take on them. Enhancing the user experience in such situations implies making *autonomic decisions* when sending/receiving application messages to/from a target node. Disruptive environments are normally highly dynamic and normally collaborative applications such as instant messengers, VOIP clients, GPS or GIS map services do not exhibit the autonomic behaviours necessary to deal with such environments.

RASCAL brings about *connection awareness* through a set of autonomic behaviours which are triggered by changes in network resources. Several autonomic decisions are available including:

- **Network handover** : Switching from one network type to another when communicating with other devices. This decision can be taken based on the reachability of a device over different networks (e.g. infrastructure or ad-hoc) and on the networks availabilities. For example, we can consider handovers from an infrastructure technology (e.g., UDP) to an ad-hoc technology (e.g., Bluetooth) when communicating with a device in the neighborhood in the face of network problems.
- **Routing optimization** : Enhancing multi-hop routing among network nodes. Parameters which affect these decisions can be based on several QoS parameters such as response delay, nominal and available bandwidth between network nodes, transmission errors, etc. For example, a self-optimization feature of RASCAL fitting into this group is to proactively evaluate the transmission delay between two interoperating devices and consequently use another path to reach the same target node.

Other behaviours within this category include those acting in response to failovers or high network load, etc.

RASCAL also offers *usage-aware communication* consisting of a set of autonomic behaviours related to the usage of deployed user-level services. For example, a group of firefighters are on the site of a major incident and must constantly communicate both with one another and with a response unit about their findings and the positions of injured people. Due to the disruptive nature of the environment, network availability may be intermittent, but the goal to reliably deliver communication must persist. In this example autonomic decisions can be taken such as:

- **Transmission contingency**: Providing alternatives to the default means of transmitting a message. This specifically includes making best use of multi-technology transmission paths including cellular networks, IP infrastructure networks, satellite systems, MANETs, etc. An important parameter able to affect these decisions is the importance of the message to be sent. An example is simultaneously sending high priority messages via two or more different technologies, and therefore routes, to improve the chances that they are successfully delivered to target nodes. The use of extra resources is justified by the importance of the content to deliver.
- **Content adaptation**: Adapting the content of a message (or stream). These decisions can be based on several

parameters like the number and the importance of the messages/streams to be sent. Examples include applying a codec to reduce the used bandwidth of a video stream, or simply stripping out the audio component and sending this in lieu of the video.
- **Deferred service provisioning**: Waiting until a connection is available before making routing decisions to mitigate uncertainty relating to the choice of optimal technologies or paths. Also in this case the parameters able to trigger this type of decisions are the number and the importance of the information to be sent. This includes the need to buffer messages while awaiting a connection.
- **Role management**: Specifying user defined conditions which must be met before taking a particular action. A parameter which affects these decisions is the role of the end-user in a particular scenario. For example within a major incident response workers are divided into response units, structured in a hierarchical way. In this scenario we can envisage policies which ensure a message (e.g. notification of an event) is sent to the right recipients in the role hierarchy (e.g. escalating).

In order to enable the end user to quickly define or modify policies which govern the autonomic features of the RASCAL System running on the his/her device, a mechanism for on-the-fly updates is adopted.

Additionally, another important feature of RASCAL is the notification and interaction aspect with the end user. In many systems when a problem occurs during a communication the end user is not notified. RASCAL is able to trace the communication and to provide *inspection* capabilities using an appropriate GUI. More details are given in Section V-D.

V. The RASCAL Architecture

The RASCAL software architecture, depicted in Figure 2 with solid lines, is fully compliant with the well known IBM autonomic control loop [9], in that it:

- *collects* information from the system and the external world,
- *make decisions* using a policy engine,
- and *adjusts* the system as necessary.

The architecture consists of six main components, described in the following subsections. In overview they consist of three managed elements (applications service, networks service and policy service), an autonomic manager (RASCAL agent), a policy engine and a GUI.

RASCAL is able to communicate and interact with different layers of the user-device communication stack (depicted in Figure 2 with dotted lines). For example, it normally interacts with components dealing with media layer technologies, e.g. UDP, Bluetooth, etc., or with components implementing high communication layers, e.g., routing protocols, discovery systems, user applications. This is the case in the PalCom project, but different scenarios where different third-party components or implementations are in place, are not excluded.

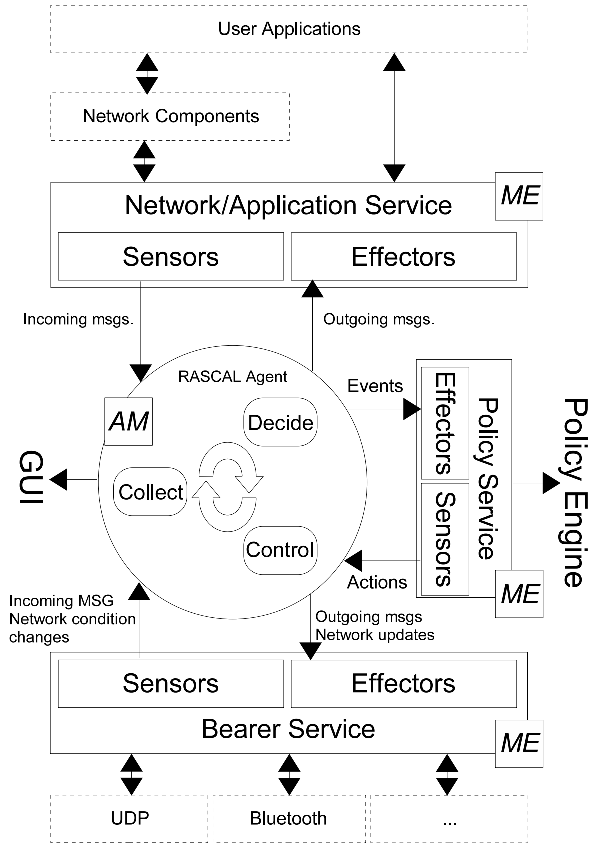


Fig. 2. The RASCAL software architecture.

The integration between a third-party network component and RASCAL is possible through the software interfaces offered by the RASCAL system.

The RASCAL architecture is implemented using JADE (Java Agent Development Framework), a software agent platform and development system [2]. Within the JADE runtime are contained the autonomic manager (implemented as a *software agent*) and the managed elements (implemented as *kernel services*). In general terms a *software agent* is defined by Wooldridge [18] as a *"computer system that is situated in some environment and that is capable of autonomous action in this environment in order to meet its design requirements"*. A JADE kernel service is defined by Bellifemine *et al.* [2] as a *"software component which implements platform level features that can be grouped together according to their conceptual cohesion"*.

A. The Managed Elements (ME)

The RASCAL agent interacts with the external world via JADE kernel services. Each service is controlled through sensors and effectors. Effectors produce actions relating to instructions received from the RASCAL agent; they implement the *Command* design pattern [6]. Sensors collect information from the external world and provide it to the RASCAL agent for processing; they implement a simplified version of the *Half-Sync/Half-Async* design pattern [16].

The RASCAL system contains three JADE kernel services:

Network/Application Service.: This is used to receive messages sourced from end user applications or high level network components. A selection of interfaces allow communication with a broad range of applications, examples of which include the previously mentioned PalCom services designed for disruptive environments, or any other user level application such as VOIP clients, IM, etc.

Bearer Service.: This is used to interact with the underlying infrastructure or ad-hoc networks. This service is able to send/receive messages over different technologies and to generate events based on network status.

Policy Service.: This is used by the RASCAL agent to communicate with a local policy engine (see Section V-C).

B. The Autonomic Manager (AM)

The autonomic manager component is implemented by the RASCAL software agent. It exhibits the following behaviours:

Sensing.: By installing sensors in the managed elements the agent is able to gather new application messages to be sent, new messages received from the network or new network status events. Data is collected both asynchronously (the managed elements notify of a status changing) or synchronously (the agent explicitly request for information).

Compiling Knowledge.: Received events are used to model an internalized representation of the external world. This compiled knowledge base will contain information relating to discovered devices, the services they provide, and the physical addresses of these services.

Decision Control.: Once the internal knowledge base is updated, RASCAL triggers a policy engine which controls decisions on which action to apply on the system. This aspect is detailed in Section V-C.

Proactivity.: Actions can be executed by RASCAL immediately or postponed until some time in the future. In order to schedule such future actions RASCAL implements a model of time allowing proactive planning.

C. Decision Making

A core aspect of the RASCAL system is its reasoning system. The RASCAL agent receives messages from user-level applications and probes the environment using the previously discussed kernel services. Decisions on how to treat the received messages are made locally using *policies*; a set of constraint rules governing system behaviour. One of the goals of RASCAL is to provide the end user with an easy means of authoring policies that will control the various autonomic features (see Figure 3). In order to modify the RASCAL behaviour at runtime, these policies are dynamically loaded when the device is running.

Policies are not coded directly within the agent behaviours. To be more flexible, the agent uses the Policy Service, shown in Figure 2, to issue events to a policy engine and wait for a set of recommended actions to perform. The particular policy server employed by RASCAL is Ponder2 [4], used as a local library, which uses an XML-based policy description language to define events and policies to be processed by the Ponder2 policy engine. The result of a policy is an action the RASCAL agent has to perform. Currently, RASCAL deals with *obligation policies*. An obligation policy is an Event Condition Action (ECA) rule in the deontic sense [17]. Given E, and C is true, it is obligatory that the agent performs A.

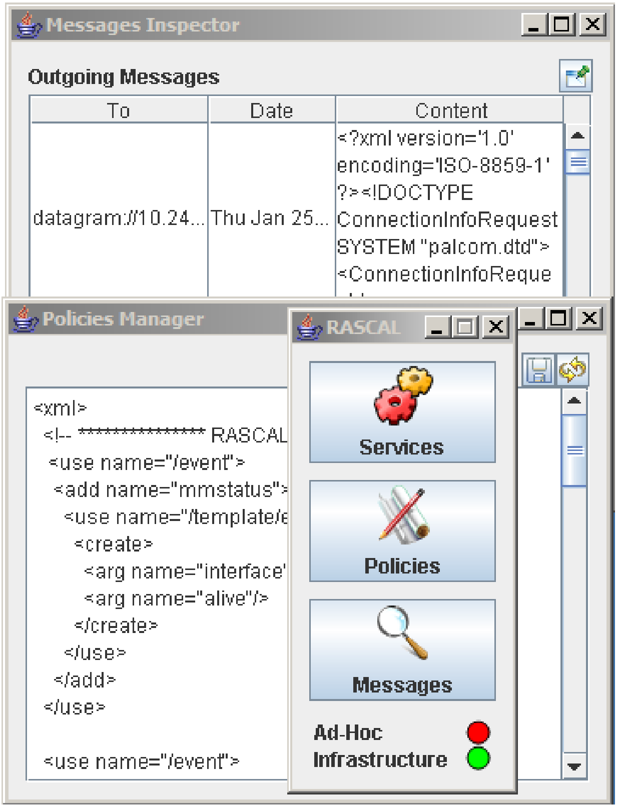


Fig. 3. The RASCAL GUI

D. Graphical User Interface

The RASCAL user interface is designed for control and inspection using event-based interaction with the RASCAL agent. The main panel, shown in Figure 3, indicates the status of the various network interfaces available on the local device and a set of buttons to open inspection views. One of these views provides a list of all remote devices interacting with user-level services running on the local device. Additionally, a second view is dedicated to message inspection and a third to inspecting, editing and controlling policies definitions. Currently, the RASCAL GUI has been implemented to work only on laptops or personal computers but it can be easily adapted to other consumer devices like PDA, smartphones, etc.

VI. Evaluation

RASCAL has recently been integrated into the iterative, participatory design process practiced in PalCom. We are currently carrying out experiments with end users in major incident emergency response scenarios. This section presents

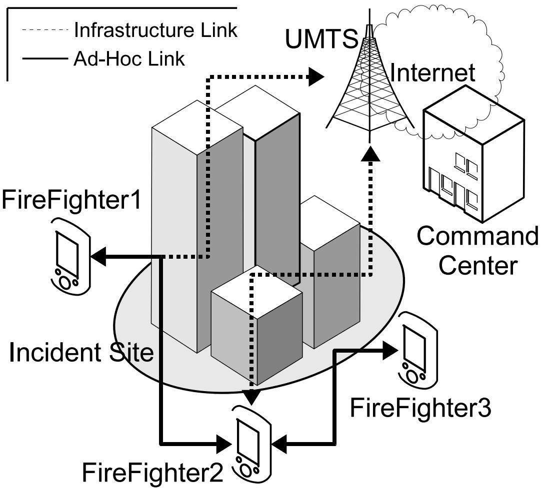


Fig. 4. The conducted mocked-up situation.

```
<use name="/policy">
  <add name="contentAdapt">
    <use name="/template/policy">
      <create type="obligation"
              event="/event/mmstatus" active="true">
        <arg name="alive"/>
        <condition>
          <eq>protocol;datagram</eq>
          <eq>!alive;false</eq>
        </condition>
        <action>
          <use name="/rascalmo">
            <sendLowResolutionPicture
              protocol="bluetooth"/>
          </use>
        </action>
      </create>
    </use>
  </add>
</use>
```

Fig. 5. Example of policy to send low resolution pictures to the command center towards the ad-hoc network when the infrastructure connection is not working anymore.

an overview of one of the mocked-up situations of a real world major incident conducted at a recent PalCom project review.

Within this experiment a building fire is considered. This particular scenario demands fast and effective actions, often in life-threatening situations. It also requires collaboration between numerous people located in different, often changing, areas: personnel at the incident site (e.g. firefighters, police, doctors, etc.), at the command center, in vehicles, etc.

Each of the people involved, and many of the vehicles and other equipment, are associated with one or more electronic devices such as radios, biosensors, GPS, health recorders, handhelds, tablet PC, etc. In the fire scenario different devices run different crisis-relevant applications including VOIP clients, instant messengers, map services and other collaborative tools.

A view on aspects of the presented scenario is depicted in Figure 4. Here three firefighters (FF) are moving relatively close to one another to evacuate people from a building on fire. They are using special ”RASCALized” tablet PCs, each with a built-in camera running a map service. Their duty is to notify the command center (CC) and the other workers of the team of findings related to the visited building(s), e.g., the positions of injured people. To do this, they make special marks on the map displayed on their tablet PC. Firefighters can also take pictures to assist the command center with gaining a visible overview of the overall incident status. Furthermore, in this example, FF1 and FF2 are connected via both ad-hoc (HOC) and infrastructure (INFR) networks and FF3 only via an ad-hoc connection. In this situation, through the multi-hop capabilities of RASCAL all the four actors (the three firefighters and the command center) are able to communicate one another. For example FF3 communicates with the command center via the ad-hoc connection with FF2.

The RASCALized devices used by the firefighters are equipped with the following policies:

1) IF (infrastructure_connected) THEN send map data to CC and FF via INFR.
2) IF (!infrastructure_connected) THEN send map data to CC and FF via HOC.
3) IF (infrastructure_connected) THEN send high resolution pictures to CC via INFR.
4) IF (!infrastructure_connected) THEN send low resolution pictures to CC via HOC.

Figure 5 shows the definition of the final policy in the list presented above. This policy sends low resolution pictures to the command center when the device is not infrastructure connected. It receives *mmstatus* events which denote if a network interface is up or not. This event has two associated parameters: the interface’s protocol and its status. The only condition that triggers this policy is that the infrastructure connection is down (see the XML *condition* element). The action *sendLowResolutionPicture* triggered by this policy notifies the RASCAL agent to decrease the resolution of the pictures for the command center and to send them using the ad-hoc network (see the *protocol* attribute of the *sendLowResolutionPicture* XML element).

In our experiment, for example, FF1 has policies 1) and 3) activated. When FF1 moves into an area where their infrastructure connection fails, policies 2) and 4) automatically become active. The RASCAL agent running on the device is thus notified by the policy engine and hands over all communication with FF2 to the available ad-hoc connection. Given the importance of sending images to the command center and giving the low nominal bandwidth of the BT technology, pictures are first automatically reduced in quality (i.e., resolution) before transmission.

Later, when FF1 returns to an area with infrastructure network coverage, communications with the command center are automatically returned to the infrastructure connection with images once again sent in normal, high resolution.

A sequence diagram of the actions taken by FF1 to send

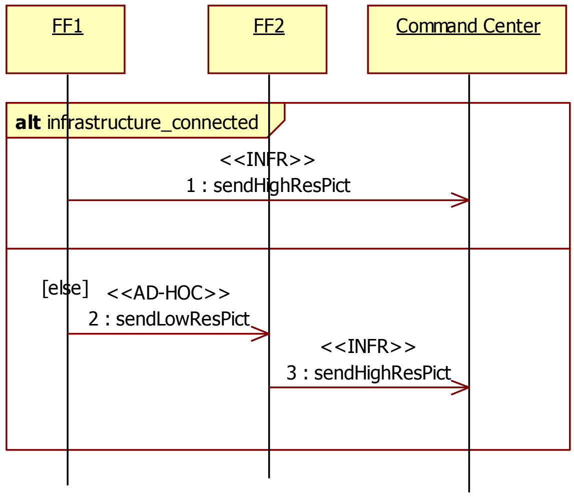


Fig. 6. Sequence diagram of the actions taken by FF1 to send pictures to the command center.

pictures to the command center is shown in Figure 6. The diagram considers the discussed situation both with and without the infrastructure connection.

VII. Conclusion

This paper has presented the RASCAL system, the outcome a work package of the European PalCom project. In particular, this paper gives an overview of the RASCAL software architecture and of its internal mechanisms able to exhibit autonomic capabilities. Using agent technologies in conjunction with a policy engine the end user is able to define communication policies able to deal with disruptive environments such as major incidents.

The RASCAL system is currently under a continuous refinement and improvement process and will remain so until the end of the PalCom project in December 2007. Future work will concentrate on additional autonomic aspects of the RASCAL system. One particular aspect targeted for improvement is the policy language, where a new structure using a process-algebra over actions will be introduced. This will allow the expression of a set of actions (i.e., workflow) rather than the current limitation to atomic actions. Other planned improvements relate to the inspectability of the RASCAL system and its use in composing dynamic assemblies of computational devices and services with flexible, self-adaptive communicative connections.

Acknowledgment

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10.2 Autonomic communication with RASCAL hybrid connectivity management

Authors: Dominic Greenwood, Roberto Ghizzioli

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Autonomic Communication with RASCAL Hybrid Connectivity Management

Dominic Greenwood and Roberto Ghizzioli

Abstract. This paper presents an approach to manipulating available hybrid connectivity to autonomically maximize the potential for sustained connectivity in the event of path disruptions. The approach is documented in terms of the features, architecture and deployment modes of an autonomic communications module, termed RASCAL. This module employs software-agent logic supported by a state-of-the-art policy engine to dynamically determine best options for packet transmission over available infrastructure and ad-hoc connections.

Keywords. autonomic, hybrid, ad-hoc, contingency, policy, agent.

1. Introduction

The ability to seamlessly communicate when mobile is now, for many, an inescapable component of day-to-day life. It is of course the electronic communications revolution has brought about this reality; one where in many respects we simply cannot perform many common tasks without access to communicative devices including cellphones, PDAs, laptops, and GPS. This fact is especially resonant in environments where communication is critical to sustaining coordination between individuals that need to remain *always-best-connected* anywhere, anytime, using any available network technology and with the maximum quality and capacity on offer.

We consider key examples of such environments to include those where human life is a critical concern, such as sites of natural disasters (e.g., tsunami, hurricanes, earthquakes, floods, forest fires, etc.), major incidents [8, 13] (e.g., plane crashes,

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multi-vehicle road traffic accidents, building fires, etc.), and theaters of military operations. In all of these there is very often a pressing need to communicate information between individuals, whether they be in either localized, or widely distributed groups. A straightforward example is the coordination of ad-hoc teams of rescue workers that need to share multiple forms of information (i.e., audio, video, sensor data, medical data, etc.) while operating in the field.

With this work we thus aim to address the problem of maximizing the assurance that communication will remain established even when communicative channels are disrupted due to environmental events. Specifically, we propose one contribution to solving this problem: an autonomic communication system providing real-time, secure, bidirectional communication of data messages from source to destination(s) while remaining agnostic to the devices, networks or carriers required to transfer the information. The reported technology prototype draws on concepts defined by many researchers and practitioners in the field of autonomic communication [1, 12].

The prototype is termed RASCAL[1] (*Resilience and Adaptivity System for Connectivity over Ad-hoc Links*). RASCAL is a novel middleware communication mechanism that automatically ensures (to such degrees as are possible within the operating environment), the continued operation of ubiquitous application services where communication may be subject to disruption. This requires some migration of message handling intelligence into user devices to allow iterative delivery decision-making throughout the communication route. RASCAL thus shifts the burden of tasks such as configuration, maintenance and fault management from users to a specialised self-regulating subsystem. A local policy engine is used by each RASCAL deployment for *self-configuration* purposes, allowing autonomic adjustment of behaviour in accordance with environmental changes. RASCAL is also *self-optimizing* as it monitors network resources and adapts its behavior to meet the end-user and application service needs, i.e., automatically handing-over sustained sessions between WLAN and Cellular connections to maximise the always-best-connected goal. Furthermore, RASCAL is also *self-healing* when managing multiple bearer technologies, such as WLAN, 3G or Bluetooth; for example, switching to an ad-hoc connection in the temporary absence of an infrastructure connection. Finally, RASCAL also offers an intuitive interface allowing the user to inspect ongoing activities, decisions and internal state of the system.

The remainder of this paper is organized as follows: section 2 discusses some relevant previous work on autonomic communication. Section 3 then presents the autonomic features of RASCAL and Section 4 presents the RASCAL architecture. Section 5 presents some initial results from laboratory-based experimentation and Section 6 illustrates a real-life scenario within which RASCAL has been evaluated. The paper is concluded in Section 7.

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[1]RASCAL has been designed and implemented as a deliverable of the European Union 6th Framework Program Palpable Computing project (PalCom) - IST-002057.

2. Related Work

As mentioned in the previous section, there are a variety of published studies available regarding the deployment of autonomic communication and network management systems in disruptive environments. The majority of these tend to consider quite specific aspects of the domain. For example, when addressing the networking aspect most papers focus on either infrastructure or on ad-hoc networks (MANET) without considering the coordinated use of both concurrently. A specific case in point is the work of Chadha *et al.* [20] who present an autonomic system developed under the U.S. Army CERDEC DRAMA (Dynamic Re-Addressing and Management for the Army) program deployed in military scenarios. In particular, this system only addresses mobile ad-hoc networks without consideration of potentially available infrastructure networks.

Those papers that deal with hybrid networks consisting of a combined infrastructure and mobile ad-hoc connectivity, few then consider either the requirements and influence of the user applications running over the autonomic communications subsystem, or the roles of end-users in deployment scenarios.

A good example of hybrid network management is provided in Hauge *et al.* [21] who present an interesting approach to the combined use of 3G cellular and ad-hoc networks. They conclude that hybrid networks provide the opportunity to transmit service data to a higher percentage of interested mobile terminals than when using only an infrastructure network. Nevertheless, the role of their user-level service (multicast) within hybrid networks is not considered. The same can be said of the work of the *Delay Tolerant Networking Research Group* [3] chartered as part of the Internet Research Task Force (IRTF). This group primarily focus on network aspects providing end-to-end connectivity in disruptive environments without considering how application contexts influence the achievement of connection/delivery goals. We address this issue as a component of the RASCAL usage-aware approach (see section 3).

Another important work in this area is that of Kappler *et al.* [22] who use a policy-engine to address hybrid network composition. Although this aspect is in line with our approach, the authors do not consider the discovery of relevant network nodes, and policies are only used for the composition of network devices, whereas our approach also considers the possibility of user-level service composition.

The notion of Unified Messaging (UM), as reported in van der Meer *et al.* [24] for example, is also closely related to our work from the perspective of supporting both fixed and mobile users with universal access to communication services. The central concept of UM is the capability of the messaging system to select the most appropriate terminal or application for an incoming message according to availability, status, and other parameters. A UM system is designed to adapt terminals to different kinds of services via content adaptation processes guided by user rule policies. However, the particular approach documented in [24] identifies CORBA as a suitable means of engineering the middleware software for handling

UM; an approach, in our opinion, not entirely suitable for application in pervasive environments where seamless mobility is a paramount issue and small footprint devices are the norm, as is particularly the case in disruptive environments.

Additionally, published work relating to the use of ambient and pervasive technologies in disruptive environments or disaster management tends to focus more on service composition or other application-oriented aspects without considering the underlying networks issues. Such an example is the reported work of Kristensen *et al.* [13] which focuses on IT support in major incidents, such as the use of bio-monitors, patient identification and collaboration tools for response units, without considering how these applications could, or should, behave in the presence of network disruptions. The RASCAL system reduces this gap between specific autonomic aspects purely based on the network management and the autonomic aspects based on the user-level services deployed in disruptive environments.

3. The Autonomic Features of RASCAL

The RASCAL software system is a middleware communication layer offering vertical interfaces to communicative applications (typically user-driven) and to low-level network bearer modules. The purpose of the layer is to intercept all, or a selection of, application-specific messages passing through the local communication subsystem of a device in accordance with a set of dynamically configurable policies defining the prioritized actions to take regarding forward routing of the messages. These policies are thus used to guide the autonomic decisions that the RASCAL autonomic controller can take in response to events sensed from the environment. The most straightforward example is the detected failure of an infrastructure connection (say WLAN), whereby a predefined obligation policy may mandate that RASCAL re-route messages via an alternative network technology (say Bluetooth) to either their final destination or another node with an active infrastructure connection. An example of such a policy is described in Section 6.

This technology thus improves the potential for communicative applications to remain connected when deployed in environments subject to disruptive behavior. When RASCAL is deployed within the local communications stack of a device, we term the device as having become *"RASCALized"*.

The primary features of RASCAL fall into two classes: *connection-aware* and *usage-aware* communication.

Connection-aware communication implies the ability of RASCAL to be aware of all available (active and inactive) network connections, their parameterization and performance characteristics (e.g., Quality of Service (QoS) characteristics). This set of autonomic behaviors are triggered by changes in network resources, with some of the most significant operations being:

- **Network handover** : The capability of dynamically switching from one network type to another when communicating with other devices. This decision

can be taken based on the reachability of a device over different infrastructure or ad-hoc networks and on network availabilities. For example, we can consider handovers from an infrastructure technology (e.g., UDP) to an ad-hoc technology (e.g., Bluetooth) when communicating with a device in the local neighborhood.
- **Routing optimization** : The capability of enhancing multi-hop routing among network nodes. Parameters which affect these decisions can be based on several QoS parameters such as response delay, nominal and available bandwidth between network nodes, transmission errors, etc. For example, a self-optimization feature of RASCAL fitting into this group is the proactive evaluation of the transmission delay between two interoperating devices and consequently the use of an alternative path to reach the same target node.

Other behaviors within this category include those acting in response to fail-overs or high network load, etc.

As mentioned, RASCAL also offers *usage-aware* communication consisting of a set of autonomic behaviours related to the usage of deployed user-level services. For example, a group of rescue workers are on the site of a major accident with human casualties and must constantly maintain communication with both with one another and with a response unit concerning their findings and the positions of injured people. Due to the potentially disruptive nature of the environment network availability may be intermittent, but the goal to reliably deliver communication must persist. In this scenario the typical autonomic decisions to be taken include:

- **Transmission contingency**: The capability of providing alternatives to the default means of transmitting a message. This specifically includes making the best possible use of multi-technology transmission paths including cellular networks, IP infrastructure networks, satellite systems, MANETs, etc. An important parameter in these decisions is the importance of the message to be sent. An example is simultaneously sending high priority messages via two or more different technologies, and therefore routes, to improve the chances that they are successfully delivered to target nodes. The use of extra resources is justified by the importance of the content to deliver.
- **Content adaptation**: Adapting the content of a message (or stream). These decisions can be based on several parameters such as the number and the importance of the messages/streams to be sent. Examples include applying a codec to reduce the bandwidth consumed by a video stream, or simply stripping out the audio component and sending this in lieu of the video.
- **Deferred service provisioning**: Waiting until a connection is available before making routing decisions to mitigate uncertainty relating to the choice of optimal technologies or paths. Also in this case the parameters able to trigger this type of decisions are the volume and the significance of the information to be sent. This includes the need to buffer messages while awaiting a connection.

- **Role management**: Specifying user defined conditions which must be met before taking a particular action. A parameter which affects these decisions is the role of the end-user in a particular scenario. For example within a major incident response workers are divided into response units, structured in a hierarchical manner. In this scenario we can envisage policies which ensure a message (e.g., notification of an event) is sent to the right recipients in the role hierarchy (e.g., escalating).

All of these capabilities are controlled by user-definable policies that may be simply and rapidly specified/modified on-the-fly by either the user or local/remote automated routines.

Additionally, one other important feature of RASCAL is the notification, inspection and control interface available to the end user. This GUI specifically allows the user to remain aware of decisions made by the autonomic controller and to affect them if necessary. More details on this are provided in Section 4.4.

4. The Architecture of RASCAL

The RASCAL software architecture is depicted in Figure 1 and is specifically designed to be compliant with the standard autonomic control loop [2], in that it:

- *collects* sensory information from the system and the external world,
- *decides actions* using a policy engine,
- and *effects* those decisions to affect system behavior.

The architecture consists of three managed elements, which are in fact software services: an applications service, a networks service and policy service, all of which will be described later. Also present is the core decision control logic in the shape of an autonomic manager (RASCAL software agent), a policy engine and the user interface control.

The RASCAL software is designed to interact with different layers of the user-device communication stack. In the default case it interacts with lower-layer communications components dealing with bearer technologies, e.g., UDP, Bluetooth, etc., and with upper-layer components dealing with, for example, routing protocols, discovery, and services/applications. Other components may also interface to RASCAL through provided software interfaces.

As we believe a highly beneficial means of implementing the control logic of an autonomic manager is with a software agent, we elected to design the RASCAL architecture for implementation as a JADE (Java Agent Development Framework) software system. JADE [2] is an open source software agent platform and development environment [4]. Thus the RASCAL autonomic manager is designed for deployment as a JADE agent and the managed element interfaces are deployed as JADE kernel services, both of which are executable within the JADE runtime. In general terms a *software agent* is defined by Wooldridge [15] as a *"computer*

[2]JADE documentation and software is available from http://jade.tilab.com/

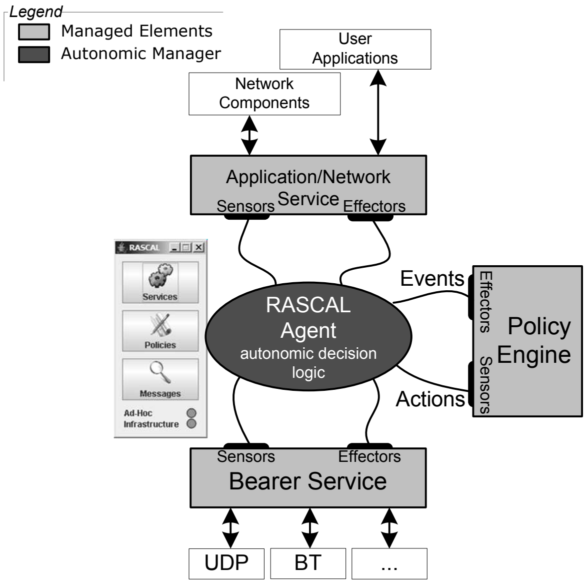


FIGURE 1. The RASCAL software architecture.

system that is situated in some environment and that is capable of autonomous action in this environment in order to meet its design requirements". A JADE kernel service is defined by Bellifemine *et al.* [4] as a *"software component which implements platform level features that can be grouped together according to their conceptual cohesion"*.

4.1. The Managed Elements

The RASCAL agent interacts with the external world via JADE kernel services. Each service is controlled through sensors and effectors. Effectors produce actions relating to instructions received from the RASCAL agent; they implement the *Command* design pattern [14]. Sensors collect information from the external world and provide it to the RASCAL agent for processing; they implement a simplified version of the *Half-Sync/Half-Async* design pattern [5].

The RASCAL system contains three JADE kernel services:

The Network/Application Service. This is used by the RASCAL agent to interact with upper-layer network services, such as routing and discovery, and application services facing the user. Messages passing through this interface may be inspected by RASCAL to determine whether any action is necessary by the autonomic manager in accordance with specified policies. A selection of interfaces are available allowing communication with a broad range of network services and applications.

The Bearer Service. This is used by the RASCAL agent to interact with the lower-layer bearer interfaces to both infrastructure and ad-hoc network endpoints.

Messages passing through this interface may be inspected by RASCAL to determine whether any action is necessary by the autonomic manager in accordance with specified policies. A selection of interfaces are available for a broad range of network technologies.
The Policy Service. This is used by the RASCAL agent to interact with the local policy engine (see Section 4.3). In brief, this engine possesses the operational rules that must be applied to control (or not control) the way in which messages are treated by RASCAL. The RASCAL agent uses these policy rules to effect this control.

4.2. The Autonomic Manager

This is the RASCAL software agent that controls the RASCAL system such that it exhibits the following autonomic behaviors:
Sensing. By installing sensors in the managed elements the agent is able to monitor new application messages to be sent, new messages received from the network or new network status events. Data is collected both asynchronously (the managed elements notify of a status changing) or synchronously (the agent explicitly request for information).
Compiling Knowledge. Intercepted messages and received events are used to create an internalized model of the external world. This compiled knowledge base contains information such as statistical flow data, historical fault logs, active and treated faults, discovered devices and the services those devices provide.
Decision Control. Whenever the internal knowledge base is updated, the RASCAL agent triggers a call to the local policy engine which dictates the policy constraints that must guide decision-making by the agent. This aspect is discussed in more detail in Section 4.3.
Proactivity. Actions can be executed by the RASCAL agent immediately, or postponed until some point in the future. In order to schedule such future actions RASCAL implements a model of time allowing proactive planning.

4.3. Decision Making

A core aspect of the RASCAL system is its reasoning system. The RASCAL agent receives messages from user-level applications and probes the environment using the previously discussed managed element kernel services. Decisions on how to treat the received messages are made locally using *policies*; a set of constraint rules governing system behaviour. One of the goals of RASCAL is to provide the end user with an easy means of authoring policies that will control the various autonomic features (see Figure 2). In order to modify the RASCAL behaviour at runtime, these policies are dynamically loaded when the device is running.

Policies are not coded directly within the agent behaviours. To be more flexible, the agent uses the Policy Service managed element, shown in Figure 1, to issue events to a policy engine and wait for a set of recommended actions to perform. The particular policy server employed by RASCAL is Ponder2[3] [16] citerussello,

[3]see http://ponder2.net/

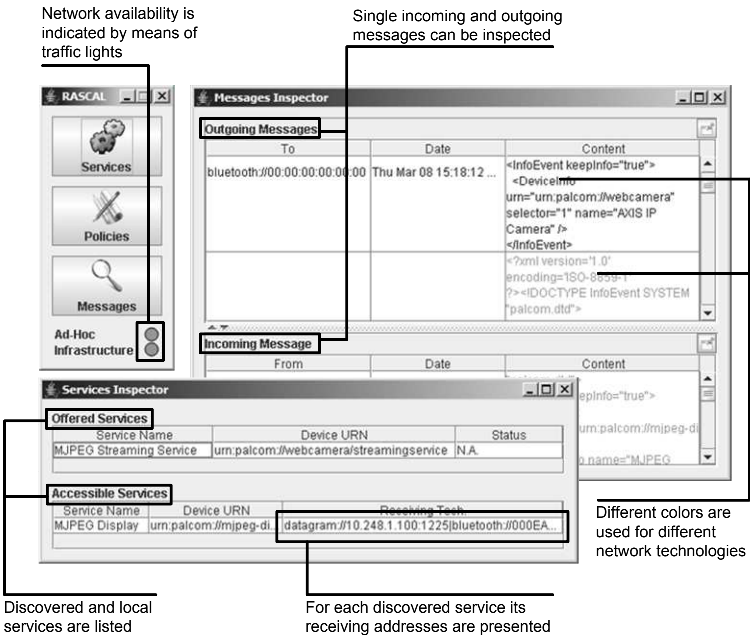


Figure 2. The RASCAL GUI

used as a local library, which uses an XML-based policy description language to define events and policies to be processed by the Ponder2 policy engine. The result of a policy is an action the RASCAL agent has to perform. Currently, RASCAL deals with *obligation policies*. An obligation policy is an Event Condition Action (ECA) rule in the deontic sense [18]. Given E, and C is true, it is obligatory that the agent performs A.

4.4. Graphical User Interface

The RASCAL user interface is designed for control and inspection using event-based interaction with the RASCAL agent. The main panel, shown in Figure 2, indicates the status of the various network interfaces available on the local device and a set of buttons to open inspection views. One of these views provides a list of all remote devices interacting with user-level services running on the local device. Additionally, a second view is dedicated to message inspection and a third to inspecting, editing and controlling policies definitions. Currently, the RASCAL GUI has been implemented to work only on laptops or personal computers but it can be easily adapted to other consumer devices like PDA, smartphones, etc.

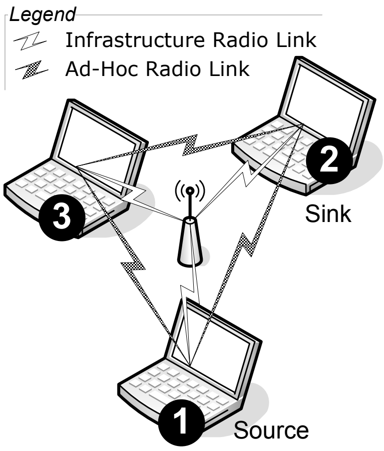


FIGURE 3. Laboratory experimentation setup.

5. Laboratory Experimentation

This section presents preliminary laboratory experiments conducted in order to validate RASCAL capabilities in terms of ensuring connectivity remains established even when some channels are disrupted.

The experimental setup for this evaluation was composed of three laptop nodes, each equipped with WLAN and Bluetooth adapters. Each node could communicate with the others using either of the two available network technologies (see Figure 3).

Each node was also equipped with the PalCom communication stack[1], which provided discovery services and multi-hop routing capabilities via the DSDV [23] routing algorithm. Selected test applications were deployed on top of the PalCom communication stack: The application running on node-1 (the source) was to send heartbeat messages every 3 seconds to node-2 (the sink), once it had been discovered. The application running on node-2 was capable of receiving and counting incoming messages. In this scenario, node-1 could reach node-2 directly, or via node-3. It could also occur that messages could be transferred via hops across different bearers.

To add uncertainty to the experiments, aperiodic network failures were simulated. Each node was equipped with a failure generator which, based on a mathematical model, blocked the transmission of messages over a particular network adapter for a certain time. The mathematical model was based on the *Markovian property* that the probability of the occurrence of an event does not depend on the history of previous events. Based on this property, technology failures were simulated with an occurrence rate equal to the inverse of the λ parameter of a *negative exponential* distribution. Furthermore, the duration of the failure was simulated

Table 1. Table of average stochastic failure occurrence time and duration per network bearer technology

Technology	Rate (mins)	Duration (mins)
UDP	2.5	2 ± 1
Bluetooth	1.25	2 ± 1

using the *Erlang-k* distribution. The expected average and standard deviation failure duration time were use to define the distribution. Table 1 shows the average failure occurrence time and the relative duration for each bearer endpoint. The choice of these values was based on experience gained when performing real-world evaluations (see Section 6).

In the experiment, every node was also equipped with a software component named *Failure Generator* which simulated the unavailability of a particular network bearer. In particular, using the parameters presented in Table 1 the component generated failure events that described when and for how long a network adapter had to be considered deactivated. When the event occurred, the failure was simulated and the node prevented from sending messages using that particular adapter. Each time an event was consumed, a new one was immediately generated. The failure generator reactivated an adapter when the failure duration time elapsed.

The entire experiment consisted of 20 runs of 10 minutes each. Every experiment contained a stoachastic number of failure events.

To measure the capabilities of RASCAL to ensure that communication remained established even when channels were disrupted, experiments were conducted both with and without the RASCAL component deployed. A node without RASCAL was only capable of communicating using a UDP bearer, with no ability to autonomically adapt. The measured output variable was the *number of messages successfully delivered to the sink* (node-2).

5.1. Results

Figure 4 shows the value of the measured output variable over 10 minutes when analyzing a single experimental instance. As can be observed, after the 10 minute cycle the number of messages delivered with RASCAL enabled was substantially higher than without it. In fact, during this period of time several network failures occurred, but nodes with RASCAL deployed continued to discover one another with heartbeat messages sent continuously using different routes. On the other hand, with nodes without RASCAL deployed when a failure occurred the sink was no longer discovered and no heartbeat messages were therefore transmitted from the source to the sink (this is represented by the flat parts of the dotted line in Figure 4).

A more significant result is given by Figure 5 which shows the value of the output variable over the all 20 considered instances. This box-plot shows that the average number of messages successfully delivered to the sink when RASCAL was

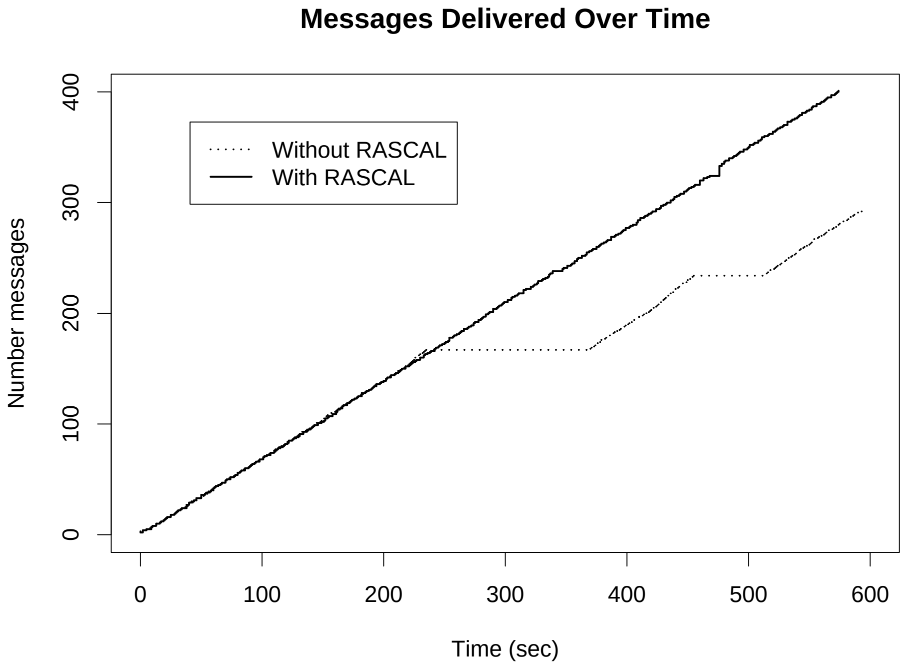


FIGURE 4. Number of messages successfully delivered to the sink in an experimental instance.

deployed, were definitely better than without it (339 messages against 267). Naturally, for simple instances with no failures the presence of RASCAL was irrelevant. In fact in both cases the maximum number of delivered messages is almost the same. The results change however when many failures occurred since the minimum of this output variable over 20 instances without RASCAL is 110 and with RASCAL is 221, i.e., system performance improved by more than 100%. This allows us to conclude that the more disruption occurs to the network infrastructure, the more benefit is provided by the presence of RASCAL technology - thanks to its capability of utilizing alternative paths over different technologies to deliver messages.

To be certain of the real significance of the obtained results over 20 instances the Wilcoxon Paired Rank Sum Test was applied. This test stated with a confidence level higher that 95% (p-value = 0.0008909) that the improvements generated by RASCAL are statistically significant.

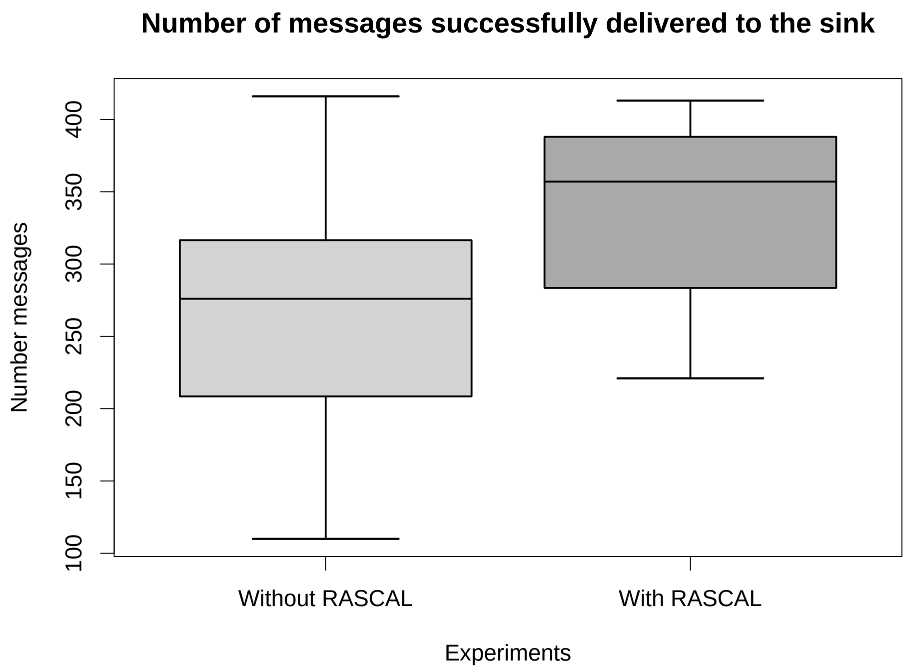


FIGURE 5. This box-plot represents the number of messages successfully delivered over the 20 experimental instances, with and without RASCAL.

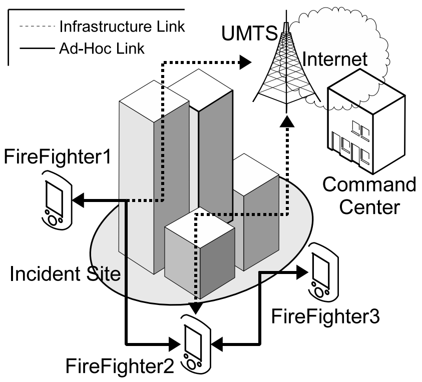
6. Real World Evaluation

RASCAL has recently been integrated into the iterative, participatory design process practiced in the PalCom project[1]. We are currently carrying out experiments with end users in major incident emergency response scenarios. This section presents an overview of one of the mocked-up situations of a real world major incident conducted recently.

Within this experiment a building fire is considered. This particular scenario demands fast and decisive action, often in life-threatening situations. It also requires collaboration between numerous people located in different, often changing areas: personnel at the incident site including firefighters, police, and paramedics, at the command center, in vehicles, and others.

Each of the people involved, and many of the vehicles and other equipment, are associated with one or more electronic devices such as radios, biosensors, GPS, health recorders, handhelds, tablet PC, etc. In the fire scenario different devices run different crisis-relevant applications including VOIP clients, instant messengers, map services and other collaborative tools.

The particular scenario is illustrated by Figure 6(a). Three firefighters (FF) are moving in relative proximity to one another attempting to evacuate people from a building on fire. They are using small, wearable "RASCALized" PDAs, each with a built-in camera running a map service. Their duty is to notify the command center (CC) and the other local team members of findings related to visited building(s), i.e., the positions of injured people. To do this, they make special marks on the map displayed on their PDA. They may also take pictures to assist the command center with gaining a visual overview of the incident location and status.



(a) The conducted mocked-up situation.

```
<use name="/policy">
  <add name="contentAdapt">
    <use name="/template/policy">
      <create type="obligation"
          event="/event/mmstatus" active="true">
        <arg name="alive"/>
        <condition>
          <eq>protocol;datagram</eq>
          <eq>!alive;false</eq>
        </condition>
        <action>
          <use name="/rascalmo">
            <sendLowResolutionPicture
              protocol="bluetooth"/>
          </use>
        </action>
      </create>
    </use>
  </add>
</use>
```

(b) Example of policy to send low resolution pictures to the command center towards the ad-hoc network when the infrastructure connection is not working anymore.

Figure 6. Real World Scenario.

In terms of connectivity, FF1 and FF2 are connected via both ad-hoc (HOC) and infrastructure (INFR) networks and FF3 only via an ad-hoc connection. In this situation, through the multi-hop capabilities of RASCAL all four actors (the three firefighters and the command center) are able to communicate one another. For example FF3 communicates with the command center via the ad-hoc connection with FF2.

In this particular scenario, the RASCALized devices used by the firefighters are equipped with the following policies:

1. `IF (infrastructure_connected) THEN send map data to CC and FF via INFR.`
2. `IF (!infrastructure_connected) THEN send map data to CC and FF via HOC.`

3. `IF (infrastructure_connected) THEN send high resolution pictures to CC via INFR.`
4. `IF (!infrastructure_connected) THEN send low resolution pictures to CC via HOC.`

Figure 6(b) shows the definition of the final policy in the list presented above. This policy sends low resolution pictures to the command center when the device is not infrastructure connected. It receives *mmstatus* events which denote whether a network interface is available or not. This event has two associated parameters: the interface protocol and its current status. The only condition that triggers this policy is that the infrastructure connection is unavailable (see the XML *condition* element). The action *sendLowResolutionPicture* triggered by this policy notifies the RASCAL agent to decrease the resolution of the pictures for the command center and to send them using the ad-hoc network (see the *protocol* attribute of the *sendLowResolutionPicture* XML element).

In this scenario, FF1 has policies (1) and (3) activated. When FF1 moves into an area where the infrastructure connection fails, this is detected and policies (2) and (4) automatically become active. The RASCAL agent running on the FF1's PDA is thus notified by the policy engine and hands over all communication with FF2 to the available ad-hoc connection. Given the importance of sending images to the command center and giving the low nominal bandwidth of the ad-hoc channel, pictures are first automatically reduced in quality (i.e., resolution) before transmission.

Later, when FF1 returns to an area with infrastructure network coverage, communications with the command center are automatically returned to the infrastructure connection with images once again sent in normal, high resolution.

A sequence diagram of the actions taken by FF1 to send pictures to the command center is shown in Figure 7. The diagram considers the situation both with and without the infrastructure connection.

Further real world experimentation with emergency services is ongoing.

7. Conclusion

This paper has provided an overview of the RASCAL autonomic communications software component designed to manage connectivity in environments subject to disruptive events. The component can be interfaced with device communication stacks and offers features including automated network handover, routing optimization, transmission contingency, content adaptation, deferred service provisioning and role management.

The key components of each local RASCAL deployment consist of a software agent autonomic control logic and a Ponder2 policy engine with which the user is able to define rules guiding and constraining the agent control logic. The autonomic controller interfaces with three (or more) managed element services, of which the policy engine is one.

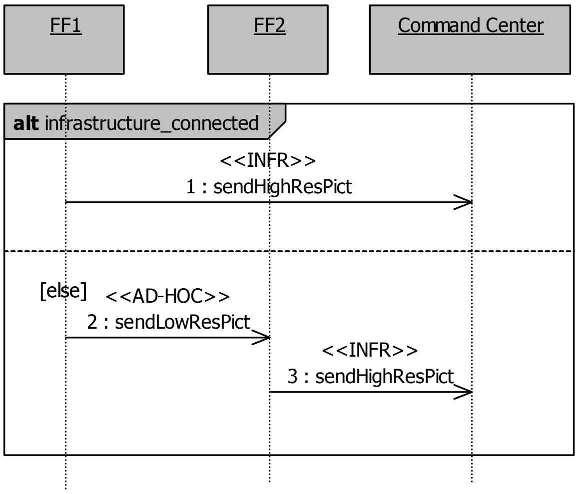


FIGURE 7. Sequence diagram of the actions taken by FF1 to send pictures to the command center.

The reported laboratory experimentation has demonstrated the operation and performance of the system under controlled conditions, with results proving the intuitive conclusion that RASCAL significantly aids the maintenance of sustained connectivity in disruptive environments. Moreover, the reported real world evaluation offers an insight into how RASCAL has been deployed in an actual setting involving firefighters working collaboratively at an incident site.

As a work in progress, RASCAL remains under a continuous refinement, in particular as feedback from real world evaluations is gathered. Particular ongoing work includes areas that enhance the autonomic capabilities of the system including the incorporation of improvements to the Ponder2 policy language (undertaken as an independent project to RASCAL), and to the autonomic controller logic. The improvements to the policy language include a new means of expression using a form of process-algebra over actions. This allows the expression of a set of actions (i.e., workflow) rather than the current limitation to atomic actions. Further planned improvements relate to the inspectability of the RASCAL system and its use in composing dynamic assemblies of computational devices and services with flexible, self-adaptive communicative connections.

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11. Ethnography and interdisciplinarity

11.1 The possibility of collaborative systems

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Status: Submitted

The Possibility of Collaborative Systems

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ABSTRACT

Many now recognise that collaborative technology requires an understanding of collaborative action that is qualitatively different from that of conventional HCI. Sociology and Anthropology have come to the fore as disciplines offering this understanding, often under the shorthand of ‘ethnography’. But have they delivered it? This paper considers two forms of ethnography: as critical social science and as anatomist of work practice. It argues that both have delivered, but in highly troublesome ways, mainly because ‘designing’ for social action is simply intractable. Does that mean there can be no such thing as collaborative systems? Since successful systems exist, that cannot be the case, and the paper describes a programme for treating the design of collaborative technology as a pragmatic matter that takes careful account of the possibilities and limitations of diverse contributors.

Categories and Subject Descriptors

I.m. Computing Methodologies: Miscellaneous.

General Terms

Design, Human Factors, Theory, Verification.

Keywords

Collaborative Systems, CSCW, Ethnography, Participatory Design, Artificial Sociality.

ETHNOGRAPHY AND COLLABORATIVE SYSTEMS

Computer supported cooperative work (CSCW) as a research field has many virtues but one of its most distinguishing features is the home it has provided for ethnographic studies of work practice. CSCW has hosted an extended experiment, now of more than fifteen years’ duration, in displacing psychology with sociology and anthropology as the core partner disciplines for computer science in ‘requirements’, in human-computer interaction, in ‘evaluation’, and sometimes in core design. While the influence of ethnography can now be found in other areas of information systems design, as described by Button and Dourish (1998), it is still only in CSCW that it can pretend to this pre-eminence as a junior partner to computer science.

One might think that the nature of this interdisciplinary relationship has by now been exhaustively ventilated, for example in [3] [59] [50] [21] [5] [56] [34] [18] [26] and more. However, I will try to show that more precision is both possible and necessary regarding what ethnography can provide and, perhaps more significantly, what it cannot.

In this paper I refer to the participation of the sociological sciences in design as 'ethnography', which is accurate in that most of the work I refer to does use ethnographic fieldwork techniques. It is also slightly misleading, however, as I argue that much of their force comes from the deployment of social theories which have no necessary connection with ethnography.[1] But I drop the term 'sociological sciences' because it is clumsy and risks appearing to subordinate anthropology, which is the main disciplinary affiliation of many pioneers and participants.

In the paper I will consider ethnography from the perspective of its contribution to and participation in systems design. This perspective is optional. Social scientists have no obligation whatever to participate in design and, as we shall see, are fully able to study it critically without such participation. Equally designers may, as Dourish [26] argues, have other and better reasons for engaging with ethnography than its 'implications for design'. But some ethnographers have chosen to try to participate in design; and designers are entitled to take the view that, whatever their other interests and engagements, their professional interest in an interdisciplinary encounter with ethnography centres on what this participation can deliver.

In this spirit, the initial premise for the inclusion of ethnography was that it would contribute to 'requirements capture' in something of a 'service' relation to systems design. It is now generally understood in CSCW that the relationship is more complex, but even here I argue that there is room for more clarity in what can, and cannot, be expected from ethnography as a participant in design. This clarification is consequential for the process of designing collaborative systems. Further, as ethnography gains visibility as a means of answering the call for more and better user focus, there is a risk of repeating these confusions in other areas of information systems design such as ubiquitous computing.

ETHNOGRAPHY AS CRITICAL SOCIAL SCIENCE

Ethnography as critical social science shows that the key determinants of a 'good' design often lie well outside the normal concerns of the engineering sciences. For example, within CSCW several classic studies have demonstrated the political aspects of design projects. Egger and Wagner [28] showed how contested motives and objectives as between doctors, nurses and administrators produced struggles over the form of a time-management and scheduling system for a surgical clinic. In this situation multiple power struggles are in play over competing interests. There is the struggle between the established profession of doctors and the rising professions of nurses and managers. This is overlain by the gender politics of the traditionally male profession of doctors and the traditionally female profession of nurses. The state is also a party to these struggles through a 'modernising' agenda of increasing output and reducing costs, using managers as proxy, and making expedient alliances with other parties. In this setting the question of the 'best' surgical scheduling system is inseparable from these struggles, and becomes a question of 'best for whom?'

[1] I agree with Anderson [3] that, while necessarily involving fieldwork, the essence of ethnography is analysis. But, obviously, not all analysis necessarily involves ethnography.

In ‘Do Categories have Politics’, Suchman [63] initiated a debate over the political implications of a particular interpretation and deployment of speech act theory in THE COORDINATOR. And the study by Suchman and her colleagues of the coding of legal documents critiqued the distinction between the ‘objective’ features of documents (which can implicitly be identified using low skilled work) and their ‘subjective’ features (which implicitly require high skilled, professional work to identify them.) They show that, to the extent that these distinctions are meaningful, the work both of lawyers and of coding clerks is rich in both of these features, and is densely populated with both mundane and judgmental activities [64]. Evidently, then, following an initial design brief for a document processing system couched in terms of this objective-subjective distinction would hard-wire a dysfunctional fiction that reflected the relative power of lawyers and clerks rather than the nature of the work.

As well as particular systems, whole areas of design may be open to critical analysis. For example Suchman, again, offers a cultural critique of futurist scenarios for ambient intelligence in terms of fantasies of robotic agents providing cosseting and personal services in replacement of a lost servant class [66]. In management programmes of change, workers are often characterised as rigid and inflexible, and technology is often proposed as the vehicle for work redesign. But Harper et al. [36] investigated work practices and technology in banking and point out that far from being in a position to leap into the future with new technology, they are heavily constrained by the massive technology investments they have made in the past, the technology being far more obdurate and resistant to change than any of their staff: ‘The bold investments of the past are tying their hands in the present and hence handicapping their move into the future.’ (ibid. 157)

These last examples show that systems design is not only a bystander in the political struggles of others. The information technology industries, including their research arms, benefit hugely from an ideology of IT-led modernisation that privileges expenditure on information systems. This makes it very difficult to raise such questions as whether spending tens of billions of euros or dollars on, say, a national electronic patient record system could, even if successful, deliver as much benefit as an equivalent amount spent on more hospitals, operating theatres and staff.

It would be patronizing and inaccurate to say that designers do not know about the politics of information systems and need to have the ‘scales lifted from their eyes’ by critical ethnographers; indeed the Scandinavian school of participatory design [31] was engaged with these issues in the early 1970s, long before ethnographers were (although it sometimes seems that the normal working of the industrial systems development process is shaped to keep designers in ignorance, as when a requirements specification descends ‘from the sky’ with no means of knowing whether it was derived from management or consultants who may have little direct experience of doing the users’ work.) Rather, what distinguishes ethnographers is that, as social scientists, they are, for good or ill, ‘primed’ to approach the setting in terms of certain theoretical orientations – for example[2], to view a site of work as one inherently characterised by power relations. In the case of surgery scheduling introduced above (Egger and Wagner, 1993) a feminist perspective serves to make power struggles between doctors and nurses immediately visible.

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[2] I will come to ethnomethodological ethnography, which sometimes claims that it eschews theory in favour of pure description, in the next section. I claim this is nevertheless a ‘priming’ theoretical orientation, albeit one that often regards social sciences’ interest in issues such as power as misguided.

The case of the coding of legal documents [64] is of particular interest in that Suchman states that her perspective is informed by feminist social theory, especially the suspicion it engenders of essentialist dualisms – here, of ‘routine objective’ versus ‘judgmental subjective’ categorisation. Suchman does not comment on this but in the fieldwork example she describes, the lawyer is female while the coding clerk is male, so the consequences of a feminist theoretical inspiration go far beyond simply finding the subordination of women. Where there is a distribution of power, albeit an unequal one, this may be visible in, for example, contests over the design of a system, as with surgery scheduling. Where power is overwhelmingly unevenly distributed, as in the coding of law documents, no contests may be apparent, and the situation may be detectable only through close analysis.

Although power relations, for example, will never be wholly absent in any work setting, this is not to deny that there can be any relatively neutral issues or occasions in systems design. It is perfectly possible that all parties could agree that one design is significantly better – more sensitively tuned to real working practices and needs – than another, without threatening the interests of anyone other than the alternative supplier. From a social science perspective it is, however, a feature of ideology that the engineering sciences so overwhelmingly offer *only* a technocratic account that is blind to social location.

It is of the essence of political and power relations that they are hotly contested and debated, so there can be no question of recommending that designers simply ‘act on the findings’ of critical ethnography. The consequence is to invite practitioners of the engineering sciences to incorporate critical social science perspectives in their work, as core participants in the debates, and so gradually to elide the distinction between the study and practice of design, and science and technology studies [6]. This may be a feasible strategy in a research context, and many in CSCW and Participatory Design are doing so. Designers cannot, however, stand outside prevailing social arrangements, so their possibilities for following this agenda may be strongly constrained, especially in industry, but also by the genre conventions through which the engineering sciences are policed [26].

DESIGNING FOR SOCIALITY

The second set of connections between ethnography and systems design has quite a different character, to do with the ways in which the detailed analysis of work practice can inform the details of collaborative systems. The foundational study in this area, of course, is Lucy Suchman’s *Plans and Situated Actions* [62] (PSA), a work of almost unparalleled influence in the relevant areas of both social studies of science and computer science (Google Scholar shows 3143 citations.) Suchman points to various antecedents including Harold Garfinkel’s development of ethnomethodology [30], Hubert Dreyfus’s *What Computers Can’t Do* [27] and Jeff Coulter’s sociology of mind [23] [24]; but it was the demonstration effect of PSA that changed the landscape. In it, Suchman explored the distinction between cognitive science, whose strategy has been to represent mental constructs and then stipulate the procedures by which those constructs are realised as action, and ethnomethodology, which treats the contingency of action not as a problem but as, ‘the essential resource that makes knowledge possible and gives action its sense.’ [62] p. 179. For ethnomethodology, the organisation of situated action is seen as an emergent property of moment-by-moment interactions between actors, and between actors and their environment (idem.) Machines, however, do not have access to these interactional resources.

The specific problem that PSA analysed was that of providing an 'intelligent' help system for an advanced photocopier. In four pages near the end of PSA, Suchman discusses practical solutions towards the problems she identified – in other words, the implications for design – confining herself to the relatively specific area of intelligent tutoring systems [62] pp. 181–185. She mentions some contemporary approaches that proceed in part by seeking to mirror aspects of human interaction, such as responding to accumulating inconsistency by looking for an alternative model of the student's knowledge, and seeking to repair troubles. Suchman expresses no strong opinion on the feasibility of these approaches, pointing to a number of difficulties, and I am not aware that any great advances have in fact materialised in this field.

In subsequent work, Suchman has reviewed the 'new AI' of situated (embodied) robotics [13], affective computing [49] and the sociable computer [12], but does not find in them grounds to abandon her 'enduring skepticism regarding the rhetorics of machine intelligence' [65]. As well as showing that these machines are very imperfectly and contingently realised even in their own terms, Suchman argues that even as imagined they would reproduce many of the deficiencies of perspective of the old AI: if embodied then with a 'Cartesian' body subordinated to a controlling mind, and with affect understood as the expression of an underlying emotional 'state'. Thus, 'the project [of new AI] is less to displace an individualist conception of agency by a relational one, than to replicate the biological individual in silicon.' [65] Suchman goes on to advocate a relational, performative account of sociomaterial phenomena, whereby both persons and machines are contingently stabilised through particular arrangements. But this has the character of a penetrating anthropological examination of the human and the posthuman, not of a contribution to the design of any system.

It is important to recognise that these limitations do not only apply to systems that make explicit claims for artificial intelligence or aspects of human substitution. In CSCW we find a wide range of studies that have shown comparable difficulties with actual, planned or contemplated information systems that, without necessarily making any such explicit claim, seek in various ways to 'act for' or 'act with' human users. The long list of such studies now includes:

- automating air traffic control [40] [35]
- the 'deviant' sequencing of activities in kanban production [41] [57] and in sales ordering and invoicing [21]
- multimedia technology and surreptitious monitoring in London Underground control rooms [39]
- constant interruption in the small office [53]
- individually-oriented technologies and voice recognition in a City (financial) dealing room [38]
- workflow in the print industry [10]
- constructive deviation from formal methods in software engineering [22]
- the specificities of organisational memory [51]
- the difficulties for achieving 'immersion' in the relation between local and virtual environments [11]
- a critique of group decision support systems [4]
- 'routine' document coding in a legal office [64]

- augmenting objects for ubiquitous computing [67]
- service integration and electronic medical records [37]
- the deficiencies of modelling in healthcare [7]
- centralisation, and 'knowledge management' versus 'expertise sharing', in ambulance dispatch [47]

and more.

All of these have drawn on the same ethnomethodological framework to reach similar conclusions to PSA, and the great majority have warned of the dangers inherent in some contemplated system for those domains. All have undertaken ethnographic studies of work practice but (in my estimation) none has argued or demonstrated that this offers clear and detailed directions for how a support system should be designed (though they quite often have things to say about how one should not be designed.)

It would seem from this that the real lesson of *Plans and Situated Actions* and its successors – at root, the lesson of their phenomenological and ethnomethodological basis – is not that one cannot design a system that will successfully recognise and accommodate to a user's actions and react appropriately *unless one employs ethnographers to analyse the work practice*; it is that one simply cannot do this at all. This is not (not only, and not primarily) due to deficiencies in the analysis; it is because 'social' systems (see below), however complex, cannot match it. For them to do so would require them to achieve the impossible by exhibiting 'artificial sociality', in ways and for reasons that are discussed in the next section.

Just as ethnography as critical social science is 'primed' to view technology in the workplace from particular theoretical perspectives, so too ethnomethodological ethnography is 'primed' to see the phenomenological aspects of work practice. What is seen is that social order and social activity are produced 'in the doing', afresh each time, and are not the instantiation of any script or set of rules, however complex. It is not a surprise, therefore, that whatever domain or activity one examines, one will find this. The studies listed above all show, among other things, how this applies in the settings and for the systems that they are engaged with.

This places strong constraints on the direct contribution of ethnographic studies to collaborative systems. They can describe features of a system that would be useful on a given occasion. But the whole point of occasioned practice is that it cannot have general application, and one cannot anticipate what other occasioned uses this same system might impede, or how something that works well for some may impact negatively on others [52]. Perhaps that is why:

- it is very difficult to point to successful[3] CSCW systems that were explicitly designed as such. In some ways the public face of CSCW seemed more impressive 15 years ago, with LOTUS NOTES and THE COORDINATOR, than it does now.
- such positive interdisciplinary findings and recommendations as emerge appear largely ineffective.
- there is a continuing round of somewhat repetitive and conservative analyses of work practice, with their (implied) injunctions against change.

[3] What 'success' would mean in this context is discussed in section 7 below.

ARTIFICIAL SOCIALITY

Artificial sociality (ASoc) or 'socionics' [29] is a term that exists in the literature, but so far as a specialisation within the field of AI, mainly concerned with role modelling and game theory in multi-agent systems, e.g. [54]. One project in particular, the INKA[4] project, active between 2000 and 2005, has had substantial participation from sociologists [45] [46]. Well grounded in a range of sociological perspectives, the participants are aware of the issue of situated action, and have tried to meet it by advocating the use of 'informal', self-organising social roles based on symbolic interactionism rather than functionalism [45]. On this basis they have used 'participatory simulation' (ibid. 1.3) to try to produce 'mixed initiative systems' (ibid. 1.4) exhibiting 'hybrid sociality' (ibid. 1.1.) They applied this in a system for negotiating exchanges of work shifts in a medical setting, but admit that they have so far only been able to implement this in terms of formal role models (ibid. 2.8.)

The kind of artificial sociality implied by an ethnomethodological perspective would be very different, and would require a system to exhibit some kind of equivalent of the accountability, documentary method, intersubjectivity, recipient design, and repair that people regularly and unproblematically achieve in their interactions. Accountability is to do with the ways in which we make our actions rationally accountable for each other. It is, for example, an accountable matter to fail to respond to a direct question, so if I do so because I have my mouth full, I may well do something like exaggerated chewing to indicate the 'problem'. The documentary method of interpretation is in a way the mirror of this situation, to do with how we will seek creatively for a relevant or plausible meaning of or reason for an apparently incongruous or irrational action on the part of another. Intersubjectivity is the condition of mutual attunement that arises from this kind of successful adjustment in understanding what interlocutors or interactants are about. Recipient design refers to the ways in which we attune our interactions to this particular person and their circumstances, what we believe they know already, what their purposes are in relation to the matter in hand, and so on. And when it becomes evident that all this has failed or broken down in some way – our interlocutor has 'got hold of the wrong end of the stick' – we can quickly recognise this and take action to repair the situation in a manner that is appropriate to this particular occasion, such as further elaborating something or putting it another way.

There is a perspective in CSCW that advocates something close to this: that of Button and Dourish on 'technomethodology' [19] [20]. They call for a theoretical rapprochement between ethnomethodology and systems design, in which design does not try to take up particular observations from ethnomethologically-inspired ethnography, but instead incorporates into itself ethnomethodology's theoretical perspectives and procedures (and vice versa). The concern then becomes not, 'with the design of this system or that system, but with the design of systems.' [20]. They wish to apply this in a variety of ways, but they pursue it in that paper through considering the relationship between abstraction in system design and accountability in ethnomethodology. Drawing on Open Implementation [42] and computational reflection [61], they propose replacing abstraction in user interface design – with its metaphorical representations and information hiding – with two interfaces operating

[4] INKA stands for 'Integration of Cooperating Agents in Complex Organisations'. The project was carried out by the Artificial Intelligence Group of the Department of Computer Science at Humboldt-Universität zu Berlin and the Institute for Sociology, Technology Studies, at the Berlin Technical University. See: http://www2.informatik.hu-berlin.de/ki/inka/index.html

at different levels: a traditional one, using abstractions, and a metalevel interface with a rationalised model of the inherent structure of the system. This, they argue, will enable systems to offer accounts of their own activity that arise reflexively in the course of action, as is the case with human interaction.

They illustrate this with the example of file copying over a network. Instead of the usual percentage bar to show progress, which bears hardly any relation to what is actually taking place, and provides no useful information in the event of breakdown about where and what went wrong, they suggest showing this as a succession of filling and emptying buckets representing real stages in the transfers. They claim this would provide accountability of the system's actions. However, it seems to me that this is far from the case. The ways in which we make our actions rationally comprehensible (accountable) to each other are recipient designed, organised around the circumstances of the particular occasion, and subject to repair (further elaboration, putting things another way) as needed. The point is not only that people in social engagement can choose from an immense repertoire of accounts or explanations as the occasion demands; it is that these accounts need not exist prior to their use: there is no prior model. The 'buckets' (or any other) representation, by contrast, necessarily deploys a particular, fully-specified model. The obvious risk is that this may provide a distracting surfeit of information on most occasions, but insufficient means to take appropriate action when something does go wrong; the key point, however, is that the system cannot 'know' this and accommodate. Though I argue, therefore, that this proposal does not amount to machine accountability, I nevertheless regard it as an important element in the 'next best' basket of compromises that I will advocate below.

I am not sure that I would wish to argue for the intrinsic impossibility of artificial sociality. I do not hold that a human has any other than a material substrate, so there is no reason in principle why any given human capacity might not eventually be artificially reproduced – save that, to the extent that this remained 'a bodied individual in a physical environment, rather than a socially situated individual' [2] quoted in [65] it might not achieve very much. But I consider that to be so immeasurably beyond our current capacities as to be for all intents and purposes unattainable. I also think it likely that so large a qualitative breakthrough would be required that significant incremental advances starting anytime soon cannot be looked for.

This claim has affinities with what Ackerman [1] has called the society–technology gap. He also concluded that we cannot look for the gap to be overcome in the short or medium term, and that compromise and amelioration measures are therefore necessary.

NON-'SOCIAL' SYSTEMS

I have tried to show the severe difficulties that attend systems that are 'processual' or 'procedural' in the sense that they seek to recognise and respond appropriately to users' actions and context and so to 'act for' or 'act with' the user (what we might call 'social' systems). It seems intuitive that collaborative systems would have to be like this. But does that apply to all systems? Can one draw a clear, or even a vague, distinction between these and systems that do not attempt this and are somehow 'flatter', more passive or more neutral tools? Here, the concern would be to provide, or replicate, means and media for communication and representation, not in order to 'engage' in social interaction, but so that appropriate social interaction can take place. Really powerful and useful systems, such as telephone, email and file transfer, arguably do exactly this. It is not easy, however, to see how a clear distinction would apply, since something as basic as deciding the collection of items to display on a particular screen involves assumptions and a model about the user's needs, purposes and likely actions. It seems clear, nevertheless, that there is a qualitative difference between, say, email and a workflow system.

O'Neill et al. [48] propose a strategy of this kind in considering how to provide remote user support for photocopying and printing machines. Arguing that 'representation can be good enough', they propose a voice channel between on-site users and remote help experts, together with a representation available to the experts which only shows the state of the machine (which doors are open, trays pulled out, etc.) based on sensors in the machine. The argument is plausible, though completely untested. It focuses on the question of when and how a system is 'good enough', to which I return below. Another example is the setup devised by Kirk et al. [43] for remote assistance for the physical assembly of components, in this case Lego models. Here, a remote assistant has an overhead video camera view of the subject performing the task, while a video overhead view of the assistant's hands is projected 'on top of' the subject's hands. It could be objected to this that it involves an artificial laboratory setting which is designed to play into the capacities and constraints of the setup. It is unclear how many real world activities would sufficiently replicate this situation and, as the authors themselves point out, there can be no knowing what further difficulties would then emerge. It seems clear, though, that it at least provides a promising basis for further investigation. An interesting aspect, however, is that – involving as it does a set of reciprocal video cameras and projectors – it so far avoids the pretensions of a 'social' system as to be in some senses barely an information or computing system at all. (There are, of course, many other studies in this general vein, such as the many experiments with collaborative drawing. These have mostly, however, thrown up at least as many problems as solutions.) In general, though, it seems clear that the simpler, more 'representational' and tool-like a system can be, the better its chances of being useful. In this vein, perhaps the lateral, 'representational' answer to organisational memory is the search engine, and to workflow and coordination is just email.

WHAT ETHNOGRAPHY *CAN* DELIVER

I have argued that ethnographic studies of work practice face strong constraints in specifying how collaborative systems should be designed, but it is equally important to clarify what they can deliver with confidence.

First, they can identify and explicate crucial aspects of how activities are currently achieved. The introduction of any system must therefore either avoid disrupting these activities, or show convincingly that they have been fully substituted or superseded. The systems in contemplation often fail this test. A classic illustration of this is the study by Heath & Luff [39] of the work of line controllers and information assistants on the London Underground, where they show the importance of surreptitious monitoring – their ability to see and hear each other – in coordinating their work. Treating the work of each of them in isolation, and 'privatising' it onto computer screens, would obviously disrupt this coordination.

Another illustration is the study by Rouncefield et al. [53] of work practices in a small service-sector office whose members – as a collectively-adopted rather than management-imposed strategy – hoped that office systems could relieve them of routine paperwork and free them to spend more time on customer-facing work. The researchers found that, though the use of paper forms involved a lot of repetitive entries, the ‘ecology’ of paper in the office was a major resource for making the state of individual and overall work visible and so facilitating coordination and awareness, e.g. in marking what had been done and what needed to be done, who was in need of assistance, etc. Their work was subject to constant ‘interruptions’ to deal with customers and other staff, but paper was effective in physically marking their point of return, e.g. in enabling them to straightforwardly pick up where they left off with a pile of forms. Their principal conclusion, though hedged with some caveats, was that computerisation risks disruption.

Ethnographies cannot, however, know that they have identified *all* the crucial aspects of how activities are currently achieved. They may have failed to spot them, or they may not have arisen during the study. More fundamentally, the undetermined character of social action means that there is no sense to the concept of ‘all the crucial aspects of how activities are achieved.’ The smallest feature of work redesign may turn out to be fatal for particular actions and coordinations.

Second, ethnographic studies can identify some problems or difficulties that people actually encounter in their work that *may* be amenable to technical support. This is not as obvious as it seems. The examples above show that a designer’s first instinct may be to see the use of paper forms as crying out for computer support. Yet paper may often be unproblematic, congenial and rich in affordances, where electronic equivalents would be inconvenient and disruptive (see also the discussion of paper flight progress strips in air traffic control in [35].) An example of a difficulty actually encountered is that of emergency service personnel trying to achieve overview in the chaotic and fast-paced setting of a major incident [44]. What constitutes ‘overview’ is a matter for careful dissection, since in essence it concerns assembling the resources necessary to achieve an adequate qualitative understanding of what is happening. This involves not only knowing where people, vehicles and equipment are, but also what people are doing and how they are communicating – for example through their embodied conduct – their orientation to the situation. This is, though, a starting point for investigating the possibilities for technical support, for example with pervasive systems.

Similar difficulties arise, however, that it is impossible to predict that a proposed solution will work and that the smallest feature may make it impracticable.

PRAGMATIC STRATEGIES FOR COLLABORATIVE SYSTEMS

Given the difficulties discussed in preceding sections, it would seem that the puzzle is not why some systems fail, but how it is that systems ever succeed. Yet there are very successful, useful and even enjoyable systems. Perhaps we urgently need research into why this is, and what it is about successful systems that makes them work. ‘Success’ of a system will always be a relative matter, and perhaps primarily relative to the alternatives. Do they, when realised in the round, offer a significant advantage? However troublesome, are they overall significantly less trouble than what obtained before, at least in some clearly identifiable circumstances (such as, for a collaborative environment, avoiding a tiresome journey to do co-located work.) And of course, are they significantly better than much simpler alternatives, such as email, file transfer and telephone.

It will clearly help to keep things simple, to avoid systems that attempt to ‘act socially’, and wherever possible to go for ‘flat’ systems that work as neutral or representational tools or instruments. Then, users can adapt flexibly to the system rather than expecting the system to adapt flexibly to users.

But what if this is not possible, and a whole area of activity which seems to offer major opportunities cannot be tackled without a more ambitious approach? An example of this is ubiquitous computing, where Weiser's recommended approach was indeed to keep things simple [68], but where that may not be compatible with other aspects of his vision. Weiser famously proposed that computers should weave themselves into the fabric of everyday life until they are indistinguishable from it, and so called for the computer to disappear or become invisible. But he also acknowledged that we need to be able to bring the computer and its actions back into the foreground of our attention again when required – when something is going wrong, for example [69]. But how are we to know that ubiquitous devices and services are available in our environment, in a way that does not involve thrusting themselves distractingly on us when we already know about them or do not wish to use them, while at the same time presenting themselves appropriately for the new arrival or naïve user? And then how to cope with the further complication that a given person may usually wish them to be invisible, but sometimes (when? how?) to be manifest? There is also a serious and so far largely unacknowledged problem of scale. Weiser wrote that, 'The real power of the concept comes not from any one of these devices; it emerges from the interaction of all of them.' [68] Weiser imagines a room populated with hundreds of such devices, all potentially in interaction. But such an environment would be bewildering, alarming, annoying and potentially dangerous. Suppose we now enter a large office, a train station or an airport and scale this situation up by a factor of one hundred or one thousand. How should these devices and services behave?

One way of describing this is that we wish computing to be 'palpable': that is, detectable and available to us in situated ways that are appropriate for our circumstances [17]. But that does seem to require something like sociality in computing. I suggest that, while we can never expect this to be achieved in any straightforward or thorough-going way, we may be able through a range of techniques and compromises to achieve an 'acceptable' outcome, where 'acceptable' means, as discussed earlier, that the benefits are 'worth' the limitations. In attempting this, it is helpful to know in advance that one is attempting the impossible, in that one is then better placed to understand the different kinds of efforts that are required, the breakdowns and difficulties that are likely to occur, and the fact that solutions can only be partial. I propose the following main elements of such a compromise.

As a first cut, and as considered in section 5, to keep as many elements of the system as simple and 'representational' as possible, and only attempt 'sociality' where it is unavoidable. 'Keeping things simple' may seem an obvious strategy, but this introduces a distinctive sense of what that means.

Second, where there is good reason to attempt 'social' systems that will act for or act with users, I have argued that they will necessarily be highly limited and compromised in their capacity to do so, and that it is quite impossible to predict whether these compromises will be acceptable and beneficial or fatal for the activities they are intending to support. This would mean that a shift from a product to a process focus [32] is not only desirable but compulsory. Acceptable 'social' systems could only emerge from continuous correction of inevitable serious deficiencies, involving prototyping, trial, revision and redesign. This in turn will necessitate novel techniques for approximating use settings for prototypes in development [14].

Third, despite their limitations, ethnographic studies of work practice are still the principal means to achieve the best starting point, to try to create the best possible designs, models and metaphors in relation to the needs and purposes of situated use.

Fourth, workplace study and analysis are not sufficient and have only a limited capacity to anticipate situated use, and to interpret what makes aspects of a system beneficial or disruptive. A Participatory Design method of working is also necessary, requiring a strongly sustained commitment from users amounting to co-design [16].

Because of this, and because solutions will be at best ‘acceptable’ compromises, then fifthly the solutions and domains must be seriously worth it, so that all those involved see the value of persisting through the difficulties. In the ‘palpable computing’ area, examples include improved support for premature babies in neo-natal intensive care units [55], and support for health and fire services in responding to major incidents [44].

Sixth, to reverse the usual meaning of ‘transparency’, and design to make available to the user what the system is actually doing. This should be decomposable in successive layers so that an appropriate representation can be found at any level. This is to take up the recommendation by Button and Dourish [20], discussed in section 4, of a metalevel interface with a rationalised model of the inherent structure of the system. Ingstrup has extended this with the development of an ‘architecture query language’ which enables users to inspect and interrogate the actions of the system through ‘architectural reflection’, providing new tools for users to conduct conversations with computational materials **Error! Reference source not found.**.

Last, solutions will have to work end-to-end, taking account of the many kinds of realisation work and fixes needed to coax systems into effectiveness [9], and the often ad hoc assemblies and ‘bricolages’ required for full implementation [15]. Without this, one will simply never know whether a collaborative system could have worked. This means trying to overcome the failure of follow-through that afflicts the majority of research-based projects, over which we generally have little control. Some strategies for addressing this are discussed by Shapiro [60].

CONCLUSIONS

Ethnography has a special role in CSCW and collaborative systems, where a relatively long term experiment in interdisciplinarity has been pursued. I have illustrated how this has taken two main, though sometimes overlapping, forms: ethnography as a critical social science, and ethnomethodological ethnography as the means for analysing the detailed constitution and production of work practice.

I argued that these two forms share structural features, though the structures are substantively populated in different ways. Each conducts fieldwork investigations in the light of its own theoretical orientations, and these powerfully colour what is visible in the study domain and how it is interpreted. Each invokes an overarching set of claims, and finds these instantiated, with significant and interesting variations, in particular settings.

In both forms, the relationship to systems design is troubling rather than straightforward. Critical social science offers strong connections with systems design, but these do not have the character of a set of steps or procedures to follow. Rather, they invite the, perhaps gradual, combination of the engineering sciences with social studies of science and technology – though they will find no more certainty there than is to be had in mainstream science. Arguably, this is an appropriate move for all the sciences, and a necessary component of a philosophically more adequate understanding of scientific method.

Ethnomethodological ethnography is troubling because, rigorously pursued, it tends to show that human and machine activity are so incommensurable that ‘social’ systems – a category that *prima facie* must include collaboration systems – are unattainable. The only course open is to pursue a pragmatic strategy for feeling towards limited and compromised forms of technical support. I outlined some elements of such a strategy. Perhaps the most important, and also troublesome, is that – although the starting point must be a carefully considered not an arbitrary one – prediction of the requirements for a successful system is nevertheless not possible, and there can be no short-cutting a protracted and messy process of trial and error.

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12. Workshop and book proposals

12.1 Workshop: Ethnographies of diagnostic work

Authors: Monika Büscher, Dawn Goodwin

Status: Workshop held at the Institute for Advanced Studies, Lancaster University, 17-18 April 2007

Following the success of this workshop, we were invited to propose a workshop on the same topic for ECSCW 2007, the 10^{th} European Conference on Computer Supported Cooperative Work, and this was held on 24-28 September 2007, Limerick, Ireland

Ethnographies of diagnostic work

CALL FOR WORKSHOP PARTICIPATION

Date: 17-18 April 2007, IAS, Lancaster University

Sponsored by: Centre for Science Studies
Department of Sociology, Lancaster University,
Institute for Advanced Studies
Institute of Cultural Research, Lancaster University,
The PalCom Project, http://www.ist-palcom.org

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URL for CFP, programme, papers, etc: http://www.ist-alcom.org/diagnosing_practice

The ability to notice trouble and see scope for remedial action is crucial in many different contexts of work. Doctors, mechanics, help-line operators, firefighters, experimental scientists, the police, teachers, surveyors, computer programmers, and many other professionals do it, and the work involved is often called 'diagnostic'. Diagnoses are often both, difficult to produce and hard to communicate. Although frequently conceived as being a 'moment' of cognition, diagnosis can be seen as a material, collaborative process involving expert skills, careful sensory and sensitive engagement with human agencies (e.g. in medical consultations, teaching or policing), and non-human agencies (e.g. physiological or material 'actants', 'bugs' in computer code, etc.). Some activities involve rational everyday knowledge, some demand 'scientific' epistemic practices – e.g. measurement, experiment and intervention, representations and calculations, and some also require other, creative, emotional and intuitive ways of knowing. Diagnostic practices are a pervasive and important feature of contemporary life. They matter, not least because it is through diagnosing and diagnoses that novices and experts, users, developers and designers, guardians of order and 'delinquents', meet. Diagnostic practices are integral to any move towards change. A deeper and broader understanding of diagnosing practices is highly desirable.

In this workshop, we are keen to explore and discuss ethnographic, engaged or ethnomethodological studies of diagnostic work in any domain of human activity. Interrelated issues contributors might wish to address include:

- *Collaboration*. Diagnosing is often a collaborative endeavour, where e.g. patients work with (many) doctors and healthcare personnel, or teams of computer programmers use collaborative tools like Concurrent Versioning Systems (CVS). How is collaboration organised and sustained? Is it made visible or invisible? What is the diagnostic ‘object’s’ role?
- *Human-human interaction*. Diagnosing demands expert interaction skills. Doctors, help-line operators or teachers must be able to listen, understand and work with their collaborators’ competence, as well as their real concerns and problems. Responses must be tailored to fit. What methods do professionals and lay-persons use to interact effectively? Where and how do breakdowns occur? How are they noticed and how are they addressed?
- *Human-matter engagement*. Engagement with physiological or material agencies often entails sophisticated skills of human-matter ‘communication’. People must learn to hear and make matter ‘speak’. How do they learn to do this? How does communication take place? What kinds of apparatuses are involved?
- *Translations.* Interacting with human and material agencies often requires multiple, sometimes layered, simultaneous, and delicately tailored translations. How are these produced and negotiated?
- *Relations*. Diagnosing brings together novices and experts, users, developers and designers, guardians of order and delinquents. It requires many different, rational, creative and intuitive perceptual and epistemic practices. How are these brought into relation?

The aim of this workshop is to bring together researchers and studies of diagnosing practices. We invite 2 page (or longer) papers, discussing studies. Work-in-progress is welcome. There is good time for discussion. Papers and/or data excerpts will be circulated beforehand.

IMPORTANT DATES:

March 9, 2007:	Deadline for submissions
March 24, 2007:	Notification of accepted Proposals, registration for the workshop
April 17-18, 2007:	*Ethnographies of diagnostic work* Workshop

AGENDA:

March 24 – April 17	Exchange of papers and data excerpts. Participants are encouraged to read all papers before the workshop.

April 17

09.00 – 09.30	Coffee and registration	
09:30 – 09:45	Introduction: Diagnosing Practice Monika Buscher and Dawn Goodwin	
09:45 – 11:00	Keynote speaker: Jessica Mesman, Maastricht	
11:00 – 11:30	Coffee	
11:30 – 13:00	Presentations 3	Discussant: TBA
13:00 – 14:00	lunch	
14:00 – 15:30	Presentations 3	Discussant: Maggie Mort
15:30 – 16:00	Coffee	
16:00 – 17:30	Presentations 3	Discussant: Celia Roberts
19:00	Joint Dinner	

April 18

09:45 – 11:00	Keynote speaker:	Karen Barad, UC Santa Cruz (?)
11:00 – 11:30	Coffee	
11:30 – 13:00	Presentations 3	Discussant: Celia Roberts
13:00 – 14:00	lunch	
14:00 – 15:30	Presentations 3	Discussant: Adrian Mackenzie
15.30 – 16.30	Group discussions, concluding comments/Plans & End	

12.2 Book proposal: Ethnographies of diagnostic work: Dimensions of transformative practice

Authors: Monika Büscher, Dawn Goodwin, Jessica Mesman

Status: Under consideration

Book Proposal

Ethnographies of diagnostic work: Dimensions of transformative practice

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Roger Slack, School of Social Sciences, University of Wales, Bangor, UK

Anita Wilson, Lancaster Literacy Research Centre, Linguistics Department, Lancaster University, UK

SYNOPSIS

The ability to notice trouble and see scope for remedial action is crucial in many different contexts of work. Doctors, mechanics, help-line operators, prison officers, experimental scientists, the police, landscape architects, computer programmers, and many other professionals do it. Diagnoses are often difficult to produce and hard to communicate. Although frequently conceived as a 'moment' of cognition, diagnosis can also be seen as a material, collaborative process involving expert skills, careful sensory and sensitive engagement with human agencies (e.g. in medical consultations or policing), and non-human agencies (e.g. physiological or material agencies, parked cars, 'bugs' in computer code, etc.). Some activities involve rational everyday knowledge, some demand 'scientific' epistemic practices – e.g. measurement, experiment and intervention, representations and calculations, and some also require creative, emotional and intuitive ways of knowing. Diagnostic practices are a pervasive and important feature of contemporary life. They matter, not least because it is through diagnosing and diagnoses that different perspectives - e.g. novices and experts, users, developers and designers, patients and healthcare professionals - meet. Visions of alternative futures and the ‘mapping out’ of paths towards them build on ‘diagnoses’ of the status quo and are informed by safety-regimes, moral, ethical, political and practical decisions. Diagnostic practices, reflexively, shape the material reality of people’s lives. A deeper and broader understanding of diagnostic practices is highly desirable.

The aim of this book is to examine the practical achievement of diagnostic work and to elucidate some of its complex and interwoven dimensions, in order to offer practice-based, theoretically grounded possibilities for re-thinking prevailing orientations and methods. Drawing on a diverse range of perspectives and empirical settings, this book will address the collaborative, socio-material, technologically augmented processes of diagnostic work, and their political and ethical dimensions, with the aim of delineating some of the transformative potential of this analysis. Diagnostic processes and their outcomes are shaped in and through everyday practices and we argue that greater attention to the intricacies of everyday practice is central to the development of strategies that can help realize more desirable alternative futures and realities.

PROPOSED CONTENT

1. Introduction Monika Büscher, Dawn Goodwin, Jessica Mesman

This chapter sets the scene for a discussion of diagnostic work, and introduces the specific themes of the book. We begin by clarifying what we mean by ‘diagnostic work’, describing existing approaches to analysing diagnostic practices and outlining how our approach both draws on and differs from these analyses. Our interest is, first and foremost, in situations where ‘diagnostic work’ is a members’ category, used by practitioners themselves to describe specific practices. However, our approach is distinctive, in that, on analyzing and comparing instances of diagnostic work that fall into this category, similarities to other situations are striking, and we believe that by broadening the concept’s scope into an analyst’s category, important insights can be gained. What members refer to as diagnosis can usefully be seen as occupying a particular space within a multi-dimensional continuum of epistemic and ontological practices of being-in-the-world. For example, the empirical studies in this book ‘explode’ Heidegger’s concern with ontology encapsulated in the concepts of ‘ready-to-hand' and 'present-at-hand'. Epistemology and ontology are inseparable as people navigate the space between these two modes of attention, and by analyzing *how* people navigate this space through a focus on 'diagnostic work' more broadly defined, empirical investigations of the lived 'epistemontological' experience of 'agential realism' (Barad 2003) become possible. Consequently, the theoretical context and potential of our approach is significant and will, therefore, be explicitly discussed. This is an exciting philosophical, conceptual prospect, but it is also of great practical relevance. Many of the chapters in this book are produced by practitioners and researchers working together to understand and constructively transform diagnostic work practice and/or its material, organizational and political contexts and support technologies. This research thus feeds powerfully into the 'engaged programme' within Science and Technology Studies, and other participatory, interdisciplinary approaches to folding social scientific analysis into innovation. This introductory chapter will elaborate on the interventionist character of the methodological context of some of the projects involved.

The chapters in this book are organized in four parts, each focusing on a particular dimension of diagnostic work. Part I investigates diagnostic work by concentrating on human/embodied aspects. Its attention is on a range of bodily modes of inquiry such as vision, touch, and experiential ways of knowing. Part II turns the analytic lens to human-matter engagement and elucidates the socio-material processes that are integral to diagnostic practices. Part III attends to the closely coordinated, interactive and collaborative elements of diagnostic work. Whereas the first three parts present a fine-grained analysis of diagnostic work, Part IV opens up political, ethical and technological aspects for consideration. Cumulatively, the chapters in this book illuminate the multi-dimensional nature of diagnostic work and its contexts, and explore the potential for change.

PART I: HUMAN/EMBODIED ELEMENTS

2. Making matters speak Johan M. Sanne

Railway maintenance work can be monotonous and boring. However, at the same time, it is critical and high risk. One of the junctures where this paradox manifests itself is the work of fault-finding. Fault finding and repair of broken or malfunctioning equipment provides a challenging and rewarding experience. Fault-finding is rewarding because it challenges technicians' practical competence and contributes to their self-identity as handy men. Fault-finding is also rewarding because it confirms technicians' importance for achieving safe and timely train traffic. Fault-finding in railway maintenance typically involves heterogeneous engineering, where technicians align and combine everyday competences, organizations, protection modes and artifacts. These are applied in a specific sequence, informed by specific strategies used for fault-finding, strategies that technicians learn as part of their participation in a community of practice, rather than in formal training. To save time, faults are usually compared to previous examples and technicians apply short-cuts that are known to have worked in similar circumstances. Technicians claim that in most situations, the problem is clear to them from the start: the matter speaks to them directly. Only when these short-cuts fail, do technicians turn to systematic searches. This chapter investigates situations where the problem is not obvious from the start, and technicians need to work to make matters speak to them.

In the context of the whole book, this chapter highlights the nature and value of experiential knowledge, contrasting it to knowledge developed in training courses. It explores the notion of apprenticeship, and the rewarding, professional identity affirming character of diagnostic work, focusing on difficult cases where closure is achieved through recourse to community expertise.

3. The ones that say they'll do it never do, it's the ones you don't expect that string themselves up': *Prison officers' diagnosis of potential suicide and their strategies for continual crisis managements* Anita Wilson

While considerable media emphasis is (quite rightly) given to the incidences of suicide in prison, the secret and enclosed nature of incarceration does not lend itself to any recognition of the number of prisoners who are saved from serious self-harm by the daily interventions of prison staff. Indeed, the notion of prison officers as 'caring' or 'concerned' is overshadowed by public reports of their brutality and violence towards prison inmates - sustained victimisation in the adult system, for example and instances of inappropriate levels of force directed towards young people and children in the secure estate. Qualitative studies of the daily life, tasks or decision-making of prison staff are few. Emphasis remains primarily on what Prison Officers don't do rather than on what they achieve.

Furthermore, while generic Prison Service training offers stringent protocols for dealing with suicide and serious self-harm - procedures to follow, risk assessment, preventative measures such as ligature-free cells and indeed the bureaucratic and practical procedures on the follow up to death in custody (Prison Service Order 2710), the day to day assessment of prisoners, the diagnosis of their potential vulnerability and the choice of preventative measures falls within the catch-all tasks of 'being a prison officer', becoming subsumed within the ever- increasing mounds of institutional paperwork.

Close ethnographic work conducted over a number of years with some of the most vulnerable members of the prison population, however, shows a different picture. On the one hand, the institution holds to a belief in the protective powers of correctly completed bureaucracy, placing total emphasis on the written word. On the other hand, prison officers see paperwork as both a necessary evil and as a barrier to face to face work with at-risk prisoners. For them, the diagnosis of potential self-harm relies more on complex configurations of visual and ephemeral texts. Reading the bodily scars of previous self-harm or ligature marks, interpreting the sixth sense of 'you can feel trouble in the air' or 'just keep on eye on that lad in Cell 43 tonight will you', together with the ability to 'read' situations quickly such as 'get the door open now 'cos she's got the sheet round her neck' figure much more strongly in the day to day textually-mediated diagnosis of preventing a death in custody.

This chapter discusses some of the intricate nuances of prison officers' decision making, the ephemeral aspects of their diagnostic work, and asks the question 'where, when and if micro diagnosis ever stops? In the context of the argument of the proposed book, this chapter focuses attention on the embodiment of diagnostic evidence, bodily inscriptions and visual texts, and it shows how the practical circulation of informal assessments and professional vision take precedence over formal modes of assessment.

4. Senses and sense-making in anaesthesia Dawn Goodwin

Diagnostic work in anaesthetic practice relies on reading an unconscious body. In the absence of discussion with the patient, other senses, and other ways of sense-making, take priority. Yet this process is still intensely collaborative, the patient's body is routinely technologically augmented and extended so as to convey details of its state, thus a wealth of digitised information is available to the anaesthetist: heart rate, blood pressure, oxygen saturation, carbon dioxide levels, volumes of inspired and expired gases, ECG traces. Proliferous though this information may be, it is insufficient for diagnosis.

Analysing scenes from anaesthetic practice, this chapter highlights the embodied knowledge that is brought to bear on diagnostic work in a highly technological setting. The use of *touch* frequently elaborates the digitised patient information, the *feel* of a needle as it is inserted tells an enormous amount about its location in the body, and the peculiarities of breath-*sounds* can indicate particular forms of respiratory distress. More broadly, a sense of the general situation also informs diagnostic work. This sense is intimately connected to learning what is *normal* for what are actually rather particular situations, and this extends beyond formalised 'anaesthetic' knowledge, this involves knowing the idiosyncrasies of certain surgeons, the volumes of blood loss related to different operations, the particularly 'stimulating' parts of operations, how to overcome the peculiarities of certain pieces of equipment, and how a patient's medical history is likely to inform the body's response to the stresses of surgery.

This chapter's contribution to the book will centre on elaborating diagnostic work as a multi-sensory, multi-agency complex in which routine practices, techniques and checking procedures are employed with the aim of sense-making.

PART II: HUMAN – MATTER ENGAGEMENT

5. Digital Material: Diagnostic work in software development and appropriation Monika Büscher

This chapter draws on an ethnographically informed participatory design project with the police and fire services in a major city in Denmark. In the project, prototype technologies that allow people to 'stretch' material practices of diagnostic work in policing and emergency response have been developed and put into use in an iterative design process (as part of experiments and as part of real everyday police and emergency response work). This process 'forces' the emergence of future practices creating a boundary zone rich with tensions, uncertainties, improvisations and innovations. Ethnographic studies of the experimental development, bricolage and appropriation of new technologies into real world professional practice provide rich opportunities for empirical analysis of different and changing ways of doing diagnostic work. For example, the use of new technologies can act as a 'breaching experiment' that makes unnoticed, but important aspects of existing diagnostic practices in police and emergency response work visible. And, as the professionals appropriate new modelling, location and communication technologies they witnessably notice, explore, assess and act on the constraints and affordances of their new work environments, inventing new forms of technologically augmented police and emergency response diagnostic practice. At the same time, the ‘debugging’ practices of software developers criss-cross, enmesh and enlist both physical and digital materialities – sometimes invisibly ‘under the feet of’ the professional users, sometimes in full view and with the aim to train the professionals’ own ability to notice, understand, control and trust the technology’s states, processes, and affordances. These activities highlight strategies designed to make matter speak and to coordinate the actions of human, digital and material agencies. Through detailed analysis of human and material actions within this zone of flux and upheaval some basic ‘matereal ethnomethods’ of diagnostic work and the possibility of an ethnomethodological exploration of material practice can be delineated.

By focusing on a fault line between existing and emergent future socio-technical configurations, this chapter opens up the space between the phenomenological contrast pair ‘ready-to-hand’ and ‘present-at-hand’, revealing a continuous flow of causes/effects, actions/reactions, documentations/interpretations that gives rise to human and other (material, physiological, technological) agencies that makes orderly material practice possible, but also facilitates innovation .

6. *Suspicious minds* Roger S. Slack, Rob Procter, Mark Hartswood, Alexander Voss, Mark Rouncefield

This chapter draws on long-term research engagement with the UK National Health Service Breast Screening Program. It uses ethnographic studies of readers reading in conjunction with an expert computer aided detection system. We consider how readers go about ‘looking for cancer’ – doing, what is for them, the everyday work of detecting and diagnosis. We observe how difficult it is to sustain this distinction in practice and, since the end point of much of this work is a ‘recall’ decision rather than a diagnosis, point instead to the idea of how readers might be seen to be ‘doing suspicion’. We show how readers use repertoires of manipulations to make certain features ‘more visible’. These repertoires of manipulations are an integral part of the embodied practice of reading as readers reflexively adapt their working practices in order to build and sustain their ‘professional vision’; in effect an ‘ecology of practice’ that is deployed as part of the routine of screening work. By showing how practical actions such as film arrangement, gesturing and pointing to features on films are all components of the lived work of reading, and despite the title of this chapter, our analysis points beyond impoverished conceptualizations of the work of reading as a cognitive phenomenon (which miss exactly what it is to be doing reading). We extend this argument by explicating detection and diagnostic work – the cultivation of suspicion – as a form of knowledge work. We argue that ‘diagnosis work’, is “social through and through” and “constituted through action”. We use the work of diagnosis to show that kinds of 'knowledge' can be distinguished as grammatical classes rather than mental classes, for instance according to whether the problem of knowing is a problem of knowing 'how' to do things, knowing 'who' is the subject, knowing 'that' something has happened, knowing an event as 'being like' other events, and so on. Finally, we seek to understand how readers make sense of the expert system’s prompting behaviour as part of a more general argument about the appropriate evaluation of technology in healthcare. We point to some general issues concerning trust and how trust is influenced by users’ capacity for making sense of how the tool behaves, building on Elvis’ original insight that ‘we can’t build our dreams with suspicious minds’.

In the context of the argument of the book, this chapter provides a rich and detailed analysis of material methods of making matters speak. It exhibits and showcases how diagnosis is so much more than a ‘moment’ of cognition and shows that it is immensely powerful to examine the lived reality of diagnostic work and that analytic insights can inform the design of new technologies.

7. Making a diagnosis through coronary angiogram Paula Hodgson, Katrina Stengel

The chapter explores the communication of medical test results from angiography (where x rays are taken of the blood vessels around the heart), and the understanding and perceptions that individuals have about their chest symptoms. It draws on fieldwork situated in the specialist cardiology centre of a hospital during weekly angiogram clinics. This entailed following patients and clinicians through the process of having, and undertaking, angiography, including the preparatory work and communication of the results. The fieldwork was an integral part of understanding how angiography takes place, and the experience informed in-depth interviews with patients, clinicians and nursing staff.

We focus upon the angiogram test and the myriad of work, actors and materials involved, discussing three main points. Firstly we give some background to coronary angiography. We argue that within medical practice, an angiogram can be considered to be a defining moment in the trajectory of chest pain patients, who will have generally started their journey in primary care. The angiogram test result is used, in conjunction with other knowledges, to make a differential diagnosis, which will then determine the medical management of a patient. For example, blocked arteries or damaged valves can lead to major surgery involving a coronary bypass operation or the replacement of valves. Next, we examine the work that is undertaken to make, and to interpret angiogram results, including the range of knowledges, technologies and materials, which are brought together for a moment. Third, we highlight the ordering and prioritising of different knowledges to make a diagnosis, and how it is mediated to the patient.

This chapter contributes to the book by posing questions about the writing, visualizing and describing of diagnostic practices; in what ways does this contribute to knowledge and experience of bodies and disease? How can this feed back into practices of diagnosis? What can it tell us about the management of cardiac chest pain?

PART III: COLLABORATION

8. Epiphanies and other aspects of diagnostic work in calls to a technical support helpline Alan Firth

This chapter draws on a detailed conversation analytical study of calls to a technical helpline to investigate how callers and call takers collaborate to address technical troubles. Diagnostic work is carried out at different, delicately nested levels and from different perspectives. While callers typically provide a description of symptoms or a preliminary diagnosis, call takers use these first formulations to ‘calibrate’ for the varying levels of technical competence that callers bring to the interaction, and to determine the ‘helpability’ of callers within the remit of the help service provider. call takers provide real-time instructions for diagnostic interventions or attempts to resolve the problem and monitor how callers are able to follow them – all in and through talk. Simultaneously, call takers seek to organize, scrutinize and categorize the unfolding talk in terms of electronic on-screen forms that track, for example, the status of the call, and interleave the call takers' accountabilities within the service organization with those s/he has towards the customer. Close study highlights not only the skilful collaborative production of help within an organizationally constrained – and only partially revealed – framework, but also draw attention to 'aesthetic' or playful elements of diagnostic work, such as a pursuit of elegance, or economies of interaction, and the experience of epiphanies and sociability.

The chapter contributes insight into how intersubjective understanding is constructed within and across turns of talk and the often asymmetric participation frameworks of diagnostic endeavours. It provides a vantage point from which to explore other, emergent forms of diagnostic work in help-line interactions, which will be reviewed, anticipating and analytically underpinning arguments put forward in later chapters (13&14).

9. Diagnosis at work in collaborative actions- Jessica Mesman

Diagnostic abilities play a crucial role in maintaining patient safety in critical care practices like a neonatal intensive care unit (NICU). The ability to notice trouble and be able to take remedial action is of utmost importance to prevent incidents. However, the preservation of safe and sound practice is as important as preventive actions for maintaining patient safety. This requires the ability to recognize adequate and accurate practices and to act accordingly. In other words, diagnostic work does not only involve the ability to notice gaps in the safety net, but, I argue, also the ability to identify good practices.

We can see both forms of diagnosis at work in collaborative actions. Collaboration is a major formative part of the social-technical fibre of the fabric of practice. To study the different forms of diagnosis we will take a closer look at one specific medical procedure: the intubation of a trachea-tube on a neonatal intensive care unit (NICU). To intubate a newborn baby requires a collaborative mode that has to be so well-timed and accurate that it can be defined as a form of tight coupling. The actions are carefully coordinated, while still leaving room for corrective measures if necessary. This raises the question how it is possible that people with different professional expertise, experience, and responsibilities, a set of devices and machines, can become such a coherent 'intubating body'? Complex procedures like a trachea intubation require the ability to be coupled tightly enough in order to act as one entity, while preserving the possibility to de-couple and act separately. Careful study of this process reveals the significance of both modes of diagnosis and their interrelatedness, and feeds insights into everyday practice through long-term research engagement with the practitioners.

In the context of the book, this chapter aims to study the significance of diagnostic work for collaboration which is crucial for the preservation of patient safety. By broadening the concept's scope to include the ability to notice adequate and accurate practices, it calls attention to diagnostic work outside the domain of error and problems. It explores the process of transduction of different agencies into one collaborating entity and its regimes of meta-stability to identify different modes of diagnostic work to provide insight into resources of successful collaboration.

10. Supporting the emergence of specific forms of encounters through location awareness: The case of the Mogi players. Christian Licoppe and Yoriko Inada.

This chapter presents a case study of commercial users of a multiplayer location-aware mobile game in Japan in which users must gather sets of related objects that are both 'virtual' and localized. The key feature is a virtual onscreen map which is continuously reset with each server request and which features geo-localized players and virtual objects within a radius of 500 meters. This particular interface allows players to 'see' the location of other players onscreen and assess their mutual proximity. We analyse how these features are exploited by participants to accomplish collaboratively four types of specific encounters, that may be characteristic of location-aware communities : a) noticing another player’s position and inviting elaboration (‘where (exactly) are you and what are you doing there?’) by a text message b) a form of co-proximity event in which two players are close enough to both appear on each other’s mobile screens, with such onscreen proximity strongly inviting text message interactions and projecting the possibility of a face to face encounter c) another form of co-proximity, invented by players, in which they disjoin and “freeze” their icon in a given place, and try to get their icon to touch the icon of another mobile player (with sexual innuendo) and d) public rating of face to face encounters between players which are experienced as a collective accomplishment and a public performance.

By studying collaborative practices of noticing, evaluating, grasping or evading, and negotiating novel opportunities, accountabilities and ‘obligations’ for interaction in a mixed reality location aware game, this chapter explores how people creatively ‘stretch’ and transform the documentary reach and interpretation of embodied conduct and movement. The analysis highlights another facet of the role of ‘diagnostic work’ in dwelling in and in appropriating new social material-digital worlds and inspires a discussion of continuities and discontinuities of practice in the conclusion.

PART IV: POLITICAL, ETHICAL TECHNOLOGICAL POTENTIAL

11. Diagnosing and acting upon dementia in care practice: the transformative power of the Marte Meo Method as therapeutic intervention and diagnostic instrument Ingunn Moser

Over the last few years a new tool and method has been introduced in care for people with dementia in Norway: the Marte Meo Method. It was developed in clinical psychology as a tool for improving communication between parents and infants but is now widely used also in schools and dementia care. It is a form of intervention that focuses on the interaction and communication between, for instance, people with dementia and their carers, and seeks to strengthen the relational and communicative competence of carers in order to fascilitate better interaction and care. At the centre stand video recordings of interaction, and collective guidance on the basis of these filmshots. A Marte Meo therapist records problematic everyday situations, such as meals, washing, brushing of teeth, or aggressive behaviour, and then analyses the interaction and presents edited sequences of these recordings in meetings with the carers. The carers are invited to contribute to analyse and discuss what they see, and learn to see both the patient, themselves, and care relations and interactions in new ways. Collectively, a shared way of meeting and handling the problematic activities is laid down.

Drawing on ethnographic fieldwork in a dementia care unit, I lay out and analyse in detail some of the uses of the Marte Meo-instrument to investigate what it makes possible and how it changes dementia care, but also to explore how it works back on and challenges the initial diagnosis, disease-definition and scope for action outlined.

In the context of this book, the chapter develops the following argument: First, that diagnosis emerges through intervention and as part of the treatment process, rather than preceeding it. Secondly, that diagnosis is processual and subject to negotiation, a distributed, collective, sociotechnical process, rather than the exclusive providence of medical expertise, cognition and decision-making. Thirdly, in this process new instruments and technologies play central roles as actors, opening up and enhancing (new) ways of seeing and sensing. In this particular case, the Marte Meo-instrument and its technologies enabled carers to see patients, problematic situations, care relations and the disease itself in new ways. Crucial to this is also the space this tool made for collective reflection and learning through a form of ‘auto-ethnography’.

12. Seeing and Believing: Cultural Politics of Objectivity in the Diagnosis of Suspected Seizure Disorders. Alexandra Choby

Based on ethnographic field-work at one tertiary epilepsy center, this chapter will examine the socio-technical and discursive production of objectivity in the diagnosis of suspected seizure disorders. Objectivity, conceptualized as a state of aperspectival, neutral detachment through which an observer becomes able to receive the unmediated truths of nature, is the empiricist core value and practical scientific objective that grounds facts as truths. Further, objectivity is often equated with impartiality and thus read as politically unpositioned, disinterested and therefore universally benevolent and good. While neurologists agree that processes for observing brain function upon which diagnoses are based are highly mediated and depend on the production of multiple images that only become meaningful through complex interpretation, they also sometimes draw on common-place tropes that equate objectivity with truth in presenting the stigmatized diagnosis of pseudoseizure to patients. This chapter explores the sociotechnical work practices (centering on the construction and evaluation of a sample of brain images) through which physicians produce objectivity, and their discursive deployment of the concept as a useful framing to encourage patients given the diagnosis of pseudoseizure (a species of hysteria) to demedicalize. Situated in disciplinary wide debates around how to depoliticize and demedicalize pseudoseizure patients, I demonstrate that objectivity is neither disinterested nor unpositioned, but a powerful rhetorical device for producing compliance.

In the context of the book, this chapter provides a powerful exposition of the ethical and political aspects of diagnostic work. By showing how observer and apparatus independent truths are actively produced and strategically employed in doctor patient encounters, the analysis draws tensions between different notions of objectivity in diagnostic practice to our attention.

13. Managing the diagnostic space: Interactional dilemmas in calls to a telephone health help line Jill Pooler

NHS Direct is a telephone health help line in England and is claimed to be the largest and most successful e-health service of its type. Nurses use a computerised Clinical Assessment System (CAS), which provides question-answer prompts to guide the consultation, upon completion of which CAS provides the action to be taken by the caller and appropriate care advice. Call outcomes are limited by CAS. There are constraints on the content of the nurse's turn; most importantly, it should not be hearable as proffering a diagnosis. The problem for the nurses is how to manage these limitations to achieve a satisfactory outcome where advice can be offered and received. This chapter will draw on conversation analytic thinking about the organization of interaction in institutional settings to consider:

a) How do the nurse advisors manage in practice, the interactional restrictions on diagnosis imposed by the organisation?

b) What practices do the nurses engage to bring the clinical assessment to conclusion?

c) How do these practices relate to practices in 'ordinary' GP consultations?

Based on analysis of 56 recorded telephone consultations between the nurse and the caller, this chapter suggests that:

- The nurse designs his/her turn to provide a candidate formulation of the problem which is framed as 'tentative' and couched in hearably not-technical, non-medical language.
- The 'tentative' formulation acts as a prelude to the advice giving sequence and can provide an interactional resource for design and delivery of advice.
- Interactional troubles can occur when the 'tentative' candidate diagnosis is treated as dispreferred by the caller.

This chapter provides an account of diagnostic work in a political context where 'diagnosis' is explicitly placed beyond the boundaries of professional practice. This unique situation reveals both some intrinsic elements and accountabilities of diagnostic work and the interpretative flexibility and competence demanded of nurses and callers in order to work effectively within these constraints.

14. Diagnosing machine problems on the phone: Technological inspirations from an ethnography of user-expert interaction Jacki O'Neill, S. Castellani, Antonietta Grasso, F. Roulland

This paper describes an ethnography of a call centre where troubleshooters attempt to diagnose and fix problems with large office devices, e.g. printers over the phone. The helpseeker is generally the user of the device, at the site where the device is installed, and often nonexpert in the technicalities of the device. Diagnosis and repair is a collaborative activity which consists of a number of activities. These include: 1) the collaborative working up of a problem description from customers' initial reports; 2) translation from customers' terminology to that of the device/troubleshooting resources and from the technical terminology of machine and knowledge-base to the customer's language; 3) mediation - troubleshooters mediate between technology resources and customers, and customers mediate between machines and troubleshooters. The distributed nature of the activities means that both troubleshooter and customer engage in co-ordination work to make this mediation work. The troubleshooter has access to knowledge whereas the customer has access to the machine. Diagnosis and repair usually involve physical manipulations of machine parts or machine software based on instructions given over the phone. The troubleshooter only has limited access to what the customer is doing and must verbalise all instructions. In addition there is often a dislocation between the site of the problem and the site of problem resolution, that is, telephones are rarely by shared office devices. The ethnography emphasised the social nature of troubleshooting work and this understanding led to some inspirations for technology design to support such work along different dimensions: online support, collaborative troubleshooting, and support between the customer and the machine. In this chapter we first describe the case study findings and then we illustrate the technology ideas that they have inspired. The aim of the technology design was to bring critical features of the user-expert troubleshooting interaction into situations where troubleshooting might be undertaken without an expert; and, where the expert remains, to better support their work. Our wider aim is to enhance the design of the technical by basing it clearly in an in-depth understanding of the social.

In the context of the book, this chapter draws attention to the entanglement of intervention and diagnosis from a different perspective. It underlines and actively engages with the mutability of user – diagnostic object – expert relations by using analytical insight to ‘ground’, inspire and inform technology design

15. Conclusion Monika Büscher, Dawn Goodwin, Jessica Mesman

In this concluding section we demonstrate how the four dimensions of diagnostic work that we have delineated – embodied knowledge and practice, human-matter engagement, collaboration, and their political, ethical and technological entanglements – are intimately connected. For example, a particular political context requires certain forms of human-matter engagement and places specific constraints on the forms of collaboration that might take place. In this way, diagnostic practices are born of and manifest existing socio-material arrangements, but they are also critical in the imagining and formulation of possible futures. This can be readily observed in relation to the ‘object’ of diagnostic work; in seeking to know the body, through iterative and incremental enactments, doctors are also seeking to establish a certain ontology for the body, one that opens they way for some potential trajectories whilst closing others. Lives, technologies, landscapes, forms of social interaction, are transformed (but not irrevocably determined) by diagnostic practices. However, the transformative nature of diagnostic work goes beyond the ‘object’ of diagnosis and extends also to the work itself, the practitioners/members, and the material, technological, political and ethical circumstances of the practice. In elucidating these elements, the chapters in this book have opened up the possibility for intervening in and transforming the various aspects of diagnostic work. Indeed, some of the chapters actually report on this process of intervening, e.g. through ‘auto-ethnography’ or by folding sociological analysis into innovation and change through long term research engagement with practitioners, and ethnographically informed and participatory technology design, Interventions range from sensitizing people to often ambiguous and opaque practices, to actively questioning normativities, to the design and development of technologies-in-use or technology-and-practice configurations informed by observations of diagnostic work. The attention this book provides to both the intricacies of diagnostic work and to possible ways of intervening provides an entry into considering what might constitute more desirable futures and how these transformations might be brought about.

1st drafts of Chapters 1 and 10 were included as sample chapters.

TABLE OF CONTENTS

LENGTH

Approx 150000 words (Contributors limited to maximum 10,000 words per chapter).

MARKET

This will be an advanced text providing a survey of the field and new articulations of 'diagnostic work' research. It is primarily aimed at teachers, researchers and advanced students in the following areas: STS, Social studies of work, organisations and technology; risk and safety studies; and medical and social anthropology. The book would ideally function as a core text for the burgeoning number of MA level courses that address the interconnections between science, technology and nature. Courses on these topics are taught in the majority of institutions within the UK, North America and Europe. As well as traditional taught courses, the growth of interest in post-disciplinary merging of state-of-the-art sociological inquiry with 'applied research', for example, in socially responsible design (Cooper), Computer Supported Cooperative Work (CSCW), will form an important secondary readership for the book. It is expected that the book will also be read by professionals – for example practitioners of health and medicine, helpline professionals, computer programmers and technology designers, since it provides exemplary case studies that show how issues at the heart of diagnostic work might best be addressed or reconceptualised. As noted, the courses and disciplines in which this book will find readership are taught throughout the EU and North America. The international authorship of the book is likely to contribute positively in this regard.

COMPETITION

Although the majority of existing texts do not deal directly with the concept of diagnostic work, there are certain analytical approaches in the social sciences that have begun to open up what might be encompassed in this notion. For example, Science and Technology Studies expound the notion that 'technologies' in and of themselves, are rarely diagnostic, it is the interactional work around them that, to a large extent, accomplishes the diagnosis; studies in medical sociology have explicated the effects – personal, institutional, and otherwise – of having a diagnostic label, and the negotiations between lay and expert knowledge entailed in achieving a diagnosis; and conversation analytic studies have shed some light on how diagnosis is accomplished in and through the talk. However, none of these approaches take 'diagnostic work' as their central analytical theme, this volume is novel in that it brings together a wide range of empirical settings and analytical approaches to concentrate on developing a deeper, broader, and more conceptual, understanding of diagnostic work.

Berg, M and Mol, A (1998) *Differences in Medicine: Unravelling Practices, Techniques, and Bodies.* Duke University Press: Durham.

This book is a collection of empirically based papers that closely examine the sociomaterial practices of medical diagnosis and intervention. It concentrates on opening up and articulating some of the disunities in western medicine. The papers focus on how incoherences (for example, between testimonies of the body and the 'diagnostic' technology) are managed in the routine activities of doctors, nurses, technicians and technologies. Collectively, these studies emphasise how the 'differences' studied are not necessarily to be remedied, rather, they are to be acknowledged and worked with since they are integral to the practices. Consequently, this focus incurs a lack of discussion on the difficulties that might arise from such incoherences, and the ways in which they are handled. In taking 'diagnostic work' as our central theme, the proposed book explicitly addresses how problems are identified, approached and resolved, and it elaborates the techniques, both practical and conceptual, entailed.

Lock, M, Young, A, and Cambrosio, A (2000) *Living and working with the new medical technologies: intersections of inquiry.* Cambridge University Press: Cambridge.

This collection of essays focuses on the study of new medical technologies and their application in practice. The essays demonstrate a range of positions in medical anthropology and science and technology studies. As such, the collection does not advance one theme but presents different approaches to, and conclusions about the effects of living and working with new medical technologies. As this volume takes the technologies of biomedicine as its organising theme, it touches on diagnostic work in many ways, for example how the body is screened for developing cancers, how brain imaging technologies can provide a 'biological' explanation for non-specific symptoms, and the difficulties of working with classification devices. However, the potential to extrapolate, from these studies, the intricate connections between the different aspects of diagnostic work is lost in failing to draw together conclusions from the shared concerns and different foci presented.

Mol, A (2003) *The body multiple: ontology in medical practice.* Duke University Press.

This book derives from an ethnographic study of the day to day practices of diagnosis and treatment of atherosclerosis. Mol demonstrates the different atheroscleroses that are performed in different locations, by different technologies, actors and treatments. The argument is that this does not imply fragmentation; rather, the disease is made to cohere through the 'coordination work' of clinicians and patients. 'Coordination work' incorporates much of what might be considered 'diagnostic work', at least as it occurs in medicine. Our proposed volume will interrogate and extend existing ideas about 'diagnosis' by exploring the differences and similarities of diagnostic work in a range of empirical settings.

Iedema, R (2007) *The discourse of hospital communication: Tracing complexities in contemporary health care organizations.* Palgrave Macmillan: Basingstoke, UK.

This book is a collection of international research studies that address issues around hospital communication and interaction. As such, it traverses many of the territories of 'diagnostic work' in healthcare – the communicative functions of the medical record, the meanings inscribed into an X-ray, and how the vocabularies used in problem formulation have far reaching implications for patient and practitioner identities and treatment options. Consequently, the attention 'diagnostic work' receives in this book is not insignificant, but inadvertent. Again, our proposed book will attend directly to the notion of diagnostic work in its various settings and manifestations to consolidate and advance what is known about this work.

Franklin, Sarah. & Roberts, Celia. (2006) *Born and Made: An Ethnography of Preimplantation Genetic Diagnosis.* Princeton University Press.

Franklin and Roberts provide a sociological study of the competing moral obligations that define the experience of reproductive medicine, in particular pre-implantation genetic diagnosis (PGD), a genetic test which avoids selective pregnancy termination. The book reveals not only the uncertainty and ambivalence among PGD patients and professionals but also the decision-making process that shapes the technology. Our proposed volume shares with this book the fine-grained moment-by-moment approach which gives attention to details in the cases and work practice that is analyzed. Like our volume they too focus on intersections, interrelations, junctions, interconnections. The specific value of our book, however, is tied to the focus on different dimensions of the notion of diagnosis by broadening the concept into an analyst's one. As such our volume can be considered as an explicit attempt to open up and do justice to the creativity and experience of those involved in doing diagnostic work.

Karl Weick and Kathleen Sutcliffe (2001) *Managing the Unexpected: Assuring High Performance in an Age of Complexity*. San Fransisco: Jossey-Bass
This book is about learning to "notice the unexpected in the making and halt its development." In other words, it shows how to detect surprises while they are new, small, and insignificant and before they become five-alarm fires. The book shows how to create what the authors call a high-reliability organization that can deal effectively with surprises. An organization does this by being "mindful," which is to say alert, resilient, and flexible. This book is useful because the book draws on real life examples of organizations and of others that paid the price for not being mindful. Similar to the chapters in our book, the approach of Weick and Sutcliffe is also decidedly process-based and suggests different routes which enable diagnostic work. Essential qualities in this matter are: preoccupation with failure, reluctance to simplify, sensitivity to operations, commitment to resilience, and deference to expertise. These capabilities for anticipating and detecting the unexpected as well as for resilience and managing the unexpected, offers a nice contrast to more static and structure-based frameworks. However, our proposed volume does not restrict diagnostic work as solely a matter of modes of knowledge but includes the material reality as well as being both an 'agent in' and an 'outcome of' diagnostic work.

Craig, Paul. A. (2001). *Controlling pilot error:Situational awareness*. New York: McGraw Hill
This book covers situational awareness, and is replete with examples of busting airspace, traffic conflicts, runway incursions, running out of fuel, getting lost and flying into adverse weather. The book analyses reports of serious accidents and 'near misses', discussing both what went wrong and what should have been done. It also comments on the element of "luck" on the part of the pilots that prevented some of the incidents from being far more serious. Although the work of Craig prefers to 'go-beyond-error', by prioritizing 'learning capabilities' over 'errors', its focus is still on breakdowns, mistakes and failures as units of analysis. The empirical studies in our proposed volume, on the other hand, do not focus on errors but on the work involved in noticing errors and problems. Moreover, the studies in our volume starts from the notion that complex practices are fallible by their very nature and breakdowns, failures and incidents are an inherent characteristic of work practices. As such they represent the growing awareness that we need to move beyond a 'deficit based' model of thinking if we want to understand complex socio-technical work environments.

SCHEDULE

Submission 12-18 months from acceptance of proposal. For example:

November 2007 Acceptance

January 2008:	Draft introduction sent to authors
March 2008:	Authors submit first draft of their chapters
April – June 2008	Internal peer review (in which each chapter is reviewed by up to 2 other contributors as well as the editors)
July 2008:	Review comments and editorial comments sent to authors
September 2008:	Final drafts submitted, draft conclusion circulated for comment.
November 2008:	Final book submitted.

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12.3 Book proposal: Matterealities, mobilities and innovation

Author: Monika Büscher

Concept & motivation

The book will investigate how people inhabit, mobilize, and shape material realities. It draws on my long-term involvement in ethnographically informed collaborative design of mobile and ubiquitous computing with professionals in landscape architecture, event security, emergency response, and healthcare, where I have co-developed prototype technologies that allow people to 'stretch' and mobilize material practices, and have helped put these technologies into use in experiments and in the context of everyday work. This approach to socio-technical innovation weaves new computing technologies into everyday experience, thereby 'forcing' the emergence of future practices, creating a boundary zone rich with opportunities for analysis of (changing) material practices. In this book I draw my studies together, connecting 'matterealities', mobilities and innovation through the notion of 'matereal methods'.

Matereal methods 'materealize' 'matterealities'. They are the practical actions and principles that enable the perceptibility, experience, and ongoing production of socio-material order. These new concepts connect Karen Barad's agential realism (Barad 2003, 2007) with ethnomethodology. They highlight the fact that realities are made, but also material, supporting an analysis that is sensitive to the asymmetries between human and non-human agencies (Suchman 1987, 2007). As our societies increasingly run on immaterial resources (knowledge, computing, connectivity) and are affected by complex material forces (climate change, genetically modified resources, resistant pathogens), this marks a significant advance for contemporary theory, including, in particular, ethnomethodology, science and technology studies, and the 'mobility turn' (Urry), where the study of matereal methods adds an important material dimension.

Specifically, my studies draw attention to the practical actions of sensory perception, of making sense and of experiencing that underpin human mobilities – for example the ways in which we come to trust and enjoy modes of transport like driving a car, but also mobility infrastructures like ubiquitous connectivity or location information, and new forms of virtual mobility. *Matterealities, mobilities and innovation* 'explodes' Heidegger's concern with ontology encapsulated in the concepts of 'ready-to-hand' and 'present-at-hand'. Epistemology and ontology are inseparable as people navigate the space between these two modes of attention, and by analyzing *how* people navigate this space through a focus on matereal methods, empirical investigations of the lived 'epistemontological' experience of 'agential realism' (Barad 2003) become possible.

A deeper understanding of matereal methods is an exciting philosophical, conceptual prospect, but it is also of great practical relevance. Matereal methods are inherently innovative: Each encounter with material agencies is 'another next first time' (Garfinkel 2002) and requires improvisation. Designers, engineers, policy-makers and other professionals engaged in hands-on innovation often struggle to enable people to 'materealize' the full potential of their products and to either support or adequately restrain unanticipated use or interpretation. My engagement with innovation at one of the frontiers of this endeavour – mobile and ubiquitous computing – allows me to propose some promising directions.

12.4 Workshop Call for Participation: matterealities, mobilities, innovation

Author: Monika Büscher

Status: Held on 5-7 November 2007 at Lancaster University, with Professor Karen Barad of University of California Santa Cruz.

A fuller illustrated version of the call for the workshop and associated art events is at: http://www.ist-palcom.org/activities/matterealities

Call for Participation

matterealities, mobilities, innovation

5-7 November 2007, Lancaster University

http://www.ist-palcom.org/activities/matterealities

A growing body of studies show that in the detailed how of ‘how matter comes to matter’ (Barad 2007) the social and the material are inextricably linked. However, the very practices that join also often conceal such entanglement - in everyday practice, politics, science and design. In this interdisciplinary workshop we seek to explore a particular set of connections between 'matterealities', mobilities and innovation:

Matterealities: If social-material realities or orders are made, two questions arise: ‘How are they made?’ and ‘How could they be made ‘better’?’ Science and technology studies and ethnomethodological studies address the first, and sometimes also the second question (e.g. through involvement in design, socio-technical innovation and ‘engaged’ research (Sismondo 2007)). However, while these studies can powerfully draw our attention to the entanglement of the social and the material, they often struggle to escape the dualisms entrenched in our languages and epistemic practices. Non-representational approaches, and Barad’s agential realism in particular, open up new possibilities for a study of ‘intra-action’, not only by focusing on how epistemic practices and 'pre-cognitive' 'matereal' methods of embodied conduct make matter matter, but also by formulating a new 'epistemontology'. The convergence of increasingly powerful and small computing, sensor and actuator technologies with everyday materials, including the clothes we wear, the cars we drive, and the places we live, play and work in – presents a particularly rich challenge for this approach. Whereas research into socio-technical settings and practices has tended to look at human-computer interaction and 'the virtual' (cyberspace and life online), research must now also look towards the intra-actions of digital phenomena and the 'materealization' of socio-technical realities.

Mobilities: A new ‘movement-driven’ social science (Urry 2007) reveals movement, potential movement and blocked movement as constitutive of economic, social, political, environmental and material relations. Movement, momentum, and motion are also integral to epistemic practices and ‘mattering’. Moreover, they rely on and can reveal the important role of media (air, water) and infrastructural support (roads, cables, satellites, networks). Combining a focus on mobilities with studies of intra-action can make important aspects of the entanglement of the social and the material amenable to study.

Innovation: Can studies of how socio-material realities are made inform the making of ‘better’ realities? A first answer must be ‘No’, because by drawing attention to the entanglement of the social and the material, such studies show that it is difficult if not impossible to know what ‘better’ might mean, to go beyond the scale of ‘us, here and now’, let alone decide what steps would enable the matterealization of better futures (without treading loose an avalanche of unintended consequences). Yet, it is tempting to attend to 'issues of social order and intelligibility that must be understood before social problems can be intelligently addressed' (Warfield Rawls 2002) and to trust that better understanding will indeed allow us to address social, material and technical problems and opportunities more intelligently. Concrete experience from ethnomethodologically informed technology design reframes the ambition: First, by changing the way in which innovation is conceived of and achieved towards a more collaborative, iterative (pervasive and never-ending), interdisciplinary process (Suchman 1999), and second, by seeking to change the objects of innovation, for example by making technologies that support creative appropriation in the context of everyday innovation (e.g. Robinson 1993, Dourish and Button 1998, Chalmers 2004, Gershenfeld 2005, The PalCom project). Agential realism opens up new possibilities for these approaches and provides an opportunity to widen the focus to other forms of socio-technical change.

In this workshop we bring together an interdisciplinary group of scholars and practitioners to explore, formulate and shape these possibilities and opportunities.

ACTIVITIES

5 November 2007

15:30 – 16:45 Coffee and Introductions for Workshop Participants
17:00 – 17:45 Public Lecture: Karen Barad talks about her new book 'Meeting the universe half-way'. Introduction by Lucy Suchman
17:45 – 18:15 Discussion
18:15 – 18:45 Introduction to artworks
18:45 – 21:00 Exhibition Opening (wine and food)

6 November

09:00 – 14:00 Site visits
14:00 – 15:30 Group work
15:30 – 16:00 Coffee
16:00 – 18:00 Free. Tim Ingold is giving a talk at the Sociology department
19:00 Dinner

7 November

10:00 – 11:00 Present Group work, discussion
11:00 – 11:30 Coffee
11:30 – 12:30 Discussion, future plans
12:30 – 13:30 lunch & end

WITH ART BY

Fiona Jane Candy, UK - http://www.a-brand.co.uk
Paul Coulton, UK, http://www.mobileradicals.com
Irene Janze and Anton Dekker, The Netherlands, http://home.tiscali.nl/burojanze/
Dr. Jennifer G. Sheridan, Alice Bayliss, Dr. Nick Bryan-Kinns
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