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.

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[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.

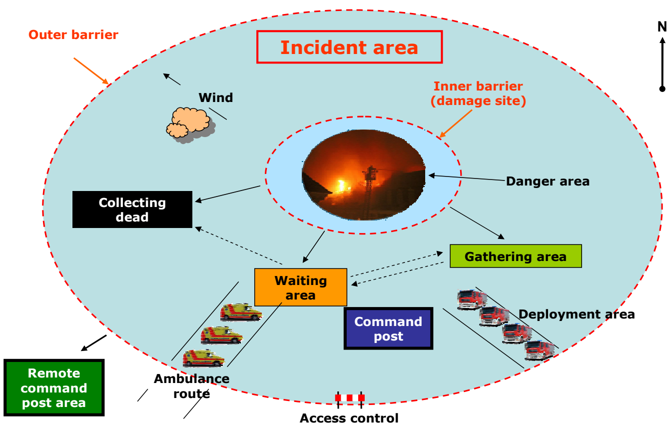

Figure 6
Schematic showing an abstract organization of an incident area.

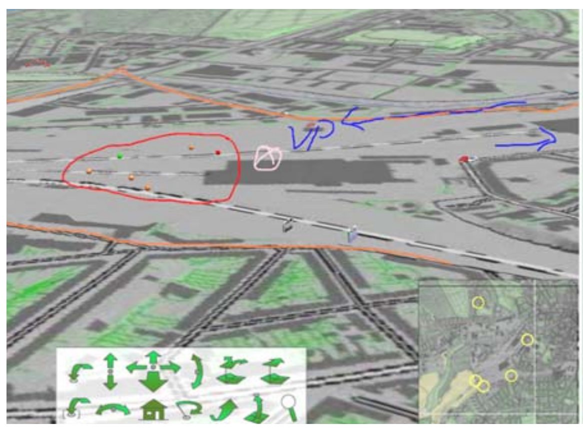

Figure 7 Detail of the organization of the scenario incident site drawn by the Aarhus fire and police commanders, with inner and outer barrier. The waiting area (Vente Plads, VP) is marked by a cross and transport routes are indicated.

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.

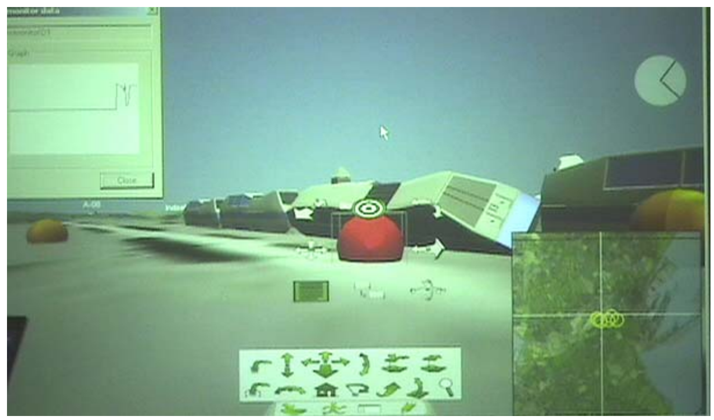

Figure 9 The red sphere marks the location of a critical victim, whose biodata is being inspected in the window on the left.

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.

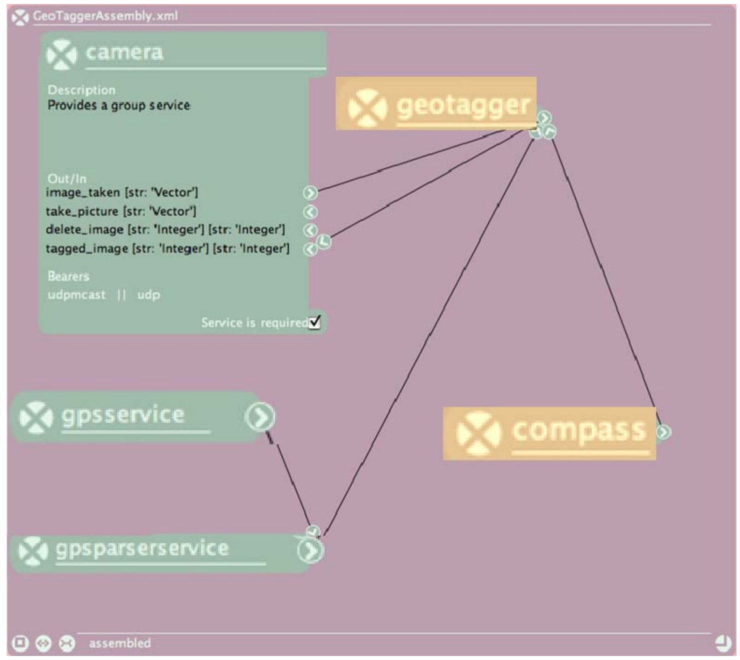

Figure 11 Map of the 'GeoTaggerAssembly'.

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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