Digital Map Table with Fovea-Tablett®: Smart Furniture for Emergency Operation Centers

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ABSTRACT

During large-scale crisis events special emergency management structures are put in place in order to execute administrative-strategic and/or technical-tactical functions for potentially large geographical areas. The adequacy of information systems and the communication capabilities within such management structures largely determine the quality of situation awareness and are thus crucial for the effectiveness and efficiency of the emergency managers' work. In this field, this paper makes a threefold contribution: In the first part we provide a description of the organizational structure and the tasks in an emergency operation center (EOC) from a practitioner's perspective. Based on this primer, in the second part we propose four guidelines which help to design human-computer interfaces, especially adequate smart room technology, for this domain. Third, we present a system we designed along these guidelines. We specifically discuss the introduction of a Digital Map Table with Fovea-Tablett® into an EOC as "smart furniture" supporting both team and individual work.

Keywords

multi-display environment, CSCW, Fovea-Tablett®, gesture-based interaction, tabletop, disaster management

INTRODUCTION

Major emergency events like natural disasters, major industrial accidents or terrorist attacks, require a timely and coordinated response effort by a number of emergency services and authorities. Initially, in the so-called "chaos phase" immediately after the incident, information is sketchy and hard to come by. When the scale of the event becomes evident and a disaster is declared, an EOC is activated, so it can eventually take control. While the command and control structure is somewhat different from country to country, it is a common observation that responsibility is shared along pre-defined lines between on-site commanders and EOC personnel, which may or may not be close to the emergency site. Thus, the flow of information between the players is critical for the success of the response effort. An adequate crisis management IT system may define the information exchange graph and provide the "plumbing" for the information flow. However, it is equally important to carefully design the interfaces of this system, with particular regard to the human-computer interface. Ideally, the IT system will "read the lips" of crisis managers and provide them, even in high-stress decision making situations, with just the information they need, without the need for complex interaction. In that way, the crisis manager's undivided attention can be given to the matter he/she is to decide on.

A "read my lips" EOC IT system is not yet available. It is however promising to introduce the concept of *smart rooms* to the emergency management domain, allowing for seamless interaction between humans and the IT system. A smart room may be able to sense who is in the room, and where, in what work situation, etc., and it can choose the most appropriate interaction mode with the individuals. A smart room has sensors monitoring people and their actions, and it has "smart furniture" for human-computer interaction, which may itself come with sensors that enable it to identify users and their moves.

One example for such smart furniture is the Digital Map Table with Fovea-Tablett®. This table, which we describe in detail later, consists of a large horizontal display capable of displaying e.g. a digital map, and a tracking mechanism for special tablet PCs placed (and moved) by users on its surface. These tablet PCs, referred to as “Fovea Tabletts” in analogy to the foveal area of the human eye, may act as simple clearview or magnifying glasses, define focus areas, or provide layers of information of specific interest to the individual user. Additionally, the system is able to recognize gestures for fast and easy human-computer interaction. In short, this smart piece of furniture seamlessly identifies users and their moves, and it provides them with information they need.

In the remainder of this paper we first describe, from a practitioner’s perspective, the communication and interaction in and around an EOC, including the current use of media. Next, along these insights, we discuss the challenge of designing smart room technology for an EOC, identifying four key design guidelines. Our Digital Map Table, smart furniture for an EOC, is described in detail, along with a look at related work and an outline of a user evaluation study. Finally we conclude and point out future work.

THE TASK: COMMUNICATION IN AND AROUND AN EOC

Since smart room technology is rather new to the domain of crisis management, and its introduction needs to be based on a thorough understanding of standard processes, in this section we sketch, from a practitioner’s perspective, the organizational structure and the tasks in an EOC which need to be supported by appropriate IT systems. This will form our basis to identify where and how smart room technology can be used in order to improve human-computer interaction (HCI). While the following discussion of the management processes during crisis events is derived from the German crisis response framework, it is kept as generic as possible in order to maintain transferability to systems found in other countries. First we give an overview of different management levels, then we describe requirements regarding information and communication at each level.

Management Structure

Depending on the size of the event, different management levels are installed in order to handle the event adequately and to distribute the workload reasonably according to required knowledge and authority. Generally these levels can be separated into technical-tactical, operational-tactical and administrative-strategic level (see Figure 1).

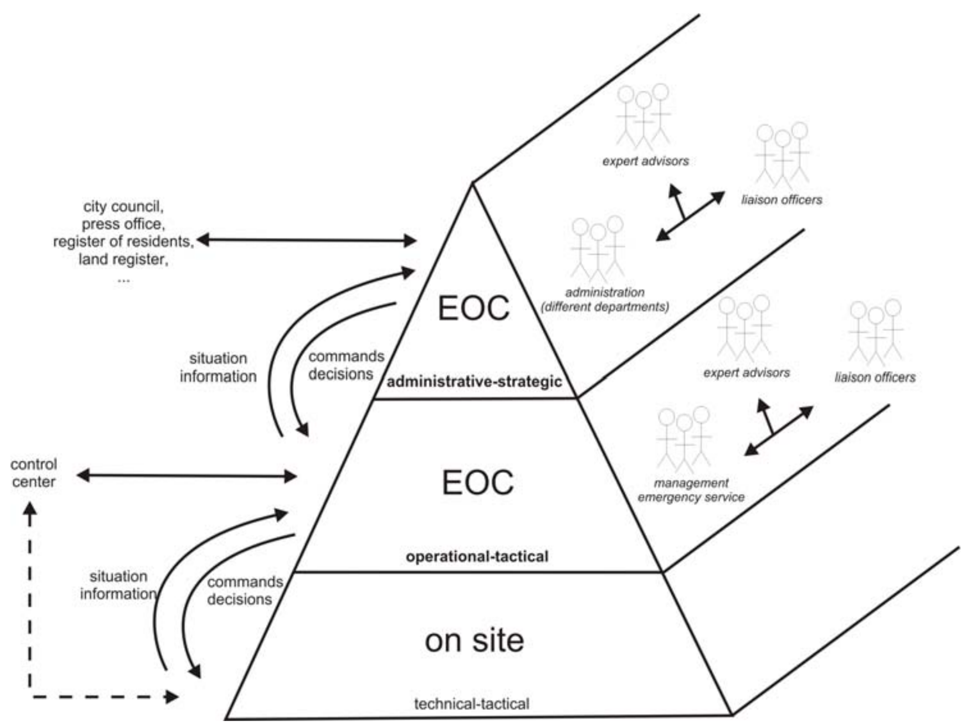

Figure 1: Organizational structure and communication between different parties involved in crisis management

While technical-tactical units (supervised e.g. by group leaders) are responsible for executing and organizing the actual on-site frontline response, management structures at the upper two levels mostly are installed in mobile or stationary EOCs. Since the latter may be away from the site, on the one hand situational awareness of crisis managers has to be supported by availability of as much and as current information as possible, but on the other hand information overload has to be avoided in order to allow for an efficient and effective decision-making process. Operational-tactical staff are mainly composed of managers from the corresponding emergency service (e.g. firefighters); they are supplemented, if required, by expert advisors and/or liaison officers of other services (e.g. police), affected companies, the military, etc. Administrative-strategic crisis management groups consist of members from various authorities (e.g. regional government, security, health, etc.) and may also be supported by expert advisors and liaison officers.

Information and Communication Requirements

Usually large-scale crisis events do not appear from one second to another, but develop over a longer period of time. In the first phase, event related messages are received and handled by local control centers which directly dispatch appropriate resources. Dispatched resources may be managed at the technical-tactical unit level. Since those units are on site and the number of communication partners and information sources is limited, communication at this level often is done face-to-face or via single communication media (e.g. radio). Communication at this level will not be considered any further in this paper.

If the crisis event worsens, operational-tactical executive staff has to be activated, forming a higher command level, in order to handle the developing situation. Communication with the technical-tactical level comprises forwarding commands and, in the other direction, transmitting updated situation information (see Figure 1). Often this communication is realized via a control center, since from there electronic information channels are already well established to technical-tactical units for communication during normal operation. However, in most EOCs (especially in mobile ones) information from control centers is, if at all, only displayed on a projection wall, and interactivity is rather limited (see e.g. Figure 2). This leads to a more up-to-date situational awareness compared to traditional paper based maps, but decisions and commands mostly still have to be communicated by paper, and at least one "human intermediate station", which has to interpret the message and forward it to the appropriate recipient (e.g. via phone or radio), is necessary. In the mobile EOC shown in Figure 2, decisions and commands are for example passed from the meeting room to the workplace for external communication via paper through a small window, and are forwarded from there to appropriate recipients. Such indirect communication however, which additionally includes media discontinuities, causes high temporal delay and error rates.

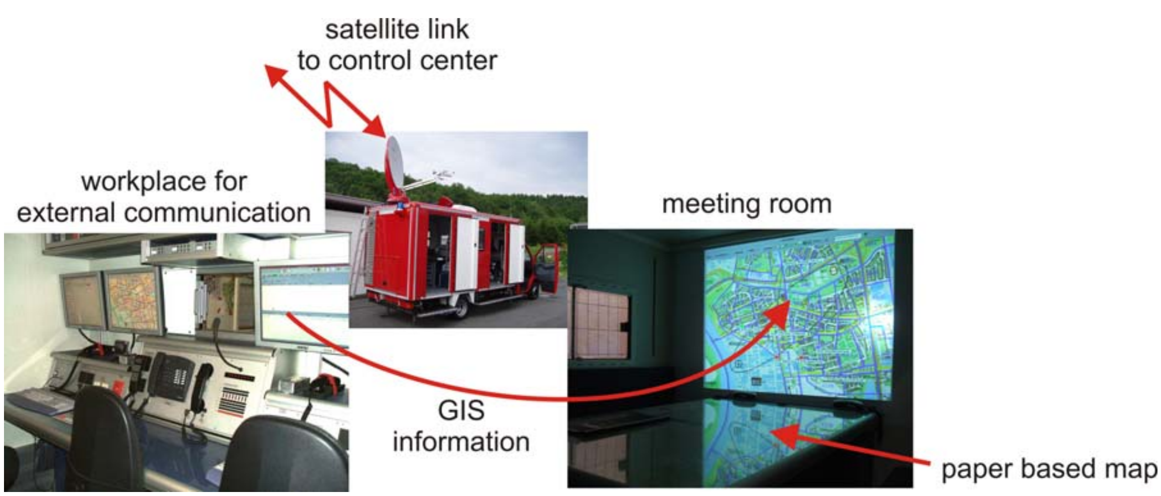

Figure 2: Example of a modern mobile EOC with separate rooms for internal and external communication

While for operational-tactical coordinating staff information about and communication with lower organizational levels (e.g. via control centers) plays the key role for effective work, at the administrative-strategic level additional information sources and sinks need to be considered. Examples are local governments, the press, and utility companies. The heterogeneity and diversity of these sources and sinks cause a high diversity of communication media and complex interaction procedures, which often leads to inefficient work flows. The work situation is typically characterized by a team effort to come up with a common operational picture.

Summarizing the discussion above, Figure 2 shows the various paths of communication between different parties involved in crisis management. While EOC internal communication is direct (face-to-face) and well structured by role based responsibilities, communication with external parties (e.g. with lower organizational levels), according to practitioners, often is complex, indirect and involves error prone and time consuming media discontinuities. In the next section we discuss how smart room technology can help improve information exchange in and around an EOC.

THE CHALLENGE: DESIGNING SMART ROOM TECHNOLOGY FOR AN EOC

The challenge of designing and deploying IT systems, in particular smart room technology within an EOC, can be formulated as the challenge of satisfying concurrent situation dependent information and communication requirements of different persons within the EOC in harmony with each other. Using current technology, communication with heterogeneous external information sources or sinks often causes complex interaction with multiple technical devices as shown in Figure 3 (a) (e.g. radio, phone, internet, email, word processor, etc.). This complexity is often reduced for staff members in current EOCs by putting one human expert in the middle who operates the complex technical infrastructure (see Figure 3 (b)). This however results in indirectness of communication which comes along with increased error rates ("Chinese Whispers") and temporal delay of message transfer.

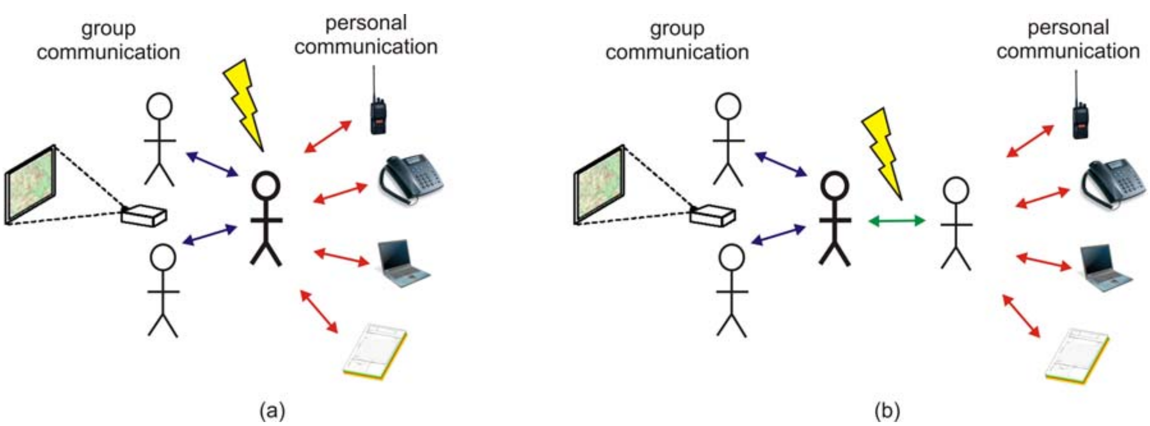

Figure 3: Complex interaction for communication (a), reduced in current EOCs by a human expert as mediator (b)

Therefore the goal of designing smart furniture or, more generally, smart room technology for EOCs, should be to make communication and interaction more direct by bringing the digital information channel up to the end-users. This is nothing else than the classical task of designing a good human-computer interface (HCI), however with certain additional requirements arising from communication and interaction patterns within and around an EOC as introduced in the previous section. Therefore, in addition to general design guidelines and principles for HCI (as described e.g. in (ISO 9241-11, 1998) or (Shneiderman, and Plaisant, 2005)), domain specific constraints and requirements need to be considered. In collaboration with practitioners we identified several points which may be improved by use of smart room technology and smart furniture. The following list of "design guidelines" by far is not complete, but represents some weak points existing in current realizations of EOCs which could be improved by adequate IT systems and HCIs:

- *Support direct interpersonal communication within the EOC*. This is the reason why these people came together in an EOC. Interpersonal communication is supported within current EOCs and should be in harmony with usage of other communication channels.
- *Separate personal and group interaction/communication but make gaps between modes small*. In order to avoid information overload caused by an abundance of items on displays used e.g. for visualizing an

overview of the situation for a group of people within an EOC, information which is only relevant to certain members should be displayed separately (e.g. on personal media). However, in order to avoid loss of context when switching from group to personal displays or vice versa, gaps between the two modes should be kept small. By sensing location, context and intention of a person representing a certain role within an EOC, e.g. information which is relevant in the current situation could be routed automatically to the appropriate display, or an interactive tool could be made available at the right location within the team workspace.

- *Bundle information and communication channels according to roles and bring them up to the end-user*. Information, communication and interaction requirements mostly are linked with certain roles within the organizational structure of an EOC. Instead of having an expert in the middle who hides complexity of various communication channels and is available to all roles (Figure 3 (b)), interfaces of different communication media should be unified in personal interaction/communication tools providing direct access to functions relevant to a certain role. Smart room technology could be used to make this access intuitive, non-intrusive and fast.
- *Make interaction and communication attributable and recordable*. Each communication step which led to a certain decision or response should be attributable to the persons who were involved, and it should be recorded to be usable in court. This also includes for example confirmation if a piece of information was perceived by the recipient. Smart room technology could be used to record perceived information implicitly, e.g. by tracking human position and gaze.

These guidelines are in harmony with system guidelines for co-located, collaborative work on a tabletop display identified in (Scott, Grant and Mandryk, 2003). However, they are more general in the way, that they are not defined for a certain user interface type but for a certain application domain. Nevertheless, the large overlap of requirements of both sets of guidelines motivates a system design as described in next section, which incorporates a tabletop display and fulfills both requirements which were formulated for the application domain and for the user interface type.

SMART FURNITURE: DIGITAL MAP TABLE WITH FOVEA-TABLETT®

In this section we present smart furniture for future EOCs providing a user interface platform which supports relevant communication and interaction patterns as described and discussed in previous sections. Earlier versions of the so-called Digital Map Table with Fovea-Tablett®, which features different visualization and sensing technologies, were introduced in (Peinsipp-Byma, Eck, Rehfeld and Geisler, 2007; Geisler, Eck, Rehfeld, Peinsipp-Byma, Schütz and Geggus, 2007). Now, going beyond these previous publications, we have included gesture based interaction techniques and a flexible software infrastructure which enables easy integration of various heterogeneous information sources and interaction devices.

Figure 4: Team working on Digital Map Table with Fovea-Tabletts

The user interface consists of three types of hardware components. The first component is a horizontal tabletop display which is realized by backprojection and measures 90x120 cm (see Figure 4). A second large display is attached perpendicular to the tabletop and provides space for displaying information on objects which can't be adequately displayed on the horizontal display for a group of people. Such extra information may include a categorization of items stored in a warehouse marked on the map, or the video stream of a surveillance camera installed at a marked location. This setup itself is not new, and similar constructions are used e.g. by (Chen, Close, Eades, Epps, Hutterer, Lichman, Takatsuka, Thomas, Wu, 2006; Johanson, Fox and Winograd, 2002). However, as already mentioned in a study on the use of large displays in automotive design (Buxton, Fitzmaurice, Balakrishnan and Kurtenbach, 2000), "[...] the story is about interaction, not displays". In contrast to conventional tabletop systems, with our approach multiple small displays, so-called Fovea-Tabletts, can be placed at arbitrary locations on the tabletop in order to provide personalized views into the information space. In the simplest case only the resolution of the visualization is locally increased (see Figure 4). In order to determine location and orientation of Fovea-Tabletts on the tabletop we use a marker based approach where mobile devices are tracked in image sequences which are taken by a camera from behind the semi-transparent projection surface (see Figure 6 and (Peinsipp-Byma at al., 2007; Geisler at al., 2007) for further details).

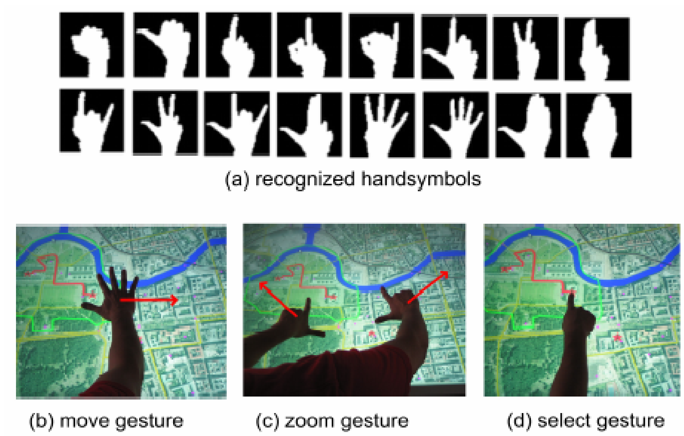

Figure 5: Recognized handgestures and sample application on tabletop

Camera images in near infrared (NIR) taken from above the tabletop surface are used for recognizing dynamic hand gestures (see Figure 6). The gesture recognition system is able to distinguish 16 static hand gestures, which make sense under ergonomic aspects (Figure 5 (a)), as well as to track movements of multiple hands at the camera frame rate of 25 Hz (Bader, T., Eck, R., 2007). The gesture vocabulary could be extended to more hand symbols (e.g. by side views of the hand symbols), but for the task at hand the vocabulary shown in Figure 5 (a) is sufficient. By reconstructing the 3D-position of fingertips from stereo-images, the distance of fingertips from the display surface is determined and can be used directly as user input or to couple feedback and system reaction with the touch of the display surface (distance = 0). The measurement accuracy of the fingertips' position is 0 - 0.6 cm in horizontal direction, depending on the position on the display surface, and 1 – 2 cm in vertical direction (distance from the display surface). In contrast to multi-touch screens like DiamondTouch (Dietz, P. und Leigh, D., 2001) or Microsoft Surface™ this camera based approach for recognizing hand gestures and touches works independently from the display technology used and also enables interaction across multiple devices (e.g. dragging objects from table onto Fovea-Tabletts). However, we currently only use gesture based input for manipulating visualization and for selecting objects on the tabletop (see Figure 5 (b)-(d)).

Inputs from different devices (by pen on tablet-PCs or gesture on tabletop) can either be used to manipulate objects in the information space or to change visualization parameters of the input device itself or any remote device (e.g. gesture based selection of objects on the tabletop for which detailed information is to be displayed on the vertical monitor). For the latter case, inputs from different devices need to be routed to devices which are to be manipulated. This is realized with a server/client architecture as shown in Figure 6. Each client may push inputs onto the I/O-server as well as subscribe to inputs of other devices. Inputs generated on any connected device (e.g. tablet tracker, gesture recognition, tablet-PCs, etc.) are encapsulated in an XML-based format, sent to the I/O-server and forwarded from there to clients which subscribed to this type of input.

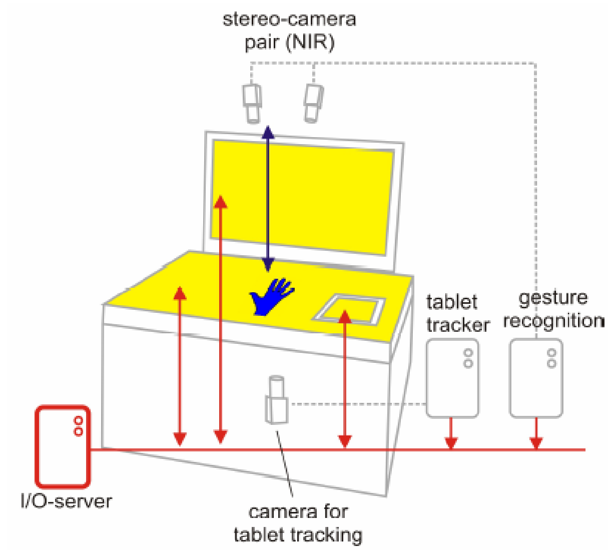

Figure 6: Combination of input sensing technologies

As central data storage for geographical related data UMN MapServer (MapServer, 2008) is used. Each connected device may request data via standardized web services, namely Web Map Service (WMS) (de La Beaujardière, 2002) and Web Feature Service (WFS) (Vretanos, 2003).We further use the Java SDK of NASA World Wind (World Wind Java, 2008) as basis for our visualization software which runs platform independent and is able to display 3-dimensional GIS-data on tabletop, vertical monitor and Fovea-Tabletts. External information sources can be connected to the system in the form of foreign MapServers with WMS and/or WFS interfaces as they are already available in many city councils or directly over a PostGreSQL database included in UMN MapServer.

With the Digital Map Table with Fovea-Tabletts various important interaction patterns in an EOC can be supported along the four design guidelines we identified earlier:

First, direct interpersonal communication is encouraged by the form factor of the HCI, namely the tabletop. Map tables were already used in the past in EOCs in combination with paper based maps, because they provide a common overview of the situation for a relatively large team and enable around-the-table discussions. Additionally, in contrast to wall projections as they are commonly used in current EOCs, the tabletop enables, in combination with the gesture recognition system, intuitive interaction by *all* group members. Wall projections mostly are mirrors of a laptop or PC displays and therefore can only be manipulated from a single user HCI.

Figure 7: Example of public and personal visualization in the same area on tabletop (a) and with higher level of detail on Fovea-Tablett (b)

Second, personal and group interaction/communication is separated. While the tabletop and vertical displays are used for group visualization and interaction, personal information and communication channels are routed to Fovea-Tabletts in order to prevent the former from being spoiled. The latter can be carried around and therefore build a mobile personal information and communication environment for their users. However they also can be placed on the tabletop and serve as personal lens, displaying personalized information embedded in the context of group interaction. This could be, for example, detailed floor plans, location of dangerous goods within a building and/or lists of available units and their estimated time of arrival, while on the tabletop only one symbol indicates the existence of e.g. dangerous goods within the building (see Figure 7). By pen based interaction different details can be switched on/off, the area of interest can be moved/zoomed locally on the personal Fovea-Tablett without disturbing other team members, while still being aware of the context displayed on the tabletop (e.g. incoming messages or alarms outside the personal area of interest). Free-hand annotations can be made in analogy to pen based annotations in the traditional paper based approach. The localization of Fovea-Tabletts on the tabletop can also be interpreted as an indirect localization of a certain user, and such knowledge can then be used to automatically display role dependent information at a certain location of the tabletop (on the Fovea-Tablett). Through this multifunctional usage of Fovea-Tabletts the gap between personal and group interaction is reduced dramatically, since a user just needs to put his/her Fovea-Tablett onto the tabletop in order to "jump in" and be involved in the discussion while maintaining his/her personal information environment. The personal environment however can be also adjusted automatically according to the context of the interaction at the tabletop display.
Third, by unifying different communication and information channels on a Fovea-Tablett and providing intuitive access e.g. by means of personalized and well known GUI-elements, they can be directly used by the end-user without any intermediate steps.
Forth, by routing personal interaction through personal Fovea-Tabletts, this interaction becomes assignable to certain persons and also can be recorded. (The latter two features however are still under development and constitute future work.) In any case our approach helps avoid the media discontinuities observed otherwise and carries great potential to improve effectiveness and efficiency of workflows in an EOC.

Related Work

Similar approaches with high resolution foveal areas integrated in large screens were published in (Sanneblad and Holmquist, 2006), (Baudisch, Good, Bellotti, and Schraedley, 2002) and (Ashdown and Robinson, 2003) with the purpose of increasing the resolution in a certain area of interest. However, in these approaches either foveal areas are static (Baudisch et al.,2002; Ashdown et al.,2003) or technology used for tracking mobile devices is limited (Sanneblad et al., 2006). See (Geisler et al., 2007) for further discussion.

The idea of using mobile viewing filters, like Fovea-Tabletts on the tabletop, which provide local different views onto the application lying underneath was also published in (Bier, Stone, Pier, Buxton, and DeRose, 1993). With their approach it is possible to view and manipulate different aspects of a scene displayed on a screen. But, since their filters are only software components, they cannot be used as mobile personal multifunctional assistants, as it is possible with Fovea-Tabletts. Another popular work in HCI research is that of (Ullmer and Ishii, 1997). They used active and passive lenses in order to provide personalized views onto a tabletop display, however their approach also considers only interaction at the tabletop and doesn't include communication around it.

USER EVALUATION

Informal user evaluation has taken place at various occasions with promising observations, and the fact that one of the co-authors of this paper is an active-duty fire service control center director underlines the relevance of the Digital Map Table with Fovea-Tablett concept for the application domain. Additionally, from the onset our system design has been based on the four design guidelines introduced earlier, which were established in close collaboration with practitioners. In the near future, a formal user evaluation study is to be carried out along an evaluation plan discussed in this section.

In a first step we will put the emphasis on investigating the effects of its core feature, namely the locally increased number of pixel per inch, for tasks relevant to the application domain. Generally this feature leads to the ability to display information with a high level of detail in foveal areas (without the need for complex interaction) and the high accuracy of pen based input. In (Sanneblad and Holmquist, 2006) qualitative differences in user behaviour were identified during a map navigation task when performed on a large display with mobile foveal areas and with a conventional interface, respectively. In order to quantify such differences for the application context of an EOC, we will compare task execution using three different experimental setups. The first setup consists of a typical equipment of current EOCs (as shown in Figure 2). The second setup is the Digital Map Table (without Fovea-Tablett), as representative of a classical tabletop display and the third setup is the Digital Map Table *with* Fovea-Tabletts. The measurements to be used for comparing the different approaches are derived from standard evaluation procedures, as e.g. described in (ISO 9241-11, 1998), and are directly linked to properties which are relevant to tasks in an EOC. First, the effectiveness will be measured in terms of error rates, which may be increased due to complex interaction procedures and/or low accuracy of input devices. Second, efficiency of task execution will be evaluated by the number of interaction steps needed for a certain task and/or speed of use. Additionally we will include usability measurements using questionnaires as well as subjective measurement of workload (e.g. by NASA Task Load Index).

In a second round of user experiments we are going to evaluate other important features of the Digital Map Table with Fovea-Tablett mentioned above, namely personalization of foveal areas (regarding communication and information visualization), effects on interpersonal communication around the table, and difficulties with the simultaneous use of multiple Fovea-Tabletts.

CONCLUSION

In this paper we have discussed how smart room technology may be introduced to EOCs in order to overcome issues observed with current technology, namely the lack of support for a work situation characterized by a mix of team and individual work, the need for ease of use in a high-stress environment, and the challenge to provide just the right amount of information to each individual team member. From a practitioner's perspective, we illustrated the organizational setup chosen for the emergency response phase, as well as key information exchange processes. Based on this, we identified design guidelines for the introduction of smart room technology into EOCs. The Digital Map Table with Fovea Tablett was described as an example of "smart furniture" designed along these guidelines. Special attention was given to the way individuals interact with the device, including the use of hand gestures. While much has been achieved, and previous versions of the table have been installed at customers' premises, a number of issues remain to be addressed in future work. A formal user evaluation study is under preparation, as discussed above. We are currently addressing the integration with existing commercial control center dispatch software, so a vast resource of static and dynamic data may be accessed and, where appropriate, manipulated by users of the Digital Map Table. The Fovea Tablett communication software needs to be enhanced in order to better support the fusion of a multitude of communication channels. The current version of our hand gesture recognition system still has room for some improvements aiming at a better support of inter-display interaction patterns. We are working closely with end users in order to demonstrate that the Digital Map Table with Fovea Tabletts is in fact a piece of smart furniture that may help improve the work effectiveness and efficiency in emergency operation centers.

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