Designing Multi-Modal Map-Based Interfaces for Disaster Management

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Abstract— **The access to current and reliable maps and data is a critical factor in the management of disaster situations. Standard user interfaces are not well suited to provide this information to crisis managers. Especially in dynamic situations conventional cartographic displays and mouse based interaction techniques fail to address the need to review a situation rapidly and act on it as a team. The development of novel interaction techniques like multi-touch and tangible interaction in combination with large displays provides a promising base technology to provide crisis managers with an adequate overview of the situation and to share relevant information with other stakeholders in a collaborative setting. However, design expertise on the use of such techniques in interfaces for real-world applications is still very sparse. We are, therefore, conducting interdisciplinary research with a user and application centric focus to establish real-world requirements, to design new multi-modal mapping interfaces, and to validate them in disaster management applications. Initial results show that tangible and pen-based interaction are well suited to provide an intuitive and visible way to control who is changing data in a multi-user command and control interface.**

Keywords-post-WIMP user interfaces; natural user interfaces; mapping; geo-visualization; multi-touch interaction; pen-based interaction; tangible interaction

I. INTRODUCTION

Our goal is to improve the management of large-scale disaster situations and complex emergencies by providing crisis managers with an interactive mapping system that aims to improve their effectiveness. Crisis managers often lack access to vital information. With digital map repositories and the proliferation of new sensors the problem increasingly changes from one where information is missing to one where the required information is too difficult to access and analyze. For example, even if the required information can be collected, crisis managers are still faced with the need to cope with large amounts of data that needs to be processed in order to guarantee successful operations.

Existing work on post-WIMP (Windows, Icons, Menu Pointer) user interfaces has largely focused on the development of base-technologies and individual visualization and interaction techniques. We complement this work using an approach that starts with the application and focuses on user centered design (UCD). In this process, we use close collaboration with end users to establish requirements, to examine new concepts in data analysis and presentation and to validate the newly developed user interfaces. With regards to user interface techniques, we are working both on the technology level and on the interface level. At the technology level we develop new multimodal interfaces, incorporating advanced techniques for interaction and information. At the interface level we provide interface solutions to real-world problems, specifically command and control interfaces with advanced multi-user capabilities.

In this paper, we initially review related work (Section II.) and then introduce our design approach (Section III.). The design of our multi-modal system for disaster management is detailed in the following sections, starting with the requirements (Section IV.). According to our hierarchical design approach these requirements are addressed by base technology components (Section V.) which are then combined into the complete system (section VI.). Our experiences and initial feedback from the end-users are reviewed in section VII. Finally, we draw conclusions from the design and evaluation process and provide an outlook on future work.

 ISBN: 978-1-61208-177-9

II. Related Work

Most relevant data in disaster management are of spatial nature (environment, location of resources) and one key challenge is to effectively integrate and unify spatial data from different sources. Geographic Information Systems (GIS) are well established to deal with the acquisition, storage, analysis and presentation of spatial data and are established tools in the management of crisis situations in many agencies. Challenges arise in the user interface, the integration of data and the integration with other systems. While the integration of static geo-data from different providers is addressed by initiatives like INSPIRE [4], a special challenge remains due to the fact that high-bandwidth sensors acquire much data in a disaster use-case at the time of use that is difficult to handle, analyze and present.

In addition, a crisis management system must also be able to handle different types of imprecise and non-digital data sources that arise in typical emergency situations.

A critical factor in the management of disaster situations is the access to current and reliable data. Novel sensors like infrared cameras, LIDAR [11] and SAR [3] allow to capture geo-spatial data when and where required, e.g., in the case of SAR irrespective of weather-conditions and visibility. Key challenges are the control of such sensors and the integration of such geo-spatial sensor information into a crisis management system. Especially in dynamic crisis situations, conventional displays interaction techniques fail to address the needs of crisis managers. Similarly, current GIS interfaces are not well adapted to use “in the field”. The extension of GIS with novel techniques for real-time data handling and advanced interaction techniques is therefore required. In the recent years, multi-modal user interfaces and post-WIMP interfaces have seen a rapid development, especially the emergence of so-called natural user interfaces (NUI), sometimes referred to as reality-based interaction [12]. While many NUI techniques have been demonstrated in research, the design expertise on the use of such techniques in interfaces for large real-world applications like disaster management is still very sparse [7]. For the successful application of NUIs, it is therefore essential to integrate contributions from a number of different research areas within a user centered design process to adequately support users of disaster management systems.

A key aspect is an up-to-date and reliable presentation of the geo-spatial environment. In the past this has been mostly presented by (digital) maps, but advancing technologies in sensors, displays and interaction devices enable the integration of real-time data and the use of new displays and output devices to provide both mobile users (e.g., rescue forces) and decision makers with more adequate user interfaces. A central challenge is to adequately adapt these emerging technologies to geo-spatial information. Again it is possible to draw on previous research, e.g., in cartography, navigation and geo-visualization, but this has to be adapted, integrated and validated in the application context.

Some earlier research has been conducted in the field of disaster management that addresses technological support for collaboration and coordination. However, few systems address the existing real-life-workflows of disaster management organizations like fire departments, police, medical services, etc. While interactive crisis management based on new interaction technology is regarded as promising [6], its adoption is limited because classical tools like pens and paper, paper-maps and plastic labels are proven and failsafe. A study of the potential use of multi-touch tabletops by the Dutch research institute TNO [13] investigated some possible uses of large scale interactive displays to provide effective assistance for decision-making during a disaster. It investigated in which departments such devices could be used, which workflows can be mapped and which not. The study shows that even casual users can use a tabletop without much learning effort and that it was effective in supporting collaborative work. The study also identified some problems in the specific system design. By using a user centered design approach from the beginning, we aim to avoid similar problems in our system.

III. Design Approach

A user centered approach is essential to develop new user interfaces that realize the benefits of technologies like post-WIMP user interfaces. In our project, we collaborate directly with the German Federal Agency for Technical Relief (Technisches Hilfswerk/THW) and draw on previous collaborations with fire fighters to adjust to real-world requirements [10]. To design and develop the system, we required an approach that takes both the requirements of large scale software engineering and usability engineering into account, while being adaptable to new and rapidly changing base-technologies on which little design expertise is available. Several approaches have aimed to integrate software engineering and usability engineering activities, either at the abstract overarching level of standards (serving as a framework to ensure consistency, compatibility, exchangeability, and quality), the level of process models (providing an organizational framework) or the operational process level (direct prescription of activities). For a detailed discussion see [9]. For our purposes the level of standards was to abstract to provide useful guidance and processes described at the operational level did not take the specific requirements (especially handling new and immature base-technologies) into account. Therefore, we started at the process model level, using the ISO standard 13407 (now replaced by 9241-210:2010) as our base, and derived an iterative operational process from this (Figure 1).

As our project involves stakeholders from many different disciplines, it was essential to provide an adequate mental model not only within the applications user interface (for the users), but also for the stakeholders in the development process (end-users, domain experts, experts for different base-technologies, designers, developers). We have, therefore, structured an iterative design process in a three level hierarchy (Fig. 1).

The base-technology level covers the hardware and software to enable an interaction or visualization, e.g., for a multi-touch device this would cover the sensors and associated processing to detect and process the touches of a user. In a project dealing with immature base-technologies it

 ISBN: 978-1-61208-177-9

is useful to decouple this development into a separate level, as many iterations or even changes in the base-technology employed (e.g., capacitive, resistive or optical multi-touch technologies) may be required.

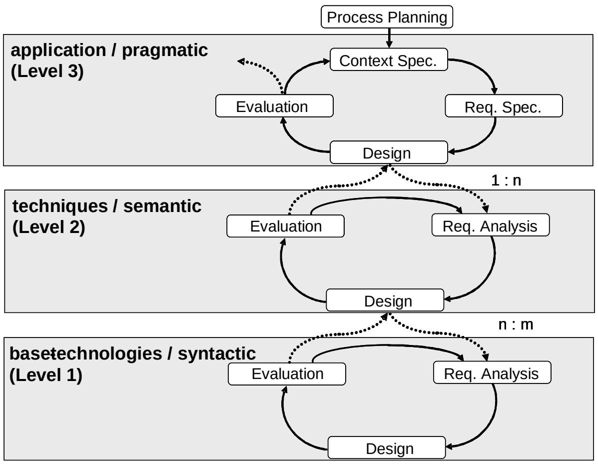

Figure 1. Hierarchical iterative design process based on ISO-13407

The second level covers individual interaction and visualization techniques. These employ the base-technologies to effect a useful task within the user interface, e.g., for a multi-touch device this could be the recognition of a specific touch-gesture. Again, it is useful to separate this design and development to achieve re-usable components. In mature environments this is typically not required because mature techniques are provided.

The third (application) level integrates different techniques from level 2, to construct a functional user interface for the application. A similar layering is applied to the data handling parts of the system.

Within the design process, the different activities correspond to common practice, specifically:

- Context of use
- User requirement (definition of scenarios, identification of requirements, definition of appropriate measures)
- Production of design solution (from scenarios over prototypes to implementation),
- Evaluation (analysis of requirements, review of designs, tests of prototypes, and evaluation of the complete system).

IV. Requirements

The requirements elicitation and analysis is conducted as an iterative, on-going process. We were able to build on experience from previous projects with firefighters and the German Federal Agency for Technical Relief (THW). Existing studies on disaster management were also consulted to provide additional background information.

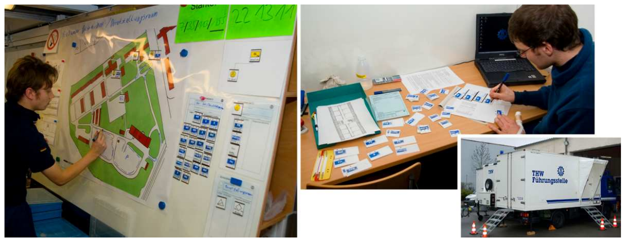

Figure 2. Observed THW exercises

However, the most important insights were derived from interviews, workshops and on-site training exercises conducted with disaster managers and technicians from THW. During training exercises we were able to observe the experts in their real work environment (Figure 2).

In order not to interfere with the exercises we installed video cameras and microphones in the operations center and recorded the course of events during the exercise. Based on the recordings we were able to analyze the details of each workflow. These insights were captured in scenarios that cover the different types of crisis situations and their information and command requirements, user roles (including professionals, volunteers, local collaborators, politicians, press, public), and operating environments (fixed and mobile command centers, operations in disaster zones).

A typical scenario is the management of a flooding incident by a THW team. Tools used include paper-based maps and special sheets, so called ‘damage accounts’, that contain summaries of local incidents and assigned units. Sheets are referenced to map locations by using little magnetic tiles. Typical activities are the creation, manipulation and spatial update of damage accounts.

These scenarios were then analyzed, to derive key requirements at the application, task and interaction level.

General application level requirements include:

- Provide access and control to information the way users are used to
- Manage and visualize the current situation in the field
- Maintain the benefits of the established robust workflow, that is clearly visible to all stakeholders
- Easily integrate non-expert personal (e.g. local support staff)
- Clear allocation of control for critical tasks
- Support for information sharing
- Separation of situation display and planning
- Data interface with OGC standard and commonly used non-standard data formats
- Enable the integration of imprecise and non-digital data sources
- Provide understandable presentations for different user groups (expert, local collaborator)
- Enable fast and easy communication and sending of commands to mobile units in the field
- Enable integration of software tools that allow a more efficient processing of recurring tasks

Expected additional benefits for a new system include:

- Seamless and scalable map display
- Support for rich media presentations of information
- Selective use of information layers
- Support for geo-referencing of units and incidents and automated transmission of coordinates
- Integration with existing GIS systems
- Access to real-time sensor and location data
- Information filtering and spatial analysis functions
- Support for private workspaces
- Combination of co-located and off-site interaction
- Ability to distinguish between different users; traceable interaction

The requirements analysis revealed a number of areas for potential improvements and indicated the need for a collaborative visualization and interaction environment. Natural user interface technologies like multi-touch, tangible, gestural and vocal interaction seems promising, but their suitability and usability must be confirmed. To ensure that the interaction remains coherent and "natural" the design of the system must ensure that users develop and maintain a suitable mental model of the system in operation.

V. BASE-TECHNOLOGIES AND TECHNIQUES

Figure 3. The useTable and it's interaction possibilities (pen, multi-touch, tangible puck)

As described previously, we address the design and development at three hierarchical levels. The separate consideration of the base-technology and interaction / visualization technique level allows to change base-technologies during development (if required) and to develop interaction and visualization techniques that can be reused.

As the central hardware component for interaction and visualization we build on the 'useTable' [14], a flexible visualization table constructed at C-LAB, that supports multi-touch, tangible and pen-based interaction. Compared to off-the-shelve solutions this approach enables us to adapt the technologies and techniques to the application and does not limit the design to the constraints of a given hardware environment. Using the feedback collected throughout the design process, the useTable has evolved into an interaction environment adapted to disaster management requirements.

The 'useTable' consists of a 55" display that offers full HD image projection. The projector is mounted beneath the surface and the image is projected on the top surface by two mirrors. For finger-tracking FTIR (Frustrated Total Internal Reflection) is applied and objects on the surface are tracked using combined DI (Diffused Illumination). The camera on the bottom of the table is equipped with a corresponding IR filter and is connected to a tracking PC that applies the filter and tracking algorithms. The projection surface is equipped with an antireflex diffusor sheet that enables pen-based interaction by using Anoto digital pens [1, 2].

On the software side, a new detection and tracking framework for advanced interaction using a depth-sensing camera [6], called dSensingNI, was developed. The dSensingNI framework is capable of tracking user fingers and palm of hands, which enables precise and advanced multi-touch interactions as well as complex tangible interactions. For tangible interaction arbitrary physical objects can be used to control interaction. Using the depth-sensing camera, physical objects can be used in common (2D) actions, such as placing and moving, and also in 3D actions, such as grouping or stacking. The depth-sensing also allows extending the multi-touch interaction to object surfaces without the need for integrated logic and sensors.

Combing RFID chips and depth-sensing cameras we are able to identify and track the persons that are interacting with the useTable. This allows applying different functionality to different users based on their roles during the interaction, a central requirement not addressed by off-the-shelve multi-touch tables.

Using the useTable and dSensingNI as base technologies, a number of different interaction and visualization techniques have been implemented. These techniques enable experiments with users, e.g., to study the usability differences between touch input, pen-input and the use of interaction-objects. A key advantage of the interactive display in the disaster management application is the ability to rapidly switch between different maps and map representations. Using a layer concept different maps and additional information (e.g., airborne imagery) can be mixed while maintaining the established workflow. The extension of the visualization beyond map-display allows experimenting with integration of derived information (e.g., danger zones, uncertainty) as well as task dependent map generalization and highlighting strategies.

Insights from these studies are used to guide the development at the base technology level. For example, experience showed that in some scenarios a strict separation between visualization of the current situation and the planning of future actions is essential. Our design approach allows to adapt to these requirements by modifying and extending the set of available base technologies. To provide an intuitive separation we extended the useTable into an L-Shape display. The L-Shape employs the useTable for planning as described. An additional wall display was added to visualize the current situation.

VI. SYSTEM

Building on the base technologies and interaction techniques we have implemented various iterations of a functional prototype that covers the functionality required by the THW to handle a regional flooding incident.

The system integrates, analyzes and presents the spatial data pertaining to the situation. To achieve this, it integrates digital maps, air- and space-borne imagery and a 3D terrain model. The use of a 3D terrain model enables important interactive analysis functions not available in the traditional setup using paper-maps, e.g., the calculation of number of pumps required to transport water along a specific trajectory.

According to the layering concept the system is structured into three different levels.

Essential tasks at the application level to be supported in this use-case are the communication and update of the current situation in the field (requirements: display of maps and additional information layers; editing of damage accounts), the planning of future actions and assignation of units (information input; communication). These in turn require appropriate interaction and visualization techniques.

For the visualization we started with a digital equivalent of the forms, signs and labels that are standardized and familiar to the THW staff. Additional features not present in the conventional environment include the possibility to overlay additional (geo-referenced) information layers, dynamic changes of symbolization and the level of detail presented, as well as the possibility to zoom, pan and rotate the map (Figure 3).

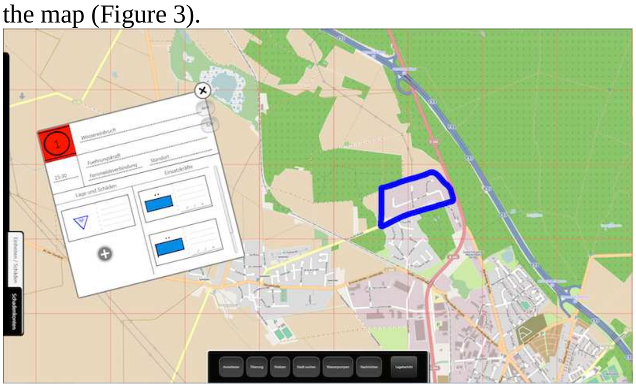

Figure 4. Situation overview with damage acount

On the interaction side techniques were required to control the system and visualization (system control), as well to conduct primary tasks, e.g., the creation and update of damage account documents that capture the current situation, and the assignment of vehicles and entities to different damages in the field.

Early feedback indicated, that for editing damage accounts the use of a digital pen (mimicking the traditional paper forms) was regarded as preferable to traditional hardware keyboard or on-screen software keyboard input (Figure 4).

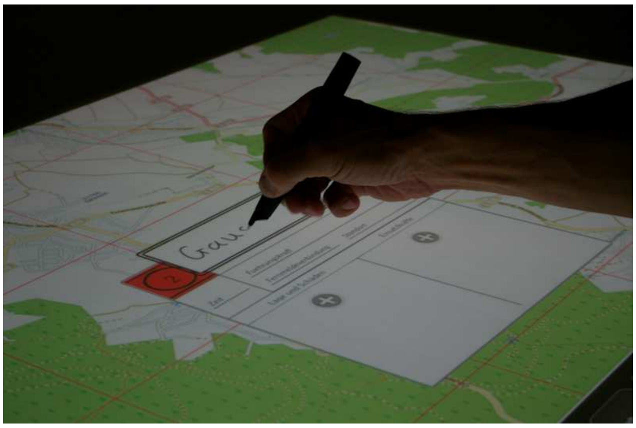

Figure 5. Editing damage acounts

In practice sessions, the digital pen also proved to be more suitable for marking and planning tasks than finger-touch input, as it allows more precise input.

While multi-touch gestures for scrolling, zooming and rotating have become popular with smartphones and tablets, early tests revealed that these are not suitable in our application scenario: Multiple users touching simultaneously (e.g., to comment) can easily lead to undesired changes. In the disaster management application usually one person should be in charge of the map representation, e.g., when changing the data layers displayed or the map scale.

Tangible interaction ([12]) using a physical puck (see Figure 2, bottom right) provides a suitable interaction technique: The puck is placed on the useTable surface - by moving and rotating the puck the map can be translated and zoomed. Since there is only one puck, it is always clear to all collaborators who is currently controlling the map. This considerably enforces group and interaction awareness.

Since all information is available in digital form the system enables simulation and planning capabilities, that are not available in the conventional workflow. E.g., in planning the transport of water between two locations the systems provides support to calculate the number of pipe sections and the number of pumps required (using a digital terrain model for the calculation). The system improves on the state of the art at all three levels - at the syntactic level by extending the scope of geo-spatial data-sources from static maps towards a wide range of (dynamic) data sources, at the semantic level by providing analysis function and at the pragmatic level through a geo-visualization component that exploits the benefits of post-WIMP interaction techniques.

VII. EXPERIENCES AND FEEDBACK

As explained in section 3 the ongoing development takes place in close collaboration with the intended end-users from THW. In addition to formative evaluation that guides the development we have also conducted initial tests with experts from the THW and also discussed the system with members of the THW authority. The feedback has been very positive. Even small improvements enabled by the digital map (e.g., switching maps while keeping the data and annotations geo-referenced) caused enthusiastic responses. Process improvements enabled by having all data in digital form (e.g., the calculation of the number of required pumps) lead to significant improvements in efficiency (in the example of calculating water pipelines a simply drawing of the intended connection with immediate feedback replaces a manual process that required 30min with paper maps and required significant experience to avoid calculation errors).

Initial feedback also led to a number of interesting insights into post-WIMP interaction techniques. E.g., while multi-touch gestures for rotation and translation are well established and one of the typical showcases for multi-touch interaction, we found out that they are not applicable in a mission critical multi-user map application. This is due to the potential for un-intended and non-comprehensible transformations and the need for traceable commands. For other interactions (especially in temporary local workspaces) multi-touch gestures were found suitable. The experience with digital pens and tangible indicates that they enable very natural interactions in our application context with correspondingly high acceptance by users.

In future work, we aim to complement the formative evaluations with more comprehensive user studies and tests, to study the usability of different interaction and visualization techniques. In addition, we also aim to study the impact on the cognitive workload of users and examine the potential physiological dangers that may be incurred by prolonged use of a large-scale post-WIMP display. While the ergonomic requirements of desktop workplaces are well understood, the same is not true for new interaction environments like the useTable. Established ergonomic standards were often ignored in early demonstrators of post-WIMP techniques because of technology constraints (e.g., by limiting lighting levels to reduce IR contamination). And while interaction techniques like free-hand gestures are intuitive they can also cause a high-level of fatigue.

VIII. Conclusion

Research is required to exploit the potential of advanced visualization techniques and user interaction techniques in disaster management and similar applications. The step from technology demonstrators to usable real-world systems requires adequate tools as well as stable base-technologies and the evaluation and validation of different design options. In this paper we present an initial step in this direction with a focus on user centered design and development in a disaster management application.

A promising extension of the system would be to extend the support not only to the planning staff in the command center, but also to individual rescue workers in the field. In a separate project (FireNet, [16]), we have conducted early experiments with a mobile personal sensor network, in which each rescue worker was equipped with a sensor node (using Sun’s SunSpot as the basis and extending it with GPS receiver and additional sensors). Integrating such functionality within the disaster management application could further improve situation awareness in the command center by allowing real-time tracking of rescue personal as well as equipment. Another area for future work concerns the extension from the current focus on observation (situation awareness) to analysis and prediction. The digital data enable the use of analysis functions (as exemplified by the pump planning) and a future extension towards simulation/prediction could be useful, especially in dynamic natural disaster situations like flooding or fires.

Acknowledgments

The authors wish to thank the German Federal Agency for Technical Relief (Technisches Hilfswerk/THW) in Detmold for the productive collaboration, specifically Torsten Meier and Oliver Charles as well as the students in our students project groups at the University of Paderborn. We would also like to thank Petre Dini for his helpful comments during the revision of the paper.

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