AUGMENTED PAPER MAPS:
EXPLORING THE DESIGN SPACE OF A MIXED REALITY SYSTEM

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ABSTRACT:

Paper maps and mobile electronic devices have complementary strengths and shortcomings in outdoor use. In many scenarios like small craft sailing or cross-country trekking a complete replacements of maps is neither useful nor desirable. Paper maps are fail-safe, relatively cheap, offer superior resolution and provide large scale overview. In uses like open-water sailing it is therefore mandatory to carry adequate maps/charts. GPS based mobile devices, on the other hand, offer useful features like automatic positioning and plotting, real-time information update and dynamic adaptation to user requirements. While paper maps are now commonly used in combination with mobile GPS devices there is no meaningful integration between the two and the combined use leads to a number of interaction problems and potential safety issues. In this paper we explore the design space of augmented paper maps in which maps are augmented with additional functionality through a mobile device to achieve a meaningful integration between device and map that combines their respective strengths.

KEY WORDS: *Cartography, Mapping, Design, Augmented Reality, Mobile, Interface*

1. Motivation and Background

Advances in mobile computing, wireless communication and satellite positioning technology have driven the development and proliferation of mobile mapping and navigation applications for a variety of mobile devices ranging from smart phones and PDAs (Personal Digital Assistants) to specialized devices like hand-held and wrist-worn GPS receivers.

As mobile devices with computing capabilities these have many attractive properties. In contrast to conventional maps they can support explicit (spatial) queries and routing, dynamically provide detail-on-demand, support animation and interaction with the content and allow for easy update of time critical information. However, the development of usable geo-spatial applications for mobile devices is complicated by several factors, including technical ones like the available displays and interaction modalities and conceptual ones like the lack of guidelines and tools for the creation of adequate user interfaces and visualizations. Many researchers have therefore addressed the development of usable map-based systems for these devices that take the specific constraints into account, often in the context of Location-Based-Services (LBS) and tourism applications (e.g. Paelke et al., 2005). Approaches range from the improvement of the maps used (e.g. Malaka and Zipf, 2000) over the dynamic adaptation of content and presentation to the context of use (e.g. Reichenbacher, 2001) to specific design approaches like task-oriented design (Aoki and Woodruff , 2000). If an electronic devices should replace a map in a practical context of use it is usually not sufficient if the primary task of navigation is well supported, but users also require support in a variety of secondary tasks, as Brown and Chalmers (2003) established for tourism applications. Despite advances in small-screen cartography limitations due to size and display technology will remain for the foreseeable future. Interactivity can be a key benefit but in current systems a large percentage of user actions is typically concerned with control interaction (e.g. pan and zoom) to address the limitations of the devices used. Reliability and power consumption are usually not critical in inner-city tourism applications, but can be essential in other contexts of use, e.g. sailing or cross-country trekking. In the Augment Paper Map (APM) project the goal is therefore to design a system that exploits the benefits of electronic devices by augmenting paper maps through meaningful integration of additional information and functionality rather than replacing them. The APM should offer fail-safe behaviour for applications where maps are safety critical with graceful degradation so that users can still rely on conventional paper map functionality in the worst-case of complete system failure.

In the subsequent sections we first discuss the relative benefits of paper and electronic maps in a mobile use context and review existing work related to augmented paper maps. For the design of the APM we follow a user and task driven approach that combines techniques from usability engineering with methodologies from agile software development. We present the process, techniques and discuss identified requirements. An evaluation of concepts and technologies that could potentially be used for practical implementations of APM design follows. The paper concludes with a discussion of the current findings and an outlook on future work.

		Paper Maps	Hand-held eMaps
Features	size	small to large, foldable, flexible	small, fixed
	power consumption	none	significant; endurance hours to days
	weight	low	wide range; typically several 100g's
	price	low	high
	reliability	very high	limited
Content	resolution (spatial)	very high	low
	resolution (temporal)	very limited (static depictions)	potentially high (animation)
	flexibility of content	no adaptation, difficult update	easy if supported by software
	content dimensions	fixed, limited	flexible, potentially unlimited
	coverage	fixed	potentially unlimited
	level-of-detail	fixed, typically high (use specific)	lower due to display resolution, flexible
Use and interaction	readability	very high	lower
	information access	mostly push; serendipitous discovery common	mostly pull; often lack of overview for discoveries if not explicitly supported
	use, interaction	well known interaction with paper; but learned map skills required	special mechanisms, devices specific, only tasks supported by the software
	accessibility	high, but no support for visual impaired	lower, but special mechanisms for target groups can be implemented in software
	flexibility of use / adaptation to other uses	very easy, common	only if supported by the implementation, typically limited
	annotation	simple with pens, post-its etc.	only if supported by the software
	query, search	only pre-designed indices	full support possible in software
	integration of GPS	none	full support possible in software
	multi-user interaction	very easy, common	difficult due to device size

Table 1. Comparison of paper maps and maps on electronic hand-held devices

2. Paper and Electronic Media

A comparison of paper maps and maps on electronic hand-held mobile devices in an outdoor use context with regards to general features, content presentation as well as use and interaction properties (summarized in table 1) indicates that they have complementary strengths and weaknesses. Paper maps are cheap and very usable for many tasks, but lack the dynamic and interactive properties of electronic maps. Maps on held-held devices, on the other hand, have high potential for the presentation of up-to-date dynamic content, adapted specifically to the user, his current position and the task at hand, but often have critical shortcomings in resolution, ease of control and reliability. A meaningful integration of paper maps and electronic devices that combines the respective benefits seem therefore highly attractive.

2.1 Related Work

Experiments that aim at the integration of paper with electronic devices can be traced back at least to the early 1990s (Newman and Wellner, 1992). Johnson et al. (1993) identified some critical benefits of linking paper and digital information and Wellner (1993) proposed the concept of the DigitalDesk to exploit these in office applications. Maps were explicitly considered in a study by Fitzmaurice (1993) in which detail information was added to a large scale (projected) map by means of a spatially registered hand-held display. Bier et al. (1993) introduced the "Magic-Lens" metaphor that is now commonly employed when hand-held devices are used to augment spatial objects (e.g. Looser et al., 2004) as well as the Toolglas concept for interaction. The use of augmented reality (AR) as a user interface paradigm for interaction with spatial artefacts was studied by Raskar et al. (1999) and applied to map based applications like urban planning in a number of applications (e.g. Ishii et al., 2002). One of the first systems that applied augmented reality to paper maps was developed at the IKG (Bobrich and Otto, 2002; Bobrich, 2004). In recent years the integration of electronic information and interaction possibilities with paper in general and maps specifically has received increasing interest. Several systems have been developed to enable the linking of electronic information to paper based content (e.g. Luff et al., 2004; Liao et al., 2005). Corresponding interaction techniques were also developed (e.g. Liao et al., 2006; Ullmer et al., 2005). Systems that augment paper maps with additional information were developed by Grund (2004) using Desktop PCs and HMDs for display and by Reitmayr et al. (2005) where a projector is used to overlay the additional information on a paper map on a table. Examples for mobile applications that use a hand-held device to augment a paper map include the "Marked-up Maps" (Reilly, 2004; Reilly et al., 2005) which useses coarse positioning by RFID tags embedded in the paper map, the system by Schöning et al. (2006) in which the optical marker-based ARToolkit tracking system is used, and the system by Norrie et al. (2005) that augments paper maps with tourist information using the high-resolution positioning information provided by an Anoto pen and a mobile device for display. Most of the existing augmented map applications are technology driven demonstrators and consider the requirements of users only to a limited amount. No system is currently in practical use. In our work reported here we aim to complement the existing work by a design approach that is driven by user requirements, specifically for the safety critical domains of cross-country trekking and small craft sailing.

3. Design Process

The goal in the APM project is to develop system designs that augment paper maps with additional functionality similar to what can be realized on hand-held devices. The concepts of Augmented Reality (AR) and – more generally – Mixed Reality (MR) that integrate interactive computer graphics into real-world environments provide a promising foundation. In contrast to many existing MR applications that were developed as demonstrators for specific base technologies the goal is to start from the requirements of a specific application and to select adequate existing base technologies where possible. Development of new base technologies should be restricted to cases where essential functionality can not be realized in another way. The development of applications like the Augmented Paper Map is currently hindered by a number of factors:

- The developers of base technologies are often focused on technical details and not necessarily well positioned to both design and develop user-centred applications.
- User interface designers are typically not familiar with the potential and limitations of new base technologies and the interaction techniques based on these.
- The actual level of usability of many (MR) techniques that have been demonstrated in research prototypes is still largely unexplored, providing limited guidance during the design process.
- Only a limited subset of the functionality required in an application is supported by existing standardized software components. Typically a significant amount of functionality must be newly developed.
- The implementation of MR functionality often requires the use of specific non-standard hardware like 3D tracking systems and specialized displays. Therefore, the hardware aspect must also be considered during the design process. This is different to the development of conventional desktop GUIs or websites where reasonable generic assumptions with regards to the available displays and interaction devices can be made.

To address these problems a suitable process is required that guides development and also supports effective communication between stakeholders with a potentially diverse background. Development processes exist in different domains like user interface design and software engineering. Because applications like the APM comprise many diverse aspects ranging from specific hardware over software implementation and interaction mechanisms to visual design a design approach is required that addresses the requirements of all stakeholders while providing the necessary flexibility.

User interface design and usability engineering (UE) are concerned with the design and development of efficient, effective and satisfactory user interfaces. Typically, usability engineering activities are not an inherent part of current software engineering processes. User centred design frameworks provide a foundation for user centred design processes. During the design process the initial application concept is mapped to an implementation by iterating the design phases of requirements specification, design, and evaluation. A popular approach in domains where the design space is still being explored is the use of iterative design where design phases are carried out repeatedly and the results of the evaluation phases are used to refine the requirements specifications for the next iteration of the process. This iterative design approach has been standardized in ISO-13407 (ISO, 1999) with the following stages:

1. Context of use: Users are actively involved in the development and a thorough understanding of user and task requirements provides the basis for the design activities.
2. User Requirements: A detailed analysis of user requirements is conducted to allocate functions between users and technology in an adequate way.
3. Produce Design Solutions: Based on the requirements and other drivers and constraints design solutions are generated.
4. Evaluation of Use: The designs are evaluated against the requirements. The results are used to refine requirements for the following iterations.

Design activities that correspond to these stages are iterated until a satisfactory design is achieved.

A large number of processes have been proposed in the domain of Software Engineering (SE). While many of these processes are best suited to large well structured development projects the recently emerging trend towards so called agile approaches with a focus on lightweight processes seems well suited to exploratory design. Compared to non-agile iterative processes (e.g. the well known Spiral Model by Boehm, 1988) the duration of each iteration is significantly shorter in agile models. Agile software development does not rely on comprehensive documentation and monolithic analysis activities; instead a more delivery- and code-quality-oriented approach is proposed. Through co-location of the development team fluid information exchange among the team members should be encouraged to compensate for lacking documentation efforts. To ensure effective development, agile models therefore emphasize informal communication and aspire towards early and frequent feedback through continuous reviews and evaluation in collaboration with on-site customers. Scrum is such an agile and iterative-incremental SE model which is becoming increasingly popular especially for smaller-sized projects (Schwaber and Beedle, 2002). In Scrum, development activities are organized in short iterations, called sprints. Each sprint lasts 30 days and starts with a sprint planning meeting where stakeholders define the functionality to be developed in the subsequent sprint. The product backlog is an artefact, which serves as a repository for all requirements related to the system/product. The product backlog is flexible and evolves along with the product. In the beginning it only contains high-level requirements and its content gets more and more precise with each sprint. Each backlog item has a priority assigned to represent its business value and an effort estimation in order to plan the required resources for implementation. During sprint planning, the Scrum team picks high priority backlog items that they think are realistic for the implementation in the next sprint. Scrum teams are small interdisciplinary groups of 7 to 9 people, which are self- organized and have full authority to determine the best way for reaching the sprint goals. There are no explicit roles defined within the Scrum team. Scrum places emphasis on an emergent behaviour of the team, meaning the teams develop their mode of cooperation autonomously. The Scrum team and its manager – the Scrum master – meet in short, daily meetings, called daily Scrum, to report progress, impediments and further proceedings. Every sprint ends with a sprint review meeting, where the current product increment is demonstrated to project stakeholders. A user centred design process for the APM (and similar MR applications) must balance the influences of MR technology with SE and UE considerations. Therefore, an integrated approach is needed that considers the (usually) technology-driven requirements of MR development while maintaining the systematic, controllable and manageable processes advocated by SE, and integrating appropriate methods and procedures from UE in order to develop usable solutions that are applicable in practice. For the APM we use a unified process based on agile software engineering (Scrum) into which user centred design activities are integrated. This process is tailored to the specific requirements and constraints of user centred development of MR systems.

3.1 An agile user centred MR design Process

Scrum features an explicit exploration phase prior to the actual development in which the development teams work out system architecture and technology topics to evaluate technical feasibilities, while customer stakeholders generate product backlog items. Compared to requirements elicitation and analysis activities in UE the exploration phase in unmodified Scrum is rather short and is supposed to not exceed one process iteration. For the APM project we have extended this phase into multiple iterations that are used to establish user requirements and to generate alternative MR designs that address these.

Requirements: For the user centred development of a system like an augmented paper map it is essential to establish central user requirements for the tasks at hand and then address them with adequate steps in the design process. An adequate requirements management is required to cover the identification, specification, analysis and verification of requirements throughout the development process. The identification of requirements is especially difficult for new emerging technologies where "users" have no clear idea of what they want/need or have problems articulating their needs. Typical requirements elicitation techniques include interviews and questionnaires, focus groups, ethnography and task analysis (Preece et al., 2002).

Scenario-based design provides techniques that are suitable for the iterative discovery of requirements (Rosson and Carroll, 2002). In addition, it affords design representations that enable not only the participation of end-users in requirements specification and refinement activities but are also suitable to describe the dynamic and responsive behaviour of interactive systems. Scenarios are descriptions of use. They describe how a system is used by narrating a concrete and detailed sequence of events in use. Such scenario descriptions aim to provide a concrete and tangible representation of a general category of interactions. A scenario provides rich context information including a description of the initial situation, the participating actors and their goals, the relevant objects, the actual sequence of actions and events taking place and the resulting consequences on the situation. Scenarios are closely related to "use-case" that have become popular in the wake of object-oriented software engineering and is usually attributed to Ivar Jacobson (Jacobson et al., 1992). Although use-cases and scenarios are often viewed and described as equivalent concepts there are some differences. The common understanding of use-cases is based on their application in the Unified Modelling Language (UML), which uses a more specific, formalized and constrained format than the general scenario perspective. For requirements specification purposes scenarios can be used as system prototypes to identify user requirements. For the small craft sailing APM a number of scenarios describe common tasks, e.g. defining a new route by specifying new waypoints or querying an area for additional context specific information. These were analyzed to identify functional requirements of an APM application. With regards to functionality this specification can still be incomplete. Non-functional requirements (e.g. preferred look-and-feel of the APM) must be established as part of the following design process to complete the set of requirements. To avoid serious problems in the implementation it is essential to establish and validate these requirements as early as possible in the design process. The following section describes the iterative process used to explore the design space of APMs.

Design: In the standard Scrum process, the design of a system emerges as a result of the implementation process. In the initial exploration activity, a basic system architecture is to be defined that is then filled and refined during the process. The lack of design expertise with APMs requires a process based on iterative refinement and evaluation, similar to other less explored domains of interaction design. Therefore, we extended Scrum with an explicit design phase to explore the available design space from the functional, interface and hardware perspective. Central to the exploration of a new design space is the generation of potential design alternatives. Typically, a variety of possible solutions are generated. These are then subjected to review and critique. In an iterative process the most promising solutions are selected and refined or the results of the review are used as the basis for new design alternatives. For the process to be effective it is essential that the design representations are quick and cheap to generate and can be discarded without a high penalty. For effective design space exploration early prototypes must be quick and cheap to create, while later prototypes should be realistic and applicable in a mobile setting to gather realistic feedback. In some sense Scrum can be viewed to follow these suggestions and apply them to the software implementation design, with the code as the design representation. However, as identified earlier implementation design is not sufficient for applications where the MR interface and the interaction techniques it consists of must also be designed. We therefore conduct design iterations on the interface and its behaviour and components using even more lightweight artefacts in the initial iterations, e.g. design sketches, paper prototypes and mock-ups. The process itself follows the principle structure of the Scrum process and thus fits seamlessly with the following activities. However, in the initial iterations the design is not represented by a partial implementation as in traditional Scrum, but by the rapidly created design representations as in traditional design. Once the design becomes sufficiently stable to identify required hardware and concrete interaction techniques the design representation can be switched to (partial) implementations, resulting in the conventional Scrum process. With these modifications the design representation of a project can evolve from very quick sketches in the beginning, over paper prototypes and mock-ups to (partial) software prototypes. To achieve this an existing iterative design process with testable design representations (Paelke, 2001) was adapted and extended with the use of more informal prototyping and evaluation techniques like sketches (Buxton, 2007), paper prototypes (Snyder, 2003) and physical mock-ups to enable more rapid exploration of a variety of design concepts.

Evaluation: Evaluation is of central importance in the development of an MR application from the design, UI and technology perspectives. Conventional Scrum only covers the verification of the technical implementation in the sense of software testing. To cover the needs of usability engineering and the enhanced design activities the evaluation activities must be enhanced as well. Design review and critiquing form an integral part of design space exploration and are therefore essential from the design perspective. From the user interface perspective it is furthermore essential to ensure that the resulting interface is usable by evaluating the usability of the solution against the user's needs. The specific technology requirements of a MR system also require that potential implementation technologies (e.g. sensors) are evaluated for their suitability in context. The sprint review in Scrum can be used to integrate evaluation activities. In the design centric initial iterations no implementation is available yet, so no software testing is required and the evaluation can focus on design review and critiquing conducted by the development team. As the design becomes more stable the focus can be move from the design centric view towards evaluation of the proposed interface. Intermediate design representations like paper prototypes

and mock-ups can be used both, to review the design or to conduct initial evaluations with users. As the implementation progresses in later iterations, evaluation techniques suitable for partial prototypes like wizard-of-oz-evaluations could be employed. Once a complete system is available usability test with real users could be conducted in the application context to validate interface and system functionality. Therefore, in Scrum such usability evaluations could be tied to the release plan.
On the technology side standard software test activities are to be conducted as partial implementations become available. The use of MR specific technologies like new sensors or interaction techniques for which no adequate experience is available may necessitate specific technology tests to establish if an envisioned technological solution is viable. Depending on the complexity of the technology tests may be conducted as a review activity within the main process or may be spun-off as separate Scrum iteration for complex technologies (Scrum of Scrum). The combination of these evaluation activities with the design activities extends Scrum to allow to establish a suitable design for the task at hand and then validate the design's usability as well as its implementation.

4. The APM Design

4.1 Requirements for small craft sailing APM

For the APM we have combined interviews and task analysis for the initial identification of functional requirements with an iterative exploratory design process in which these were refined and augmented with non-functional requirements (e.g. look-and-feel, usability) through the use of prototyping techniques like sketches, storyboards and prototypes. The initial set of functional requirements for augmented paper maps was established by students as part of a one semester laboratory course on advanced geo-visualization. For the use-case of small craft sailing these were refined by studying the navigation and map skills required in the exams for the corresponding german certificates (Sportbootführerschein See and SKS, see. Sportseeschv, 2007). The identified requirements were then verified against the functionality provided by certified ECDIS systems for commercial shipping that comply to IMO SOLAS requirements (IMO, 2007). With ECDIS an electronic solution that provides the central benefits of e-maps and complies to SOLAS requirements is available for commercial shipping. However, ECDIS implementations are not designed for use on small water craft. For the near future yachtsmen will have to use conventional paper navigation charts for legal and security reasons. An adaptation of systems from commercial shipping is currently no realistic option due to cost and the need for on-board infrastructure with adequate backup. A common approach on board larger yachts is the combination of a laptop with non-certified chart-software (ECS) and a GPS receiver. These systems offer most benefits of e-maps but are officially only approved as additional navigation aids to complement traditional navigation for security reasons. On smaller boats (e.g. dingis, rowingboats, kajaks) a hand-held GPS is often used together with a paper chart. This can be cumbersome and error-prone, for example when new waypoints should be entered. Existing mobile platforms like PDAs and Smartphones are suitable to only a limited extent for this kind of use. For a small craft sailing APM the following basic project objectives can be identified:
Purpose: To integrate GPS positioning, additional location specific updates and interactive e-map functionality with paper navigation charts.
Users: Yachtsmen and other users of small water craft that need to navigate using charts.
Context of Use: On board small water craft, where the use of ECDIS is not viable. Typically on a small navigation table, but sometimes also hands-free. To be used together with conventional tools like ruler, compass, pencil.
Task Scenarios: Positioning, plotting, planning, warnings, chart update/correction, radio information, touristic information, ...
Functional Requirements: Establish current position on chart, input waypoint, query area, query location, ...

4.2 Example design concept for small craft sailing APM

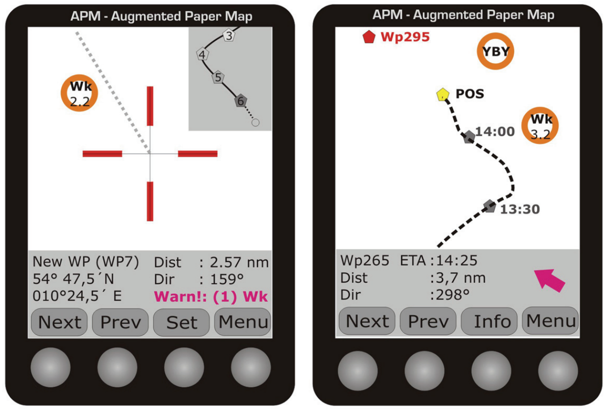

Figure 2: Visual mock-ups of an APM design concept

Designs for APM concepts were developed by using a variety of design representations from scenarios over sketches and paper prototypes to physical mock-ups in increasing fidelity and production effort. Sketches allow to quickly discuss several design options with potential users. Their rough un-finished look clearly communicates the preliminary nature of the concept proposed and thus helps to foster open discussion. Sketches are very easy to produce and modify with pencil and paper and thus enable the early exploration of a large variety of concepts for both functionality and look and feel. For early usability evaluation of concepts sketches can then be refined into paper prototypes. Paper prototypes can cover a significant section of the intended functionality and can be used interactively with a human facilitator who simulates system response. Paper prototypes also require only standard office supplies for prototype creation that are therefore easy and quick to produce. While paper prototypes can be well suited to refine and validate functional requirements of a system they do not represent the look and feel of the application in a realistic way. For the inclusion of look and feel visual and physical mock-ups can be created. They can be used to provide users with a realistic impression of the system in use but require a higher production effort. For the APM a number of concepts were refined to the mock-up stage.

For the central tasks of course plotting, waypoint and route specification and location specific map augmentation with update information and warnings the following detail requirements were established in the design process:

- Ideally, an APM device should correspond in weight and size to standard navigation tools (e.g. set square) with the weight and size (especially thickness) of current hand-held GPS devices as an upper limit.
- For position input, users should be able to indicate positions directly on the map.
- Augmentation information (e.g. the planned route, update information and location specific warnings) should be shown together with the original map, ideally without loss of resolution.
- Additional interaction options beyond just selecting a view of the augmentation information are desirable, e.g. user annotations.
- It should be possible to use the most common functions with only one hand, limiting the use of bimanual interaction to rare occasions (one hand may be required to hold the chart).
- The system should be able to operate with charts in a partially folded state.

Figure 2 shows a visual mock-up of a hand-held APM device that operates as a see through lens directly on the paper navigation chart. The Figure 2 (left) shows it's use to specify waypoints and routes: A cross-hair is displayed and the user positions the device directly on the map so that the cross-hair matches the intended waypoint. A small inset visualizes the route consisting of several waypoints. The buttons allow to set and manipulate waypoints similar to current hand-held GPS devices. The integration of the map with the device not only enables intuitive waypoint specification - the APM can also check the specified route for potential problems and issue context specific warnings (e.g. a wreck close to the specified route, that may not yet be recorded in the paper chart). Figure 2 (right) shows how the overlay presentation of the current position, the next way point and the recorded track.

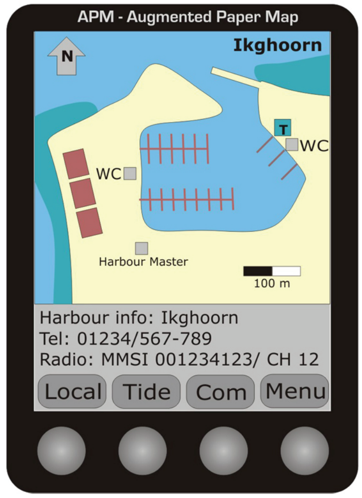

Figure 3: Purely computer generated content on the APM

As Figure 3 shows this APM concept is not restricted to augmentation content but can also show purely computer generated content (e.g. if the paper maps has no representation of the desired content or a direct positional link is not required). A physical mock-up of the APM concept in combination with a paper navigation chart is shown in Figure 4.

Figure 4: Physical mock-up with paper navigation chart

4.3 Concept Evaluation

Before significant effort is expended on potential implementation technologies for a design concept it is useful to validate the overall interaction concept. The specific design concept introduced in the preceding section differs from previous work in its use of “on paper” interaction. The APM device is positioned directly on the surface of the map to conduct the interaction. While there is some experience with augmented maps in which a device is used at some distance from the map (e.g. using a mobile phone in with the camera on the back is used for positioning as in Schöning et al., 2006) there is little expertise with this kind of interaction. While “on paper” interaction seems well suited to the use-case at hand and corresponds to interaction with conventional navigation tools on paper maps an informed design decision requires experience with the concept itself. To gather this experience within the iterative prototyping framework of our modified Scrum process we have used “testable design representations” in a wizard-of-oz setup (Figure 5). The basis for this is a paper map fixed on a tabletop. A PDA with Bluetooth connection (HP IPAQ HX 4700) serves as a placeholder for the APM on the map and is used to display the “virtual” parts of the augmentation. The visual content is rendered under the control of the human wizard on a PC and transmitted to the PDA via Bluetooth. While in theory the human wizard who simulates system response could manually observe the PDA position on the map to generate adequate responses a faster and more accurate positioning facility is desirable. We therefore use a webcam (Philipps ToUcam Pro II) together with the marker based tracking library from ARToolkit (Kato and Billinghurst, 1999) to automatically determine position and orientation of the PDA on the map. ARToolkit determines the relative orientation and distance between the webcam and the marker through image processing. Since the marker is fixed on the PDA and the position of the webcam and the map are known this allows to determine the position and orientation of the PDA on the map in real-time. A more sophisticated approach would be the use of a projection based augmentation similar to the system by Reitmayr et al. (2005) that would allow to test conceptual devices of arbitrary form and size and does not require markers for positioning. With the current system the positioning of the PDA is not as accurate as desired but it was sufficient to validate the overall concept as viable and thus worthy of more detailed exploration as discussed in the following section. One benefit of the ARToolkit based approach is that it provides 3D positioning and orientation information, so that the same setup could be used to compare “on paper” interaction to “off paper” interaction concepts in the future. While the setup allows to test the actual interaction mechanisms it is still subject to a number of limitations and differences compared to the actual design concept, including the limitation of experiments to a static table-top setup, the limited resolution of the PDA display, the fact that the map is obscured by the PDA so that the “see-through” effect must be simulated (resulting in a significant loss of resolution at the focus of interaction), and the need for markers that obscure further parts of the paper map. Thus, after the basic viability of the “on paper” interaction concept is validated further experiments with regards to potential base technologies for positioning and display of the APM are required.

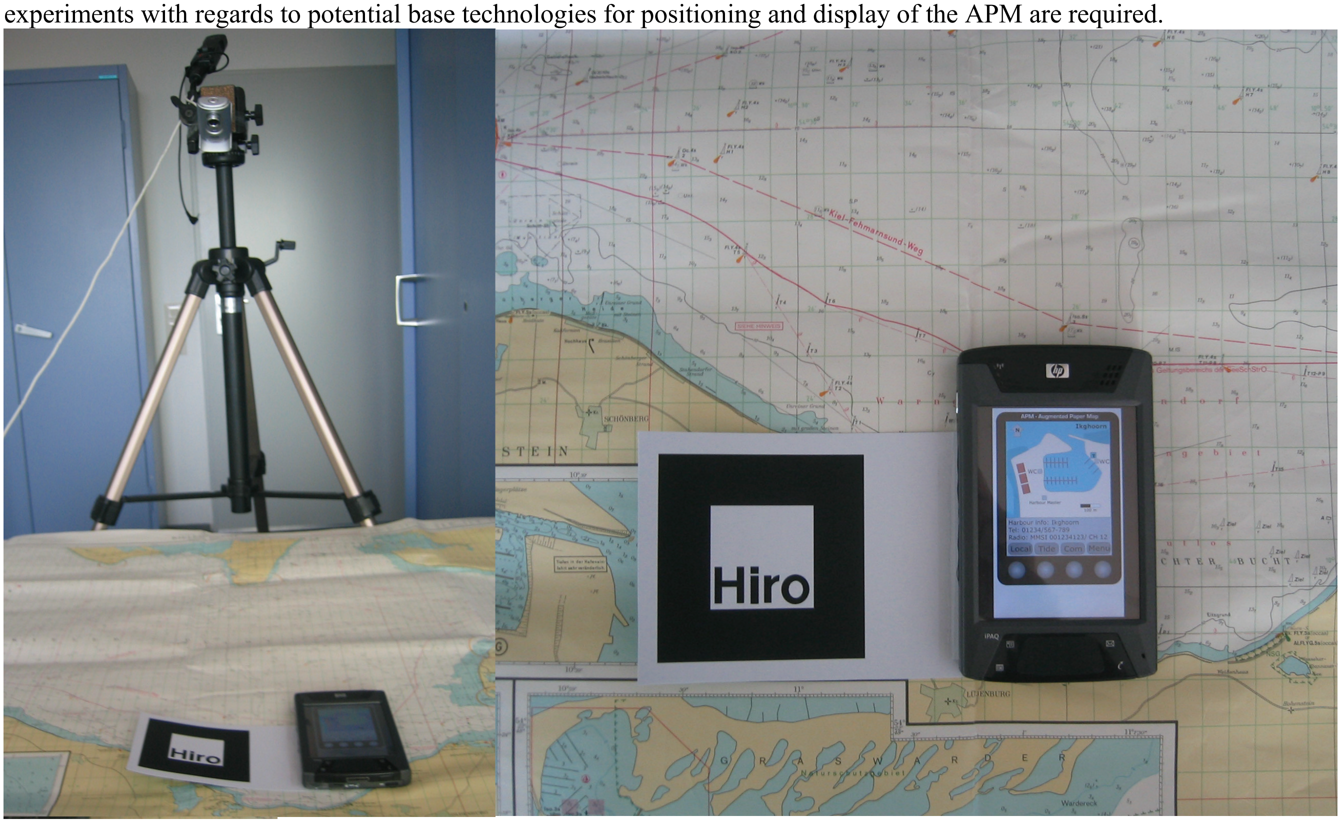

Figure 5: “On paper” concept evaluation prototype using a PDA and marker-based positioning

4.4 Technology Evaluation

While prototyping techniques are helpful to explore a variety of design options without actual implementation these are only useful if they can be implemented eventually. For promising design concepts it is therefore necessary to establish the technical requirements inherent in the design. Then technologies that are potentially useful to implement the system must be identified and evaluated.

All APM concepts must address the uses of information display, positioning relative to the paper chart and the provision of adequate and reliable means for interaction. For the design concept presented in section 4.1 the technical requirements can be refined as follows:

Information display: A display technology that allows to overlay the augmentation information directly on the map, without obscuring the original map content in other areas. It should be applicable in a variety of lighting conditions and colour display capability is highly desirable. Since the original high-resolution map remains visible a resolution of 100dpi would be adequate.

Relative positioning: A positioning technology that allows to identify the position (and orientation) of the APM device directly on the paper. Although it depends on the chart resolution the positioning resolution should be 25dpi / 1mm or better. The positioning should be reliable and provide integrity information. It is also desirable that the map itself can be identified automatically and the map datum is set automatically, as this can be source of serious errors.

Interaction: Because the central spatial interaction task is handled by the combination of device placement on the chart and the positioning technique, only a simple mechanism to select and trigger a selection of discreet events is required.

The interaction requirements are easiest to address with current hardware. A simple combination of buttons with soft-key menus would be sufficient to implement the desired interaction mechanisms.

For the display a number of emerging technologies appear suitable. A very promising option are displays based on organic light emitting diodes (OLEDs). Like LCDs they can render colour displays with adequate resolution. Benefits compared to LCD technology include more brilliant images since the light is emitted by the display itself, promising better readability and reduced energy consumption. Since the organic layers of an OLED can be transparent in the visible part of the spectrum the see-through aspect can be easily implemented (Kowalsky et al., 2007). An evaluation in practical use should be conducted in a hardware prototype. A possible alternative could be the use of small laser projectors (e.g. Tomasi et al., 2003).

Relative positioning poses the most difficult technology challenge in the previously presented design concept. Common positioning techniques are problematic in the given physical setup: Ultra-sound tracking can provide a cheap solution for positioning and is used in some digital pens (e.g. GeneralKeys, 2007). However, it is not easily applicable when the map is not on a well defined surface or folded. Precision and masking problems are other shortcomings of ultrasound tracking in this scenario. Another common approach is the use of a standard camera in combination with optical tracking techniques, often using markers (e.g. ARToolkit, Kato and Billinghurst, 1999). These are not applicable in this design because the device is intended for use directly on the paper, with insufficient distance between the camera and the map. The use of markers can also mask important information on the map. A possible approach to the marker problem is to either use advanced image matching techniques directly on the map image (which is known and can thus be interpreted as a very large "marker") or the use of markers and cameras with wave-lengths outside the visible spectrum. The need for operation directly on the map surface could be addressed by special optics, e.g. by adapting techniques from flat-bed scanners.

Another option would be to embed positioning "hardware" in the map itself. RFID tags can provide only coarse positioning and are therefore not suitable for our design. One possibility would be to use flexible printed polymer circuits on the map or a flexible map cover (PolyIC, 2007). This technology would enable direct integration of a positioning grid and interaction buttons on the map (later possibly even display elements). Interactive paper menus where options are selected by touching "buttons" printed on paper have already been demonstrated (Printed Systems, 2007). While flexible printed circuits have very interesting properties they are not yet a practical option for prototyping. We are therefore currently evaluating the use of the positioning technology developed by Anoto (Anoto, 2007) for electronic pens for use in APMs:

Digital pens using the Anoto technology are available from a number of companies (e.g. Logitec, 2007 and Nokia, 2007). The Anoto system uses normal paper on which a specific micro-dot pattern has been printed in addition to normal content. From a normal viewing distance the pattern is not visible to a user and only appears as a light grey. The pattern encodes a unique position on a 60.000.000 km^2 pattern space. The corresponding pen contains a positioning unit that operates in the infra-red spectrum, as shown in Figure 6. It consists of a small IR-sensitive camera and a corresponding IR light mounted on the tip of the pen with approximately 1cm distance to the paper. From the IR-camera the pattern on the paper is recorded and analyzed using image processing techniques. The pattern allows to identify the current position in pattern space. By assigning a unique area in pattern space to each map both positioning and map id can be implemented. In normal use as a digital pen the sequence of positions is recorded as strokes that are later transferred to a computer. For use in mobile applications bluetooth versions of pens are also available. Because the design concept under consideration requires augmentation with a see through display point-based position information is not sufficient. Orientation information is also required. This could be achieved by using two positioning sensors in opposite corners of the device. The necessary hardware could be incorporated into a device with the desired format. We have conducted a number of experiments to establish if map prints can be combined with the Anoto pattern. Problems can arise in highly saturated areas on a map but special inks are available to address this. We have found that it is usually possible to adapt the visual parameters of map styles so that the visual information remains well visible to users while the Anoto pen can reliably recognize the position on the map. In our experiments precision and reliability were sufficient for the intended scenario. The positioning technology would therefore be suitable for an APM. A practical problem is that the Anoto sensor is not available as a stand alone sensor that can be easily embedded in another device like the APM.

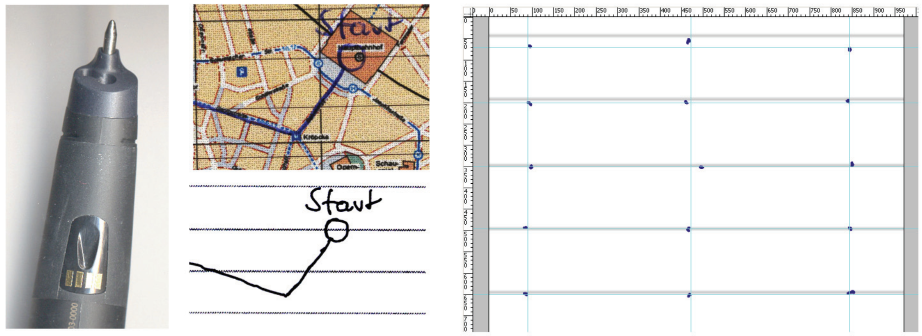

Figure 6: Anoto digital pen system technology test

5. Discussion and Outlook

In this paper we have discussed features of paper maps and hand-held electronic and identified a number of potential benefits of integrating electronic map functionality with paper maps. The use-case of small craft sailing was introduced as a potential application in which the benefits of augmentation are clear and where a complete replacement of paper maps is not possible due to safety reasons. We have presented an iterative exploratory design process that enables agile user-centred development. Benefits of the process include: The support of iterative exploratory design, the flexibility to integrate stakeholders and activities from different domains, the flexibility to adapt to changing requirements, the consideration of hardware development, software engineering practice and UI design and the ease of integration with existing SE practices. Our extensions of the Scrum process are especially suitable in early design phases where they support the use of light-weight design representations that are accessible to all stakeholders in the design process and thus ensure effective communication.

The process was demonstrated on the small craft sailing use-case for which augmented paper map concepts were developed and evaluated. The example illustrates the potential benefits of integrating electronic devices with paper maps and would offer clear benefits in practical application. Potential implementation technologies for this use-case were also discussed and partially evaluated. The iterative design approach enabled end-user participation throughout the design process and the early testing of application concepts without concern for the availability of base-technologies. For further refinement of interface designs we aim to introduce a number of tools that should enable interactive simulation of concept designs to conduct more realistic tests in cases where the hardware is not yet available. Specifically, we aim to extend our wizard-of-oz setup that exploits the idea of a “testable design representation”. Initial experience with the APM concept itself and the use of rapid prototyping techniques for concept design are promising. Future development steps are therefore to refine the interaction mechanisms using an interactive simulation and to create mobile prototypes that can be applied and tested in the real mobile context of use. Furthermore, it will be interesting to extend the APM concept to other domains like cross-country trekking and off-road navigation or the areas of LBS, tourism and entertainment applications.

6. References

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