DESIGN EXPLORATION OF AUGMENTED PAPER MAPS

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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.

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&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&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 the limitations due to size and display technology will remain for the foreseeable future. Interactivity can be a key benefit but 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 hiking. 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 is introduced in the following sections presenting the process, techniques and identified requirements. An evaluation of technologies that could potentially be used for practical implementations of APM design follows. The paper ends with a discussion of the current findings and an outlook on future work.

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&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&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. 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

		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

(Preece et al., 2002). 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 detailed in the following section 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 that comply to IMO SOLAS requirements (IMO, 2007).

3.1 Requirements for small craft sailing APM

A development projects start with a requirements elicitation, specification and analysis activities that aim to produce a comprehensive list of accurate design requirements. A typical approach is the analysis of system functionality to establish tasks of future users that are then analysed in detail to provide the requirements.

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, ...

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.

4. DESIGN EXPLORATION

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).

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. Effective design requires the use of appropriate design representations that are supported by tools for creation, modification and refinement. 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. The lack of design expertise also limits the applicability of evaluation techniques like expert reviews for APMs, leaving experimental evaluation through walkthroughs and tests with potential end-users as the most promising option. To explore the design space of APMs the following features were identified as essential:

- The use of a process with fast turnaround through the three design stages of requirements specification, design and test. Iterative design is only effective if the cycle is fast and carried out repeatedly. The time and cost of the conventional development of complete application prototypes before testing is to high for the iterative exploration of a large number of concepts.

- The use of "testable design representations" that enable early and repeated tests of concepts before and during the implementation of a working prototype. The design representations should always provide a representation of the system that is accessible to all developers and test users, potentially at different levels of refinement so that they can be applied in tests using walkthroughs, paper-prototypes, the wizard-of-oz methodology or specific tools.

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. The following subsection illustrates an example APM concept developed for the small craft sailing use-case.

4.1 Example design concept for small craft sailing APM

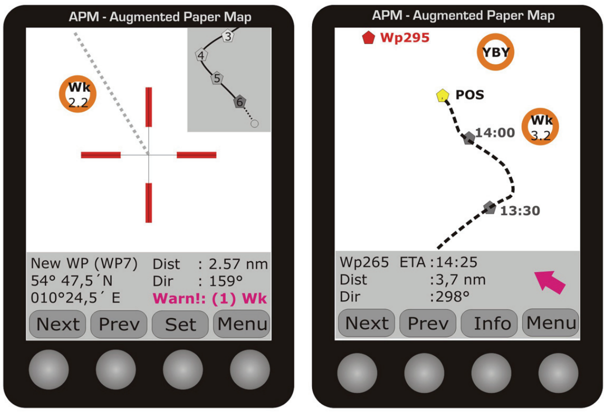

Figure 2: Visual mock-ups of an APM design concept

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 future we aim to further refine these into interactive mock-ups coupled to a simulation and eventual implementation for the most promising concepts.

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.

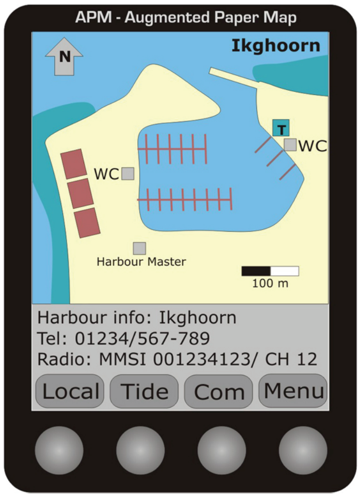

Figure 3: Purely computer generated content on the APM

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

5. 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, as discussed in the following section.

5.1 Anoto positioning technology

For positioning we evaluate the use of a technology developed by Anoto for digital pens. 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 5. 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 in 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 largely sufficient for the intended scenario. The positioning technology would therefore be suitable for an APM, however the status of a proprietary technology makes the implementation of prototypes like the APM difficult in which the sensor should be embedded in another device.

Figure 5: Anoto digital pen system

6. 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 described an iterative exploratory design process for the user-centred development of augmented paper map concepts and illustrated it in the small craft sailing use-case. 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 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” by using a projection based augmentation similar to Reitmayr et al. (2005) as a test-platform on which concept design for hardware devices that exist only as software prototypes can be used interactively by test users on a physical paper map. Such a setting will allow to test the actual interaction mechanisms (but is still restricted to a static table-top setting). 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 than creating 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 or the more common areas of LBS, tourism and entertainment applications.

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