Designing guidance along audio-haptically augmented paths in a city environment

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2011

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Licentiate Thesis 2011
Lund University
Design Sciences
Rehabilitation Engineering Research

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Licentiate Thesis – 2011

Lund University – Design Sciences
Certec, Rehabilitation Engineering Research

LUND UNIVERSITY

Licentiate thesis
Lund University – Design Sciences
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Sweden

www.certec.lth.se

ISBN 978-91-7473-216-0

Printed by Media-Tryck, Lund University, Lund, Sweden

Abstract

The main purpose of this thesis is to show in a case study how it is possible to inform, with Activity Theory, the design and evaluation of a pedestrian navigation system that uses audio-tactile feedback.

The case study consists of an iterative design process that results in a tourist guide application used in a mobile phone. The interaction with the user is mostly through the audio and haptic modalities. The mobile phone is used as a scanning device and guides the user by means of vibrations. An auditory ambiance and recorded speech information also enriched the augmented reality experience. The tourist guide was evaluated in the real context of its use. This interaction proved to be an unobtrusive way to guide tourists to points of interest in the city.

During the evaluation, several tools from the framework of Activity Theory were used. The evaluation benefited from the following: the Activity Checklist, the Activity Diamond, the hierarchical structure of activity and the extended activity framework.

Activity Theory was chosen so that more than just the interaction between the user and the device/technology would be included in the evaluation. Other elements of the artifactual and natural environment were also taken into account, as well as the human environment, the object of the user's activity and the user's motive. Activity Theory provides a solid theoretical background when analyzing the subject's behavior toward the technology, offering a better understanding as to how it is possible to improve the mediating technology.

Other important factors for the design process have also been identified and are discussed as well.

Sammanfattning

Det huvudsakliga syftet med denna avhandling är att med hjälp av en fallstudie visa hur det är möjligt att genom tillämpning av aktivitetsteori, informera utformning och utvärdering av ett mobilt audio-taktilt navigationssystem för fotgängare.

Fallstudien utgörs av en iterativ designprocess som resulterar i en turistguide-applikation för en mobiltelefon. Interaktionen med användaren är främst baserad på ljud och taktil återkoppling. Mobiltelefonen används som en scanner och guidar användaren genom vibrationer. En virtuell ljudmiljö med omgivningsljud och inspelat tal förhöjer upplevelsen. Turistguiden utvärderades i ett verkligt användningssammanhang. Interaktionsdesignen visade sig fungera väl som ett diskret sätt att guida personer till sevärdheter i staden.

Under utvärderingen har flera verktyg baserade på aktivitetsteori använts. Aktivitetschecklistan (”The Activity Checklist”), Aktivitets-diamanten, den hierarkiska strukturen av aktivitet och det utökade aktivitetsteoretiska ramverket var särskilt användbara vid denna utvärdering.

Motivet för att använda aktivitetsteori har varit att säkerställa att mer än interaktionen mellan användare och teknik beaktas. även samspelet med omgivningen (miljö, artefakter, personer etc) samt inflytandet av aktivitet och motiv ingår i utvärderingen. Aktivitetsteori är dessutom ett sätt att få en mer hållbar teoretisk bakgrund för att analysera teknikanvändning och generera en förståelse som gör det möjligt att skapa bättre framtida lösningar för hur medierande teknik kan utformas.

Andra faktorer av betydelse har identifierats och det diskuteras även hur dessa kan ha påverkat designprocessen.

Résumé

Le principal objectif de cette thèse est de montrer dans une étude de cas comment il est possible d'informer, avec la théorie de l'activité, le design et l'évaluation d'un système de navigation piéton qui utilise un retour audio-tactile (non vocal).

L'étude de cas consiste en un processus itératif de conception qui aboutit en un logiciel de guide touristique utilisé dans un téléphone mobile. L'interaction avec l'utilisateur est principalement réalisée via les modalités audio et haptique. Le téléphone mobile est utilisé comme un dispositif de balayage et guide l'utilisateur par des vibrations. Une ambiance sonore et de l'information par voix enregistrée enrichissent aussi l'expérience de réalité augmentée. Ce guide touristique a été ensuite évalué dans le contexte d'utilisation réel. L'interaction est apparue comme une manière discrète de guider des touristes vers les points d'intérêts dans la ville.

Pendant l'évaluation, plusieurs outils provenant du cadre de la Théorie de l'Activité on été utilisés. L'évaluation a bénéficié particulirement de : la liste de vérification de l'activité, le diamant de l'activité, la structure hiérarchique de l'activité et le cadre étendu de l'activité.

La Théorie de l'Activité a été choisie pour inclure dans l'évaluation plus qu'uniquement l'interaction entre l'utilisateur et le dispositif/la technologie. D'autres éléments de l'environnement artéfactuel et naturel sont pris en compte, ainsi que l'environnement humain, l'objet de l'activité de l'utilisateur et le motif de l'utilisateur. De plus, la théorie de l'activité fournit une base théorique solide pour analyser le comportement du sujet vis à vis de la technologie, donnant une meilleure compréhension sur comment il est possible d'améliorer la technologie médiante.

D'autres éléments importants pour le processus de conception ont été identifiés et sont aussi discutés.

Acknowledgments

A thesis only has one author, one subject. But in the activity of writing a thesis, the mediation of many more is involved. I want to thank all the people who made this thesis possible, by their feedback, support or simply by believing more than myself in what I can achieve.

I would first like to thank my supervisors. I thank Charlotte Magnusson, for all her feedback and insightful comments to lead me along the way. I am grateful to Kirsten Rassmus-Gröhn for her daily feedback and support that I really needed. I also thank Per-Olof Hedvall, for the insightful discussions related to Activity Theory, that helped me shape my thoughts.

Many thanks to Eileen Deaner who, on top of being a welcoming colleague, proofread this thesis and helped me with language issues.

I also thank my other colleagues at Certec who welcomed me from the start in Sweden and included me in the group.

I am grateful to the European Commission which co-funds the IP HaptiMap (FP7-ICT-224675), as well as to VINNOVA for additional support. I also want to thank the colleagues in the European HaptiMap project, who have given me a broader perspective on the research conducted and presented in this thesis.

Last but not least, I cannot forget the many friends and relatives who are supporting me from afar, often through the valuable mediation of technology. Most of them are not close to me geographically, but a lot closer in heart.

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1 Introduction

1.1 Background/motivation

The initial focus of the research presented in this thesis was to provide a solution that was more accessible to visually impaired users in the domain of maps and more specifically, pedestrian navigation. The solution was also meant to be useful for a broader audience, namely people rendered visually impaired by the mobile situation (sun glare, need to attend to a busy environment, etc.). This led my fellow researchers and me to use audio and tactile modalities for the user interaction with a mobile phone device.

To meet these requirements, a human-centered iterative design process took place, with a design for all perspective. Because my background was mostly technical, I felt the need to find a theoretical framework to guide my work and the design process *also* on the human side of the interaction. I decided to use the Activity Theory framework because it takes into account both the human participants and the artifactual elements involved in an activity when the interaction takes place. I subsequently included the Activity Theory approach in the design process, namely in the evaluation of the prototype we produced.

This thesis is an account of that process, explaining the theory behind the method decisions, then describing how these were applied in the design and evaluation of an audio-tactile augmented reality application. This account will show how it was possible to use a theory of human activity and how this can contribute in the evaluation of an interactive application. Finally, the concrete insights from this process into the pedestrian guiding application are also presented, giving the reader some ideas about how to implement an audio-tactile guide that can support, for example, a tourist experience.

1.2 Purpose of the thesis

The main purpose of this thesis is to show in a case study how it is possible to inform, with Activity Theory, the design and evaluation of a pedestrian navigation system that uses audio-tactile (non-speech) feedback.

1.3 Outline of the thesis

The first three chapters present the background and theory on which this thesis is built. This is not an exhaustive review, but the main theory points are explained and some previous work is presented.

Chapter 4 provides a short summary of the four papers, as well as an explanation of my contribution to each. The full papers can be found as appendices.

Chapter 5 describes the iterative design process. It starts with an overview of how the research was conducted followed by the methods and results.

The remaining chapters are dedicated to discussion, limitations, conclusion, as well as future work perspectives.

2 Theory

2.1 Using a human-centered approach in design

2.1.1 User-Centered Design (UCD)

User-Centered Design (UCD) consists of keeping the user as the center of focus in design. Gould and Lewis (1985) stress three important principles:

- **Early focus on users and tasks**
  The users should be directly involved from the beginning of the design process, where they can actually influence the design and not only be asked for validation. Involving real participants rather than theoretical ones is preferred.
- **Empirical measurement**
  The evaluation of the product by real users who can be novices in the product use is advised. Analytical evaluation is not enough when a user interface is involved. An empirical measurement of the product usability needs to be conducted.
- **Iterative design**
  Finally, to take advantage of the empirical measurements, the outcome of the evaluation should be reused in the next version of the product, thus calling for an iterative design process.

There are many methods that one can use to involve the user either directly or indirectly in the design process. Some guidelines can be found in ISO 9241-210 “Ergonomics of human-system interaction – Human-centered design for interactive systems” (formerly ISO 13407:1999). For a discussion of more concrete methods, see section 3.4.1.

The involvement of users can be at various levels, ranging from no involvement, to consultations, to actively taking part in designing. The latter is referred to as participatory design. According to Ehn (1988) as cited in Löwgren and Stolterman (2007, p. 152): "Participatory design is a process of mutual learning, where designers and users learn from and about each other". At this level, the design is shared by the user and the designer, whereas at lower levels of involvement, the designer stays in charge of the process.

2.1.2 Iterative design process

Designing means planning for the construction of an object or system. According to Schön (1987) as cited in Löwgren and Stolterman (2007, p. 23), the design is a "conversation between the designer and the situation". A surprising solution will lead the designer to reflect and build on the previous solutions toward a new and improved design. Schön calls this "reflection-in-action" and "reflection-on-action". This progression is taken into account in an iterative design process.

In Gould and Lewis (1985), the iterative design process is called for as needed to incorporate the feedback gained after empirical measurement (i.e. user evaluation). The steps of iterative design can be listed as follows:

1. Design
2. Implement
3. Evaluate empirically
4. Integrate the evaluation and redesign
5. Implement (go to step 2)

When the outcome of an evaluation at step 3 is satisfactory, then the process can stop and deliver a "final prototype" that is indeed the finished product or application. Nielsen (1993) advocates for the significant gain of going through more than one iteration loop in the final usability of the interface.

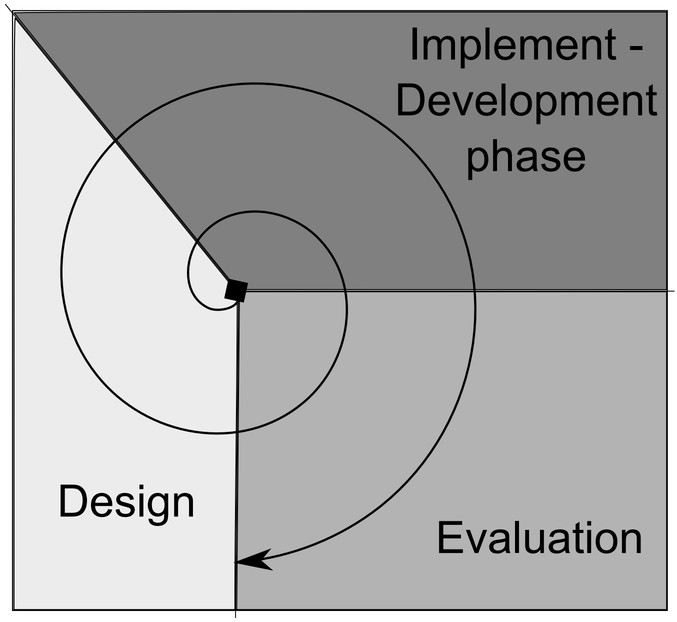

Figure 2.1: The iterative design process

This process should not be seen as only fine tuning or accessorial. Some designers mention the fact that you need to be able to “kill your darlings” in a design process, as in Brewer (2010). When engaging in an iterative process, it is beneficial to have room for a complete rethinking of the parts that are invalidated in the empirical evaluation.

One possible way to represent this process that loops back on itself is to use a circle or a spiral. A circular representation is a good way to illustrate phases that are repeating, as we find in an iterative process. Using a spiral further demonstrates an evolution from the initial prototypes. Taking into account Gould and Lewis’s three steps of design, implementation and evaluation cited earlier, this results in the kind of schematic representation seen in figure 2.1.

2.1.3 Design for All, Universal Design, Accessibility

The Design for All perspective takes into account the need for more accessibility while still aiming to be relevant for a broader population. The aim of design made with a design for all perspective is not to be particularly usable for this or that specific group of users, but rather to be designed with all types of users in mind. According to Mace in Connell et al. (1997), Universal Design is defined as: “The design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design”. Applying this perspective is often achieved through applying the Universal Design principles.

Universal Design proposes seven principles for greater inclusion in design (Connell et al., 1997). This is particularly useful when considering accessibility for people with specific impairments, even if only induced by the situation. The principles are:

1. Equitable use
2. Flexibility in use
3. Simple and intuitive
4. Perceptible information
5. Tolerance for error
6. Low physical effort
7. Size and space for approach and use

Aside from general principles to take into account possible impairments, the relevance of user-centered and iterative design in the field of rehabilitation technology is clear. Designing for people with disabilities needs to include considerably more than just the impairment itself, but also the motives, wishes and needs of the users. Including them into the design process is beneficial in order to take this into account (Jönsson et al., 2006) as well as to expose the users to new ideas and prototypes that may be crucial to evaluate the design, because: “You cannot know until you have tried” (Jönsson et al., 1998). The next section also considers a framework that takes the motives of the user into account.

2.2 Explaining CHAT and the Activity Diamond

The following presentation is mainly based on the book “Acting with Technology” (Kaptelinin and Nardi, 2006), which presents the currents of Cultural Historical Activity Theory (CHAT), putting it in the perspective of Interaction Design.

Even though Activity Theory originates from psychology and social sciences, its approach of taking the activity as the core element of analysis is meaningful for interaction design because it considers the mediation that the technology is enabling between a subject and what he or she wants to do. The activity is defined in Kaptelinin and Nardi (2006, p. 31), citing Leontiev as “the purposeful interaction of the subject with the world”.

I will first present why I considered Activity Theory and then the contributions of four authors to it.

2.2.1 Finding the appropriate theory

There are many ways to describe human activity. From a background in computer science, I needed to find the right tools to study not only the artifact – the computer program – but also the human involved in its use.

Some theories, such as phenomenology, focus on the human. It is through introspection that one can discover what happens during the tool use. Other theories, such as Actor-Network Theory, are more focused on the system. They take into account all actants on the same level. This is discussed in more depth in Kaptelinin and Nardi (2006, ch. 9).

Activity Theory struck me as a good way to focus on the human – taking into account the motives that are specific to human beings

– yet still not missing the bigger picture of the system. The part an interaction designer can act on is, not the human, but the artifact. The goal is to make the artifact fit the human needs. So both the human focus and the artifact focus were needed. I found these multiple foci in the Activity Theory and because of this, chose to use it in my work.

Lastly, this theory fits the next step of the theories described in “The Design of Everyday Life” by Shove et al. (2007). Initially this book tries to pose the problem that *having* a product (even the best designed product in the world) and *doing* (i.e. using that product) are not the same thing. This problem was present in earlier examples of rehabilitation technologies I had encountered. In Shove et al., three evolution steps of the design focus are presented. The first is a design centered on the product. How can the designers improve the products they make by changing the product’s aspect, affordances, etc.? The second step is User-Centered Design, described earlier. By continuing to take into account the relevant information around a product’s use to shape it in a better way, the next step is called by Shove “Practice-oriented Design”. I found that Activity Theory, encompassing in the activity the whole of the practice, provided a good theoretical framework to this approach.

2.2.2 Activity Theory in four authors

Lev Vygotsky

Usually, Activity Theory is complemented by the words “Cultural” and “Historical”’ to form the CHAT acronym. According to CHAT, human action is mediated by tools that are cultural (such as a two dimensional multiplication table) or physical (such as additional support wheels on a child’s bike). The idea that one learns by internalizing these tools, both cultural and physical, that mediated his or her actions before, was formulated by Vygotsky. He described the zone of proximal development as the difference of level between what a child can achieve independently or with the help of an adult. This is elaborated in Kaptelinin and Nardi (2006, pp. 41–50).

Aleksei N. Leontiev

Leontiev worked with Vygotsky. He added a focus on the concept of hierarchical levels in activities.

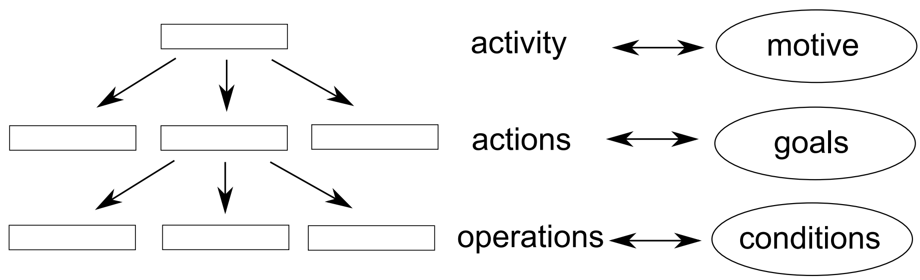

Figure 2.2: The hierarchical structure of activity (Kaptelinin and Nardi, 2006, p. 64)

At the highest and most general level is the activity. The activity is then decomposed into diverse actions, themselves decomposed into operations. A motive drives the activity, while goals are behind actions. The operations used to complete the actions answer to specific conditions.

The subject is not always directly aware of the motive while the goals are conscious. For example, a young person might be taking driving lessons. The goal is to get the license, while the motive might be to gain more independence by being able to drive alone. The activity here is to learn how to drive independently, while the actions that compose the activity would be the lessons and taking the test.

The difference between operations and actions is the automaticity. Operations are routine processes of which the subject is often unconscious. For an experienced driver, the action to go from A to B in a car is decomposed into routine operations like changing lanes. The same driving can be interpreted differently for the young learning driver, where changing lanes is not yet a routine, and is thus an action.

These levels were summarized in a schematic view by Kaptelinin and Nardi, see figure 2.2.

Yrjö Engeström

The triangle or pyramid proposed by Engeström (figure 2.3) is useful to explain a complex activity system, particularly when it relies a lot on the collective dimension.

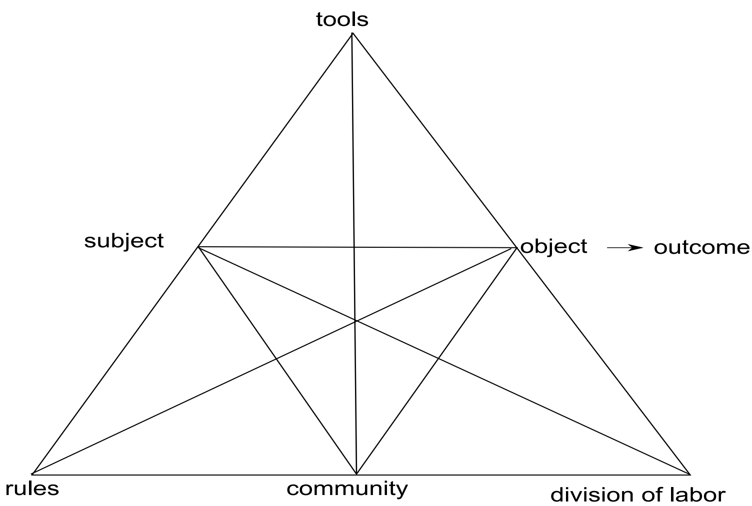

Figure 2.3: Engeström's activity system model (Kaptelinin and Nardi, 2006, p. 100)

The inner triangle considers three poles: the subject, the object and the community. The three end points of the triangle are the three mediating elements: the tools (between subject and object), the rules (between subject and community), and the division of labor (between community and object).

Per-Olof Hedvall

Another model of activity systems was proposed in “The Activity Diamond” (Hedvall, 2009). This view takes the core of Engeström’s pyramid and has been applied to situations where the subject needs an assistive device or a personal assistant to realize the activity.

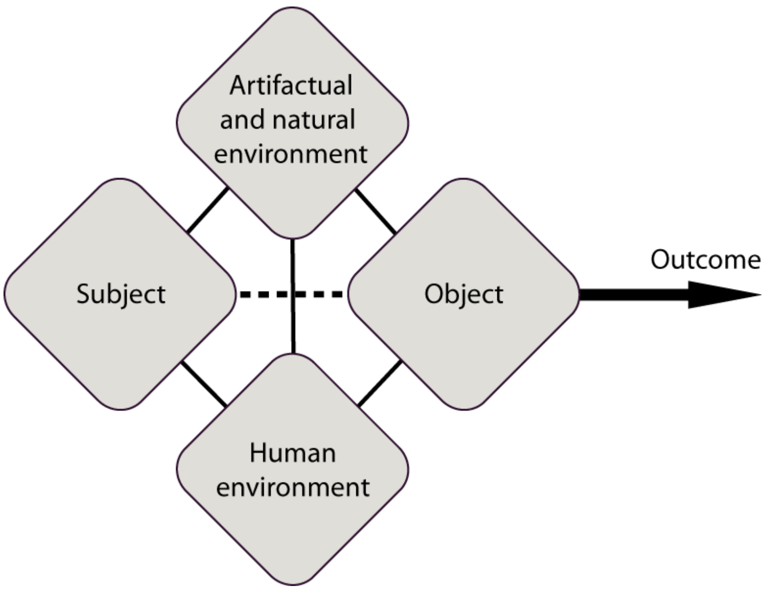

Figure 2.4: Hedvall’s Activity Diamond

The Diamond view proposes four quadrants. The subject to the left is trying to accomplish an action, in order to produce a desired outcome to the right. One example could be a visually impaired person who wants to navigate in the city. Another example is a student writing a thesis. To accomplish the action, the subject uses the mediation of tools and the artifactual environment (upper quadrant). For a visually impaired user, it can be a white cane; in the thesis writing process, it can be the articles as references and the computer for writing. The subject can also take advantage of the help/mediation of other human beings (lower quadrant) – a personal assistant in the first example, or a supervisor in the thesis writing example.

2.3 Qualitative methods

Using qualitative methods to evaluate a prototype in context was not done without reference to "best practices" in that field.

One of the main sources of data in this research was the interview that was conducted after the actual test (see section 5.2.1). Kvale (2008) describes the important points of doing interviews. He emphasizes the planning of the interview from early on. By choosing the interview questions carefully, one can already prepare the analysis. Interviews are often a good way to gain a better understanding of what happened from the participant's point of view.

Observation was another main method used (see section 5.2.1). Ehn and Löfgren (2010) state that sometimes interviews are not the best way to collect information, because we may miss the more unconscious or private actions that the participants may not mention or have in mind during the interview. "Doing ethnographic and observational research" (Angrosino, 2008) describes what to consider when engaging in this kind of activity. Knowing how much you are part of the observed culture and how the observation can modify the situation are important aspects. It is also important to record and take note of the events or describe the observed setting both with naiveté (to be able to question the obvious) as well as in detail. The importance of knowing your bias is also mentioned, and perhaps countering it by having a team of observers from different backgrounds when possible. Lastly, ethical considerations should not be forgotten, and it is important to obtain permission from the people involved to observe and eventually record them.

Kvale also emphasized that the outcome of a qualitative inquiry depends on the researcher's own personality. For example, an interviewer who is asking open-ended questions can choose to follow-up on many different things, thus influencing the conversation. The observer will keep in mind only parts of what actually happened, and will only see through the filter of his or her own background. Taking into account the researcher's bias is needed, especially in the project presented here, where all members of the team had a mainly technical background.

To ensure the quality of the qualitative work, Flick (2007) recommends using triangulation. This is defined as the use of more than one source of data (several locations, different times, different participants), or more than one method to retrieve the data, or more than one person in the analysis, etc.

3 Previous work, state of the art

3.1 Mobile audio and haptic augmented reality

Many cases of augmented reality are based on screen interaction, but that might not be the most insightful way to interact (Oulasvirta et al., 2005). This review focuses on audio and haptic solutions that either let the sighted user use vision to attend to the real environment or that are more accessible to visually impaired users.

The *Audio GPS* (Holland et al., 2002) was an early attempt to use sound as guidance. More targeted to visually impaired users, the *Swan* project (Wilson et al., 2007) provides auditory feedback about context and routes. 3D audio and music is used in the *ONTRACK* system (Jones et al., 2008) for user guidance, while the *Soundcrumbs* (Magnusson et al., 2009b) varies the volume of chosen audio tracks according to the user's phone bearing. *Audio Bubbles* (Mcgookin et al., 2009) gives auditory feedback about nearby landmarks.

The use of vibration has also been explored to convey the information. Information on nearby points of interest is given through vibration feedback in *Sweep-Shake* (Robinson et al., 2009). This design was then evolved to support users' navigation in *I did it my way* (Robinson et al., 2010). Directional information can also be given through a vibrating belt as explored in *The Tactile Wayfinder* (Heuten et al., 2008).

The navigation can also be more explorative with less guidance. Soundscapes have been created to this purpose, as for example the *Urban Sound Garden* (Vazquez-Alvarez et al., 2010) and the *Tactical Sound Garden* (Shepard, 2007).

In the *Backseat Playgrounds* (Bichard et al., 2006), the location and orientation associated to the participant influence the content of a game. The location is associated to where the car is located. The direction is given by a device with an integrated compass that the player can point with, described in-game as a “directional microphone”. The story told in speech is enhanced by sounds that are chosen to match the objects that the players can see from the backseat of the car during the journey, according to the direction in which they decide to point their device.

3.2 Assistive mobility devices for visually impaired people

Traditional aids for mobility used by visually impaired pedestrian are the guide dog and the white cane. The white cane device is used both for perceiving a greater range of the surroundings than the arm can reach, and to signal the visual impairment to others. These aids are complemented by mobility training – the use of auditive and tactile clues from the environment in navigation.

Research has been carried out on some more technological devices, resulting in the production of useful commercial devices and prototypes. For example, the white cane has been enhanced with ultrasound obstacle detection to let users discover obstacles at various heights. The *UltraCane* (UltraCane website 2011) consists of ultrasound distance detection integrated into a cane. This enhancement makes the white cane a little heavier for the user. Another example of a close-range detection application is the *Zebralocalizer* (Ahmetovic et al., 2011), which detects zebra crossings through a camera.

In the research presented in this thesis, we are not working with close-range obstacle detection. The assistance provided by the devices described is at the level of giving more general directions and distances, relying on the accuracy of a satellite based positioning system, such as the Global Positioning System (GPS). This precision is often in meters, not in the range of close obstacle detection. In the domain of GPS based mobility aids, some previous work can be cited.

In Gaunet and Briffault (2008), a user- and activity-centered approach was used to inform the rules of a speech-based navigation aid destined for blind participants. The rules were tested through a Wizard of Oz technique, without being implemented in hardware. The detailed audio descriptions were recognized to be useful and in many cases sufficient to fully guide a visually impaired pedestrian in an unknown environment.

In Loomis et al. (2005), the display of the route instructions with speech is compared to an egocentric display giving directions (angle/bearing) and distance information in several ways (speech, audio tones eventually spatialized). The GPS provides the location, but a compass is needed to know the direction in which the person is pointing. In Loomis et al., the compass can be located on the head, on the torso or in the hand (used as a pointer). If the person is heading or pointing in the right direction, the feedback is a confirmation. On the contrary, when the user is heading in a wrong direction, the signal is either different, absent, or gives instructions to turn. In this thesis, the tests were made using the compass as a pointer in hand, letting the users scan their surroundings for the right direction, and getting feedback related to the direction and distance to the next point in various modalities.

In Magnusson et al. (2011), the *NIVINAVI* game is successfully used in visually impaired children mobility training. The child holds the mobile phone in hand. The phone tracks both the GPS position and the orientation, and gives feedback according to the direction to the goal. The child is supposed to catch animals along a trail, and uses the phone as a scanner to find them. The *NIVINAVI* game derives its interaction method from the one described in this thesis.

Other devices have been released commercially. The *Trekker* (2011) is a GPS based system that gives route instructions in speech. It is adapted for visually impaired users both in its interface and in the instructions. Similar systems have been integrated to braille notetakers like the *Sense Nav* (2011). In software, the *Mobile Geo* (2011) can be mentioned. The *Loadstone GPS* software (2011) running on Symbian has the particularity of being open-source, but based on personal points of interest instead of map data. The *LoroDux* project (2011) is based on *OpenStreetMap* data.

3.3 Review of previous applications of Activity Theory in related domains

The Activity Theory framework has been applied in the domain of human-computer interaction mainly through two productive areas. One of them is Computer Supported Cooperative Work (CSCW) (Kaptelinin and Nardi, 2006, p. 85) where the "computer" or technological device is thought of as mediating a collaboration. The focus is then more on the interaction between the subject and the lower level on Engeström's pyramid – the community. The role of the computer/artifactual environment is thought of as supporting this collective dimension. The other productive area where CHAT has been applied is learning (Kaptelinin and Nardi, 2006, p. 89). The historical aspect and, for example, Vygotsky's zone of proximal development were already paving the way for this domain of application.

In Kaptelinin et al. (1999) a tool is proposed for applying Activity Theory to human computer interaction (HCI) at various steps. The Activity Checklist is composed of lists of relevant elements to pay attention to. In the preamble, four guiding topics are presented:

- The means/ends perspective based on the hierarchical structure of the activity,
- the environment perspective based on the object-orientedness of the activity,
- the learning/cognition/articulation perspective based on the concepts of externalization and internalization,
- and finally, the development perspective.

All these perspectives are the headers of two checklists, one for evaluation and another for design, where detailed aspects of each perspective are enumerated Sample questions in these four categories are proposed. The checklists are intended to be used by the designer or evaluator not as a list of mandatory points, but more as a read-through in which one can choose the most relevant aspects in his or her specific activity.

In "Using Activity Theory to Identify Relevant Context Parameters" (Huang and Gartner, 2009), two aspects of Activity Theory are highlighted. These were chosen in order to propose a method to shed light on context elements that help pedestrian navigation.

The first element is the hierarchical decomposition of activity into actions. This decomposition enables one to use the actions as units to identify context parameters. One example can be given for the action "moving from origin to destination": Here the object is to keep on the right track. The proposed relevant context parameters such as user orientation and velocity are transcribed into possible changes in the display of the map, such as map orientation and zooming level, respectively. The examples used seem to refer mostly to visually displayed maps.

The second highlighted element was an extension of the theory, called the extended Activity Theory's framework, so that the environment is also taken into account. Indeed, when identifying elements of the context that are meaningful to the activity, the global environment does not find its place in the current “cases” offered by various depictions of activity. Huang and Gartner (2009) propose enclosing Engeström’s pyramid into a box that they call the “physical environment” or “environmental context”.

3.4 Previous work in HaptiMap

In the HaptiMap project in which the presented research is included, the iterative design process, as well as the design for all perspective have been applied. Before the presented work was initiated, methods were reviewed and conducted to identify the user requirements relevant to pedestrian navigation systems. This section presents these preliminary studies.

3.4.1 Methods

There are many methods that have been tried and used to apply the principles of *design for all* or *iterative design*. Many of these were reviewed at the beginning of the HaptiMap project, which this thesis builds upon.

The “User Study Guidelines” (Magnusson et al., 2009d) is a synthesis of this review and regroups a number of methods for involving users in the design process.

The methods vary in level of user involvement. They range from no user involvement were the user can be even modelized (e.g. personas), to low user involvement where the user is only consulted (e.g. questionnaires), to high user involvement (interviews, focus groups, workshops, longitudinal studies). A number of methods consider the user involvement to be optional.

The engagement with materiality (e.g. lo-fi prototyping, bodystorming) or, on the contrary, the focus on ideas and thought processes (e.g. brainstorming) are also elements of differentiation of these methods.

Some methods put an accent in getting into the real context of use (e.g. mobile usability tests in the field, field observations and field studies), and others are doable from inside the lab (e.g. controlled usability tests).

Some methods are more destined for idea generation while others are more destined for evaluation. The length of the activity as well as the degree of technology development needed is also a factor.

Paper A presents a continuation of this review of methods, with a specific focus on observing the mobile user experience. Although not within HaptiMap, the method of walkshops was presented at the same conference in Korn and Zander (2010). It consists of moving the workshops to the outside environment.

3.4.2 Recommendations

The methods described above have been used in combination in Magnusson et al. (2009c) to produce user requirements for non-visual mobile navigation systems. This study identified important elements to take into account for such a system: primarily landmarks and information about objects in the environment (such as houses, house numbers, etc.) were stated. Other elements identified were hands-free and eyes-free operation, position accuracy, speech feedback – but non-disturbing, confirmation that the user is on the right track, routing design, correct user orientation in the environment and updated map content. These requirements have been produced by a combination of activities (focus group, diary study and design workshop) involving two target group of users: elderly people and visually impaired young students.

Another study developed the method of the *Mobile Oracle* (Magnusson et al., 2009a) which is a mobile Wizard of Oz method, with the particularity of giving information on-demand. The study presented involved users from the three target groups: sighted, visually impaired, and elderly users. They were given the task to shop for a specific occasion in a mall. This allowed the researchers to gather the kind of information that was felt to be needed or relevant for the users in a pedestrian navigation situation. The requested information was categorized under: Content overview, Spatial layout, Direction/route, Distance, Notification/prompts, Confirmation, Content, Recommendation, Memory, Time, and Capability of the device. The features noted as interesting to the users were landmarks, distances, directions and orientation hints. An accent on relative locations (behind, in front, to the left), imprecise distances (a bit further, a fair distance away), and physical pointing was also noted. For more severely visually impaired users, the precise location of entrances and obstacles and the optimization of the way to a shop were noted as specific requirements.

Other than these specific requirements, the idea that an explorative navigation support was useful in cases like hiking was formulated in an internal HaptiMap report (Magnusson et al., 2009e). Beside what has already been noted in the two studies above, the importance of flexibility of the application was reported, meaning that the application should adapt to the person and situation. The main additional requirement for visually impaired users was a greater level of detail. Finally, the two key assumptions that additional sensory channels should be used when possible and that there is a need for a pedestrian-centered navigation device were reaffirmed.

4 Summary of papers

In this chapter, a selection of the papers I was involved in is presented. They are representative of the whole iterative process to develop an audio-tactile navigation interface.

For each paper, a short summary and a description of my contribution is given. The papers follow roughly the chronological order, but they are also ordered to illustrate the iterative design process.

4.1 Paper A: Methods for understanding the mobile user experience

Charlotte Magnusson, Kirsten Rassmus-Gröhn, Delphine Szymczak

This paper is a review of mobile observation methods. It was presented in 2010 in the workshop on "Observing the Mobile User Experience" (OMUE) at the NordiCHI Conference.

This paper lists different possible methods to evaluate the user's experience in the wild, from logging to interviews and including direct observation and simulations. I reviewed and compiled the methods. I wrote part of the descriptions as well as gathered some references.

The need to use more than one method to obtain a good understanding of the mobile user experience has to be balanced with the increased cost of additional methods – that cost lying in the difficulty to use the methods in the wild or in the time needed to analyze the data afterwards.

The limitations due to context (e.g. weather, busy environment) or safety concerns for the participants are also brought up.

I gathered the various methods and wrote a substantial part of this review/state-of-the-art paper.

4.2 Paper B: Pointing for non-visual orientation and navigation

Charlotte Magnusson, Miguel Molina, Kirsten Rassmus-Gröhn, Delphine Szymczak

This was published as a short paper at NordiCHI in 2010. It describes the *PointNav* prototype and the scanning and guiding tests that have been conducted on it. *PointNav* gives audio-tactile feedback both when standing still (to learn about the surrounding points of interest) as well as when navigating toward a point of interest (to guide the user).

PointNav has been tested by visually impaired people in a park environment, demonstrating the accessibility of this type of scanning interaction. It provides a complete system that also supports explorative behavior of the surroundings.

I participated in some of the application design discussions.

4.3 Paper C: Navigation by pointing to GPS locations

Charlotte Magnusson, Kirsten Rassmus-Gröhn, Delphine Szymczak

This paper was published in 2011 in the *Personal and Ubiquitous Computing Journal*.

A controlled, in-the-wild test is described, complemented by a simulation. The interaction method tested relies on audio feedback being given when the orientation of the scanning device – a mobile phone – is within a certain bearing angle of the direction to the next goal. This test aimed at determining the best angle around the target direction to give audio feedback to guide someone. The test helped to refine the described method of interaction for guiding people with non-visual modalities.

The results of the study showed that angles smaller than 30 degrees are more difficult to use. Angles from 30 up to 120 degrees were recommended. The angle from this study applied in further studies was 60 degrees.

I participated in the test design discussions as well as in the pilot tests.

4.4 Paper D: A real-world study of an audio-tactile tourist guide

Delphine Szymczak, Kirsten Rassmus-Gröhn, Charlotte Magnusson, Per-Olof Hedvall

This paper has been submitted to the *Journal of Pervasive and Mobile Computing: Special issue on Mobile Interaction with the Real World*. It describes the evaluation of the *Lund Time Machine* tourist guide and how Activity Theory has been applied on this occasion.

The *Lund Time Machine* is a tourist guide with an interaction design also based on the interaction system used in Paper C. Part of the evaluation described took place in a city environment, with participants that were not experts in GPS use. This test was part of the iterative development process, since the results will be fed back to improve the current prototype. Activity Theory was used as a theoretical framework to guide the design of the test as well as the data analysis.

I had the main responsibility for writing the paper. I participated in the iterative design process of the *Lund Time Machine* application by taking part in discussions and influencing the prototype development. I designed the evaluation: I helped to shape the interview questions, to choose and organize the observation methods, to conduct the evaluation and to analyze the results.

5 Description of the iterative design process

This chapter will be guided by the iterative process in which I participated. It consisted of the design and evaluation of a tourist guide which supports pedestrian navigation along the tourist track. Many steps and prototypes had to be developed before the final application and its evaluation. The first section describes the methods used and the resulting application as it was before the evaluation. The second section describes the formative evaluation of the *Lund Time Machine*.

For each step, relevant details will be given, ranging from the initial ideas, the iterations of prototype development and pilot tests, the more extensive formative evaluation, to the results from tests that were fed back to the development.

When needed, relevant information about the application, the project or context will be given, but if the reader wants a better overview of the *Lund Time Machine* application or its evaluation, the Paper D is the one to turn to.

Referring again to the spiral used to represent the iterative design process, one can place those steps as in figure 5.1. The progression is drawn chronologically. It begins with ideas that resulted in the *Soundcrumbs* prototype (Magnusson et al., 2009b). The first evaluation that I was involved in was the angle test as described in Paper C. The *PointNav* prototype was then designed, implemented and evaluated. This application can be seen as a first prototype in the context of the *Lund Time Machine* design process. The spiral ends there at the time of writing with the formative

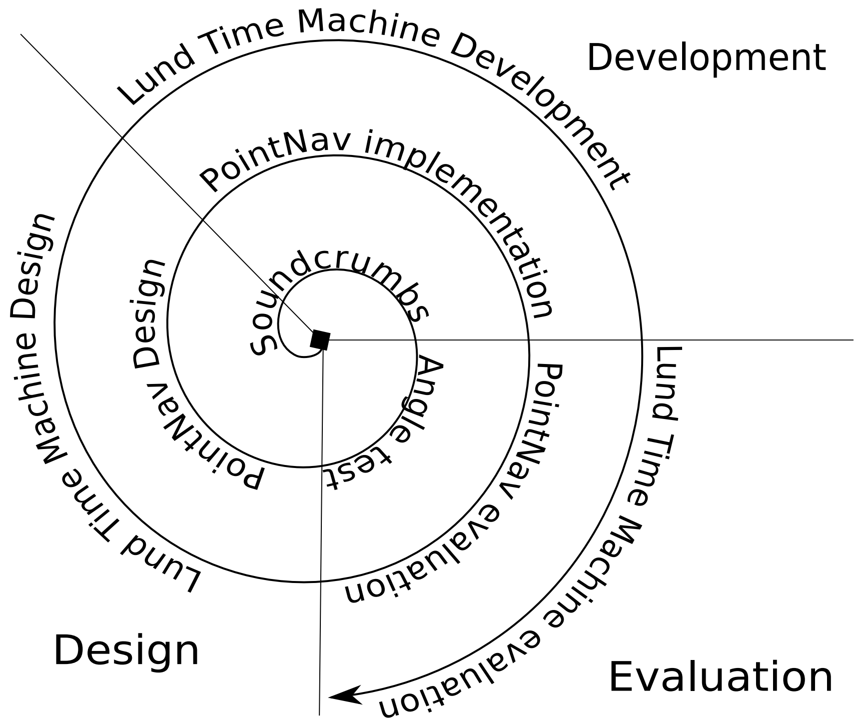

Figure 5.1: Iterative design process applied to the *Lund Time Machine* application

evaluation of the *Lund Time Machine* application, which is the latest completed step I am reporting.

5.1 The *Lund Time Machine* application

This section highlights interesting steps of the design process of the *Lund Time Machine* application – up to its formative evaluation – and what results the methods applied to this application development yielded.

The *Lund Time Machine* application is a tourist guide. This application uses both the users' location (GPS) and the orientation (compass) of the device (mobile phone) they are holding to give audio or tactile feedback. The idea is to give the feedback when the user is pointing the device in the "right" direction, the one that they should walk to reach the next goal. This interaction was introduced by Magnusson et al. and Robinson et al. independently in 2009, *Soundcrumbs* (Magnusson et al., 2009b) being an early prototype for the *Lund Time Machine*. In the process described in this thesis, we explore the details of how to give feedback, as well as more general considerations on the tourist guide as a whole.

5.1.1 Method

Three guidelines are first presented. They describe accurately the main characteristics of the methods we used. Then, selected concrete examples of how this was actually conducted are presented in the two last sections.

User-centered process

The design process that we engaged in was human-centered; users were directly involved through various methods (questionnaires etc.) earlier in the project as well as in pilot tests.

Iterative process

The process was iterative. The evaluations results were reused in the application development of further prototypes. On several occasions, a sub-part of the application was tested in a separate and organized test. The sub-part was implemented either as part of an existing prototype or in a separate application in order to fine-tune specific parameters. The test about angle size presented in Paper C is one example of this process. The results of such evaluations were then used in the next prototype or the next iteration of the same prototype.

During the development, the iterations were not very strict. Smaller and informal tests could also give feedback about an ongoing prototype development and inform it in very short cycles. An attempt to render this is presented in figure 5.4 and its explanation.

Design for all in the process

This process also has a design for all approach, where one goal was to include visually impaired users, as well as giving benefits for all possible users. This is clear in the description of goals of the project in which the *Lund Time Machine* development happened: "The HaptiMap project is aimed at making maps and location based services more accessible by using several senses like touch, hearing and vision. Our end goal is to increase the number of persons who are able to use mainstream map services. Thus our user group contains both sighted persons and persons with visual impairments (including elderly persons)." (Haptimap website 2011)

The evaluations were thus conducted with a diversity of users. The *PointNav* evaluation described in the Paper B involved visually impaired users while the evaluation on angle size presented in the Paper C was conducted with users of all ages. In the formative evaluation, this diversity is also maintained.

Ideas

At early design stages, the team regrouped for brainstorming meetings. All ideas were written down on a whiteboard and then discussed. The result of one of those meetings was a lively flowchart (see figure 5.2) intended to relate to each other the necessary elements of the application in an integrated way.

The meetings to discuss specific ideas or more global design problems with the application continued to occur at least weekly. It was then possible to confront the ideas in the team, to get feedback

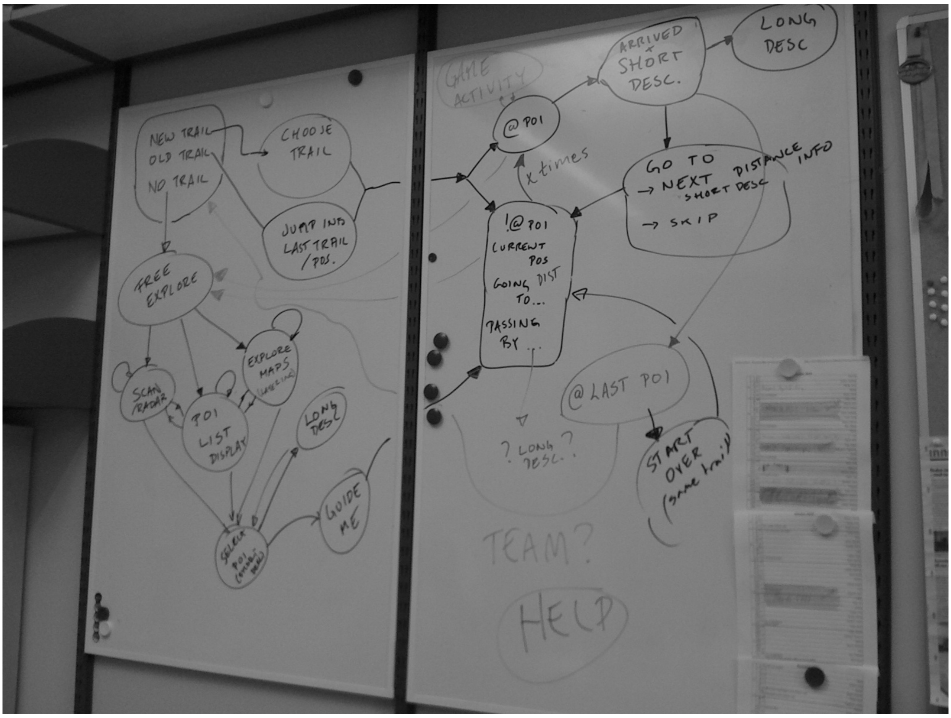

Figure 5.2: A lively result of a brainstorming session
(picture taken by Kirsten Rassmus-Gröhn)

and to remind each other of potential missing elements or technical difficulties.

Pilots

When a version of the prototype had gained enough in functionality, a pilot test could be conducted. This happened several times during the development, with simple tracks that were not meant to be interesting, but mostly to exhaustively test the prototype features. Coming back from these tests outside in the field, the observations were shared with the team and the needed changes were prioritized and then implemented alongside the scheduled original features in the prototype.

The frequent meetings enabled us to share the insights from pilot testing and to agree on needed changes in the development. Many occurrences of this back-and-forth process occurred during the development.

5.1.2 Results

The results from this design process were ultimately integrated in the *Lund Time Machine* application, but during the process, multiple stages with a diversity of prototypes resulted from the diverse iterations.

Chronologically, figure 5.1 gives a good picture of the different prototypes that resulted from the process.

At the beginning, the ideas and implementations from earlier projects like Magnusson et al. (2009b) were gathered. Section 3.4.2 describes the resulting requirements that came out of this process.

At that stage, we felt the need for a more focused test on the size of the angle feedback, and a specific study on that parameter was conducted (see Paper C). The results concerning the angle were then implemented in the next prototypes. In his master thesis, Miguel Molina implemented the first prototype, *PointNav*, described in Paper B. This prototype took into account the earlier recommendations. At this stage, the application provided an exploration part as well as a navigation part. In the next iteration, the *Lund Time Machine* tourist guide was developed. This new prototype is described in Paper D, as well as the last step represented in figure 5.1, the evaluation of the *Lund Time Machine*.

Here I will present relevant points that resulted from this design process. For more detailed information, please refer to the appended papers.

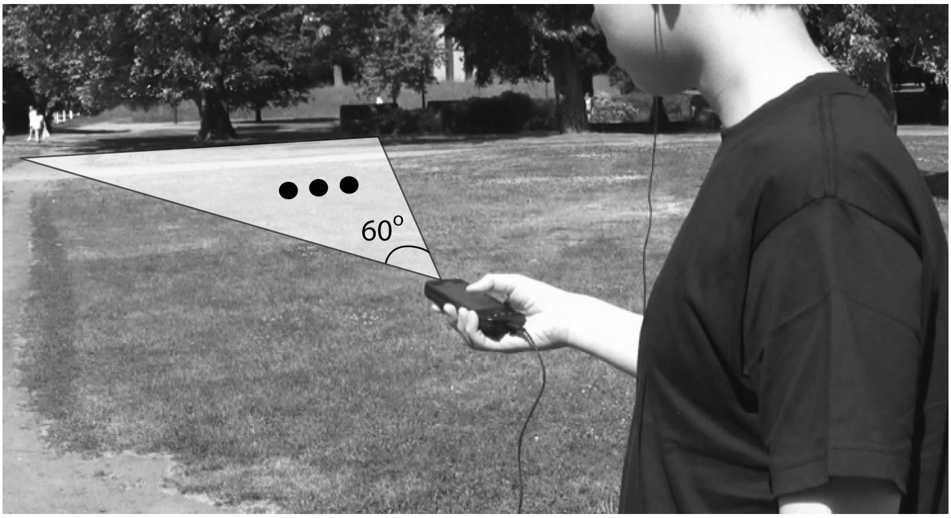

Figure 5.3: Angle feedback in pulses toward the goal
(picture taken by Charlotte Magnusson)

Guiding with angle feedback

The main interaction with the *Lund Time Machine* consists of being guided by means of vibration pulses coming from the device (a mobile phone) to a desired goal. This interaction was taken from earlier prototypes and refined in its parameters. In figure 5.3, a user is holding in his hand the device running the *Lund Time Machine*. We can suppose the goal is the tree in front of him.

While he points the device within 60 degrees around the direction to the goal, the user will feel pulses to confirm the direction. When pointing away from the goal with a deviation of more than 30 degrees to the right or left, the phone does not vibrate.

The feedback is based on the phone's compass orientation, its GPS position and the GPS coordinates of the goal. The compass orientation depends on where the walking person is pointing, and the phone's position is interpreted as the pedestrian's position.

During the user tests, we witnessed several scanning behaviors. Tilting the hand, the arm or turning with the whole body were three ways of moving to find the right direction. To deal with compass jittering problems as well as GPS jumps or imprecisions, the angle of feedback as well as the radius in which the goal is considered reached have been adapted. More details can be found in Paper C.

Compatibility with mobility aids for visually impaired pedestrians

When designing the various prototypes, we kept in mind the need to have a device that was compatible with the mobility aids that visually impaired people already use. For example, we tried to take into account the fact that, when using a white cane, at least one hand is busy. With the same concern, the audio was thought to be usable with only one earphone (non-spatial audio) to let the users get the auditory clues from the real environment as well. The study described in Paper B confirms that this type of interaction was usable by visually impaired pedestrians using mobility aids.

In the evaluation described in the next section, this was extended to all users. We made sure that at least some of the users had one of their hands busy, and we told them that they could use only one of the earphones. One of them had a handbag while another used a white cane. We thought of offering them an ice-cream at the beginning of the test, but the weather and practical conditions did not allow for it.

Benefits of pilot testing in the wild

A GPS application often needs to be tested outside buildings. Since the pilot tests mostly happened in the real use conditions, it was possible to discover problems due to the context of use in the interaction.

For example, the cold weather made it clear that it was not always possible to require people to take off gloves, thus the implementation of shake gestures for getting to the next point in the track.

Some inaccessible points, due to GPS inaccuracies, led to an adaptation of the goal radius.

Sounds too similar to what happens in the real environment (bird sounds) seemed not to be noticed or to be confusing. It was then possible to either prevent this confusion or use this effect.

Vibration feedback

The feedback for following the angle is a good example of a nested iterative process within the main one. At first, the discussion occurred between other members of the team. Several vibration patterns were implemented following these specifications. Then a small test was carried out to evaluate which vibration pattern was the best to give distance information. Finally, one of the patterns was chosen for the main evaluation.

At that point, I got involved for pilot testing of the application. The pilot test, conducted with a colleague, led to identifying one problem: the “turn around” pattern made the signal too confusing. Then another version of the signal, which took away the feedback outside of the main feedback angle of 60 degrees, was implemented and included in the prototype. In the end, this version was used in the main evaluation of the prototype.

This could be represented by a nested spiral (figure 5.4) in the main iterative spiral development:

1. The first step consisted mainly of ideas.
2. The ideas were then implemented in several parallel vibration feedback patterns.
3. An evaluation of the qualities of those various patterns, in a comparative way, was then conducted.

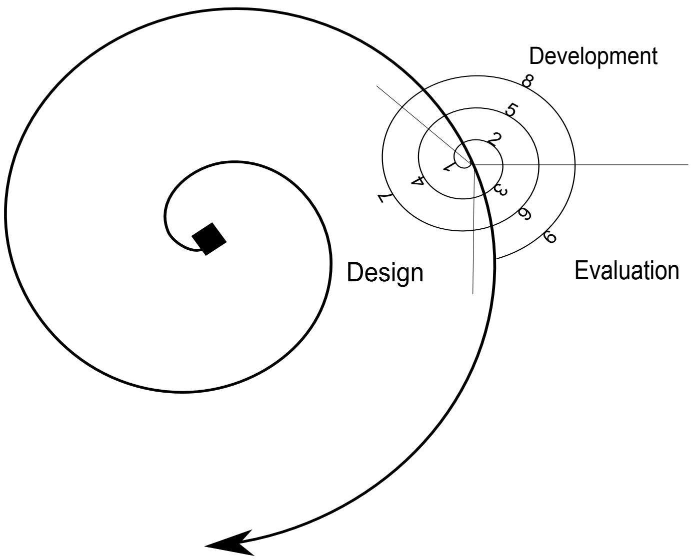

Figure 5.4: The embedded iterative design process

4. One pattern was validated after the comparative evaluation.
5. The pattern was made to be the default one in the application code.
6. A pilot test let the turn-around problem appear.
7. This led to the idea of implementing a simpler version without tactile feedback when turning around.
8. This was then implemented in the prototype.
9. Finally, the next evaluation step was merged into the main evaluation step of the main spiral.

Confirmation sound icons

During the pilots, we realized that for some points, depending on the audio information, it was not always easy to understand that one should stop. When arriving at a point, the vibrations just gave a final burst and stopped. The audio information could make it clear that it was the description of a specific point, but it was not always the case.

It was thus decided to add an “arrival” sound when reaching a point, so that the participants would not continue scanning to find the next point without realizing that they had to validate (with a button on the screen or by shaking) before going to the next point. In the same manner, the final point was attributed a very distinctive sound (like trumpets).

It was not possible to achieve a signal distinctive enough with only the vibrations. When moving and scanning, it was expected that the overall vibration pattern would be irregular, making it possible for the user to confuse the complete stop of vibration with a wrong direction. The idea that the vibrations might have stopped because of a device bug needed to also be clearly overruled. The audio stopping signal was then a good way to achieve clarity.

The sudden change of modality also prepared users well to receive the speech or audio information associated with the point of interest they had just reached.

Sound bubbles/windows from the past

The application attempts to enhance the tourist experience with sound windows on medieval Lund. Sounds that were considered typical from the medieval city of Lund were chosen and played when the user passed by associated locations.

Some examples would be the religious chants around the cathedral, or the animal and crowd sounds around the location of a medieval market square.

The position of the sounds as well as the distance from which they should be audible was fine-tuned during the iterative development process. In the city, some locations were linked to a real object, or to a building that was there at the Middle Ages. However, the global "medieval ambiance" around the city was mainly created by adding animal or other typical sounds from medieval times along the streets or in open spaces. In the second location, the archeological site of Uppåkra, the track was much shorter. In this case, the distance from where you begin to hear the sound windows needed to be shortened, so that not all sounds are played at all times. A more detailed description with the exact distances can be found in Paper D.

In some cases, we realized that the real sounds were filling a purpose. Car sounds at dangerous intersections are an important trigger to pay attention to the traffic. At one of these dangerous intersections, the sound of horses on the ground was played, representing the sound of the heavy traffic in medieval fashion. This played out in an interesting way during the evaluation that will be now described.

5.2 The *Lund Time Machine* evaluation

This section will describe the formative evaluation of the *Lund Time Machine* that took place during the iterative process, as well as its results. A more detailed account of this can be found in Paper D: "A real-world study of an audio-tactile tourist guide".

Activity Theory (Kaptelinin and Nardi, 2006) was used as a framework to guide the evaluation and gain a better understanding of the *Lund Time Machine's* use. It is a tourist guide giving audio and visual (on screen) information about specific points of interest. The *Lund Time Machine* also guides the user to the next point of interest in a ready made track. The main activity considered when designing the test was a person wanting to visit the city of Lund and discover historical information about unexpected places of the town. We did not consider only one kind of activity. The idea of someone already familiar with Lund and wanting to get a little help to be a good tourist guide to their visiting friends from a device was also envisioned. In the real evaluation, we also needed to consider the case of someone in the activity of beta testing, trying to find bugs in an application to help researchers.

5.2.1 Method

One of the goals of the evaluation was to have a broader perspective on the interaction. The evaluation method was thus chosen to enable the analysis to take the whole activity into account.

Shaping the tests with the Activity Checklist

During the elaboration of what would be done during the evaluation, the Activity Checklist (Kaptelinin et al., 1999) in its evaluation version was used. As recommended, the different categories were screened and the items that seemed meaningful for this specific evaluation were noted. Later on, when choosing the questions for the interview, some of the chosen topics were integrated. For example, a question about the comparison between using the *Lund Time Machine* and a paper tourist trail/guide was asked. In the same way, the setting for the actual test tried to take into account several aspects brought to our attention through the items in the Activity Checklist. For example, the idea to ask the participants to follow two trails, one with a paper map the other with the *Lund Time Machine* was considered, but later abandoned for practical reasons. This was kept in a lesser version by handing out typical paper guides during the interview, and asking the users to remember previous personal tourist experiences they had using paper guides. The question of comparison between the paper map and the *Lund Time Machine* was then asked, with a preference rating and an open question calling for comments.

Making the team of researcher and observers aware of the focus on activity

Not all of the chosen items could be reused, mainly to keep the guidelines for the evaluation simple. In an effort to let the other researchers conducting the experiment be aware during the interviews and the evaluation about the changed focus, an internal document was used (Rassmus-Gröhn et al., 2011). This document already regrouped a checklist of aspects not to forget in the elaboration of the evaluation. To this was added the list of the four activity related components (Means and Ends, Social and physical aspects of the environment, Learning/cognition and articulation, Development). Then a short description of CHAT was given with a focus on taking into account – and thus trying to identify during the interview – the participant's motive during the test. In the same manner, the focus of observation was pushed to shift from the user-technology to the human acting in a broader environment. This encouraged the observers to look not only at what happened between the participant and the mobile phone, but also between the participant and the world, or more specifically, the city he or she was visiting, and the other people around.

Using the hierarchical structure of activity

Finally, the hierarchical structure of activity was presented in the internal document. It aimed at making the practical decisions about the setting of the test possible without knowing in advance the participant's motives. "Target" activities were considered (a tourist with the motive to discover Lund, a Lund native with the motive to show his city to a friend, maybe discovering new sights...) and then decomposed into actions. The test tried to reproduce these actions (following a trail between points of interest, beginning at the tourist office in the center city, alone or in company). Since these actions were common to several target activities, it was possible to conduct the tests and encompass diverse activities that the participants would have in reality.

Recorded and direct observation

During the evaluation, the observations were carried out in several ways. A direct observation took place by following the participants. A video recording was made in most cases by this observer. The participants' actions as well as the surroundings were filmed. This was meant to enable a better understanding of the context of use.

In some cases, in the city evaluation, an audio recording of the participant was also set up. This enabled an "inside view" of what happened between two people walking together with the *Lund Time Machine*, by merging the video and the audio recordings.

The use of recordings was also a good way to counter the bias of the observer. When the observation is only made by following the participants and taking notes, the bias of the observer will be expressed through the filter that they have when viewing the situation. Even when explicitly stating lists of important points to observe, as was done in this evaluation, the observer cannot see everything. With the recordings, it was possible to go back to the video and audio and to see things that had been filtered out during the actual observation.

Semi-structured interviews and questionnaires

It is not easy to get an understanding of the human-device interaction only by observing. This concern, as well as wanting to know more about the participants, was dealt with through time dedicated to interviewing after the tests.

The participants answered standardized questionnaires. The

NASA-TLX was a way to get information about the effort required to engage in the tourist experience and use the application. The "basic questionnaire" asked about the gender, age and abilities of the participants. The bodily abilities (vision, audition, mobility) as well as the relevant learned abilities (familiarity with smartphones, GPS) were taken into account.

The semi-structured interview then took place in Swedish, the participants' language. There were global questions about the interaction, but those were meant to let the participants choose the relevant parts of the device to comment on. In case they did not have any detailed ideas, the interviewer prompted them about elements of the application. The elements were characterized either by their modalities (vibrations, sounds, screen) or by their meaning (conveying distance information, direction, touristic content, ambiance).

During the analysis, the answers were grouped around meaningful elements of the device. The interviews were also screened for specific quotes of the participants and transcribed, to get a more specific understanding of the participants' views in their own words.

Quality

As mentioned earlier, to ensure the quality of qualitative research, Flick (2007) recommends using triangulation. In the *Lund Time Machine* evaluation, both interview and observation were used. The participants and the paths walked were varied, and more than one researcher was involved.

5.2.2 Results

The main results and details of the study can be found in Paper D. A selection of relevant results is presented here.

Participants

The *Lund Time Machine* evaluation involved two groups of participants. The first was mainly composed of 8 elderly people and 2 experts in visual impairment. The second group was composed of 24 schoolchildren, age 10. Two locations were used for evaluation. The first was in the city center of Lund, with two different tourist tracks. The second location was situated in a field in the south of Lund, were a track based on archeological findings was created. The elderly group was invited to both locations, while the schoolchildren group only came for an evaluation in the field environment.

Both groups had some knowledge of the use of a mobile phone. The use of touch screens and smartphone was something familiar to only half of the elderly group and very few in the school class. The use of a GPS device was mainly restricted to cars, and more than half of both groups never used a GPS.

By inviting these two user groups, we aimed at a diverse range of users, fitting the goal of a design for all perspective. Only one visually impaired user tested the *Lund Time Machine*, but this allowed us to identify critical non-accessible parts of the applications for the final prototype.

It was also beneficial to involve users who were not all mainly interested in the technology but also in the tourist experience itself. This enabled the evaluation to be conducted with activities that were a little closer to the real use case of someone with the motive to visit a place and live a tourist experience.

Observation and analysis

During the test, the observation was direct as well as recorded through video and recorded through audio. The goal for the recording was to obtain the best reconstruction of the real experience for the analysis afterwards.

The video and audio recordings were at first carried out using video glasses. This was meant to give the participants' viewpoint, as well as to see what parts of the environment they focused on. The observer was wearing another pair so as not to miss the participants' gestures during the analysis. The audio was also recorded through the glasses. This method had some limitations. The video was a little higher than the wearer's eyesight, and it was not possible to see exactly what they saw, such as the mobile phone's screen that was out of the picture. The audio was also limited; it was only possible to hear the wearer's voice, and not what they were hearing. After two or three attempts, the video glasses broke, and we needed to switch to normal video cameras used from behind the participants.

The videos produced through the normal video camera were helpful when combined with the two separate audio tracks taken directly on the participants. When combined, it was possible to analyze what happened on a global level and to have the verbal exchanges of the participants together during the test. In many cases, the verbal exchanges were a good way to inform and better understand the situation and the breakdowns that actually happened. In some cases, it was only with the combined video and audio that the breakdowns discovered during the direct observation could be explained.

Surroundings, environment

The focus on activity that was pushed through during the test preparation was translated during the actual test observation by an increased focus on participant's interaction with their environments. When the participants were disturbed or helped by the environment, or even when a part of the city was in their focus (as object of their activity), this was specifically noted. This resulted in discoveries about how the environment comes into play during the activity.

One example of a disturbance was sun glare. The *Lund Time Machine* did not require the user to look at the screen, but information was still available on it, and the participants wanted at times to interact with it. Some of the evaluations were conducted on sunny days. The sun glare on the screen made it totally impossible to distinguish the visual information. This disturbance was noted mainly by observing people moving into the shadows to look at the screen. The participants also tried to shade the phones with their hands, or to clean the screen – with obvious problems because of inadvertently clicking many buttons.

An example of participants using the city environment as a support in their activity are street signs. These were a reliable element of the environment. Some of the points of interest mentioned a street name. It was then possible to receive confirmation that you were indeed in the right place, or that you were going in the right direction if you could associate the street sign near you with the one listed in the device. The street signs also help to have a clearer direction that is more compatible with the common visual overview of the street network. When the device pointed precisely in between two possible street directions, for example in the case of a curbed street, the street name on the sign could help to determine which way to go around the wall or building.

Finally, the city and elements of the environment could also become the center of attention, the object of the participant's activity. At points of interest, obviously, the description given by the device referred to buildings that could be there. A sculpture that you can approach while hearing its description was definitely becoming the object of the activity, being scrutinized, or contemplated, or sometimes explored in a tactile way. At other moments, during the navigation between two points of interest, the participants engaged with their environment. They obviously had to pay attention to the street traffic, to the other pedestrians and cyclists of the city. Moreover, some features like interesting shops, or surprising details of the city pavement were noticed. All this deliberate focusing on the city environment by users clearly indicated that the device did a good job of mediating the interaction with the city environment, since it could go in the background, and allow the user to both navigate and pay attention to other things rather than the device itself. This low cognitive effort was confirmed by ratings on NASA-TLX tests.

Screen interaction

When identifying the breakdowns, both in the interview and in the observation, the touch screen appeared to be a big source of problems for the participants. Besides the difficulty in seeing what was displayed, the action of touching did not function flawlessly.

It seems that the finger dryness – that can be associated to age – and the windy and dry environment exacerbated the occurrences of misselections. When touching one of the screen buttons, the “click” was sometimes not validated. Since the visual feedback was not always seen or understood, the participants did not know that they had not selected the button, leading to a blockage in the navigation.

In other cases, the soft buttons on the device – a Nexus One Android phone – were inadvertently selected. This led to other applications being launched or sometimes it caused the *Lund Time Machine* application to shutdown. In many cases, the help of the observer was required to understand what had happened and to recover. Nor was the use of the back button always understood well in the Android application.

These problems may have appeared only because our participants were not users of such smartphones before.

Routing and walls

The *Lund Time Machine* application did not provide any routing. The device would lead you in a direct manner, as the crow flies, to the next point of interest. With this in mind, the points of interests were kept fairly close together. Despite this, there were locations where the device would lead you directly into a wall.

For about half of the users, this was no problems, and they used the supports of their other navigation skills to naturally go around the blocking buildings and walls.

For others, the directions given by the device were strictly interpreted, and they did not come up with the idea of going around. Telling the participant that the goal could be further away than they thought or when needed, explicitly telling them to go around was sufficient for all of them to complete the track to its end point.

Overall, and because we want this application to be usable by visually impaired pedestrians, the recommendation to add routing to the guidance will be included in the next prototype.

6 Discussion

6.1 Focus on the artifactual environment

In Engeström's pyramid (figure 2.3), the base of the pyramid is meant to portray elements of the collective and how it is organized. In the task supported by the tourist guide, the collective dimension is not absent. The making of the device in itself involved both engineers and historians, as well as the knowledge of geographers to accurately place the medieval roads and churches. The points of interest in the application were based on the knowledge of all these experts, associating the historical information to the medieval locations' coordinates. The collective activity of creating an interesting tourist track was thus synthetized and present in the final device, the *Lund Time Machine* application.

However, when using the tourist guide, the participant is not engaging with all those people. He or she can listen to their stories, reflect on the technological choices, but there can be no human interaction with these people. The collective dimension *during* the activity of visiting the city with the tourist guide is mainly inscribed in the interactions with other pedestrians and eventually the other participants visiting the city at the same pace.

In such an evaluation, our focus is already on the artifactual environment, since we want to adapt the device to the activity. The base of Engeström's pyramid was not very helpful there, and thus I found Hedvall's Activity Diamond (figure 2.4) to be a more adequate tool. The focus can then be broader on the upper quadrant, the artifactual and natural environment.

I think that having less focus on the collective dimension fits well activities involving mobile pedestrian navigation with the mediation of technology. When visiting a city, the world is often providing the object of the activity. When a person is present in the role of guide, the guide can be the mediator to the discovery of the city. However, when describing the design of a technological tourist guide, where no human guide is present, the interaction with the device will be the main element that the designer can modify or influence. Moreover, the most frequent object of the activity is not a collaboration between humans, but an exploration of the city.

The historical perspective on the Activity Diamond is also one possible way to analyze the mediation. Following how the elements around the participants move between the upper quadrant and the right quadrant (object of the activity) is also a way to give an account of successful and unsuccessful mediations. In a successful mediation, the city is the object and the device is a mediator in the upper quadrant. When the device becomes the focus of attention, this may signal a breakdown in its mediation activity.

6.2 Navigation guiding design

Following the evaluation, the interaction model chosen to guide the participants seemed unobtrusive and adequate for a tourist experience, as discussed in Paper D. Some details can still be discussed further. The vibration pulses gave some distance clues, by getting more frequent towards the goal. This was reported as adequate and understandable when getting closer to the goal. When further away, this design can cause doubt when looking for the right direction. Since the pulses are less frequent, it takes a little more time to find the right direction by scanning. The effects of a continuous design as described in the audio feedback from Paper C are not exactly the same with pulses. Particularly the stuttering of the signal on the limits of the angle might be a little more confusing to the users when the signal is not continuous. Obviously, the main advantage of using pulses is that you save on battery life.

Another advantage of the guiding design in the *Lund Time Machine* is that you can play audio files at specific points along the route. The audio files can contain description of the points of interest, but also any instruction to reach the next point. This enables the utilization of a rules system like the one presented in Gaunet and Briffault (2008).

6.3 Design for use, design in use and task-artifact cycle

In the iterative process that was used, the artifact – the phone and the application running in it – goes from design phases to use phases and back. Users are involved in the artifact evaluation to inform its design. This, however, might not be what is called design in use.

In Rabardel and Waern (2003), the artifact is considered first as a design object with an envisioned function. The design happens in advance, so that the artifact can fulfill this function. This is called *design for use*. When the user takes possession of the artifact, and uses it, this original anticipated operation might evolve. The user can find new ways of using the artifact or alter the anticipated usage. The user thus makes the artifact into an instrument of their own actions, taking or not taking advantage of the possibilities of the artifact. This is *design in use*.

A description of the task-artifact cycle (Soegaard, 2006) states that the artifact is continuously being redesigned during its lifetime. An application given to users will modify their task. The modified task will then call for a modification of the application itself. This process is not thought of as ending, but more as something that can continue indefinitely.

Including sessions where users make the artifact their instrument for a short period of time, as is done in an iterative design process such as the one described here, is probably a way to include to some extent the modifications of this design in use. In this thesis, I have pictured the process as an outward spiral precisely in agreement with the idea that the evolution resulting from this process is not thought of as having a definite end point.

During the design process, the activity considered by the researcher to be the one that he or she is designing for is evolving. When the prototype was very simple, it could be only to go from A to B. At early stages, for example in the *Soundcrumbs* prototype (Magnusson et al., 2009b), the activity was, for example, a visually impaired person going to the woods by bus, and wanting to go back safely to the bus station (goal). The resulting prototype was then based on open area environments, with little consideration for routing or being able to attend to the environment. Then the prototype was used, and the testing carried out in the city in mixed environments (open areas near streets). This demonstrated that it could be used to navigate in busier environments like the city. The prototype was evaluated in such an environment with the perspective of a different activity (a tourist experience) and then other features were scheduled for inclusion (routing, street names).

In this process, the artifact/instrument passes through both stages of design for use and design in use in turns. Can it still be considered the same artifact then? When the activity is modified so much between different iterations of the design process, perhaps making that evolution clear and explicit might better inform the design process. It would be interesting to make the designer aware of the new context and modified requirements for the application when feeding back the results from a design-in-use session, after an update of the task.

6.4 Hierarchical structure, multiple activities and evaluation

In this research, the fact that different participants in a user-test have different motives and activities was recognized. In order to still be able to conduct a common analysis and a common evaluation, the similar actions of the participants were taken into account.

In using this tool, we agree with Huang and Gartner (2009) that the hierarchical decomposition of the activity into actions is useful for identification of the relevant context parameters. The extended framework they present also felt useful during the analysis to place an element that did not fit but should be kept in mind during the analysis – the city that was being visited. The city was indeed always around, and this was an element of focus for the observer, but only elements of the city are taken as either mediating tools or purpose of the participant's actions, thus excluding it from the immediate mediating tools.

By finding common actions at a lower level of the hierarchy, it was possible to give all of the participants the same goals (to follow the path and discover the tourist information at specified points of interest) without getting into the diversity of their activities. This is beneficial in a practical way, because it makes it possible to conduct the evaluation with a common protocol. But is this enough when it comes to the analysis and interpretation of the results?

In the analysis, we used the results, observations and interviews of all participants together, in order to incorporate the "main comments" from the participants into the next iteration. When trying to interpret a specific comment or to better understand an opinion that deviated from the group, the person's actual activity and motive were considered. Even though these were not clearly known by the researcher, the activity and motive of the participant (containing his or her actions) seemed to be helpful in understanding some differences in the participant's experiences. Even though we could not reconstruct the activity of all the participants, it seemed that for a number of them, at least one of their activities coincided with the activity that we envisioned for the evaluation.

Considering the fact that the participants probably have multiple activities going on when doing the test can also influence the evaluation. It is not clear how to deal with multiple activities. In the tourist trail, both the tourist experience and the “beta tester” experience can be there in parallel. In the first case, since the activity is about discovering the town, the attention will be naturally directed toward the city, and the device would be validated as being “non-obstructing” if it does not actively block this natural focus. In the second case, the device will be in focus, and the validation that the device lets the user attend to the environment will be considerably more difficult to make. However, in this second case, and because the participants will have paid more attention to the device and its possible detail improvements, the comments will probably be much more detailed and helpful in the next iteration of the prototype.

When agreeing to participate in such a study, it is highly possible that the participants will conduct both those activities at the same time, during the same set of actions and goals. It seems that during the interview, detailed questions about the device/application foster answers about the “beta tester” activity, while more general questions about the participants’ experiences let them answer with more of the “tourist” activity in mind. This might be an indication to look for participants with a certain type of motive in mind when doing an intermediate or early evaluation and a different one when doing a final or validating evaluation.

One way to choose between one type or the other, might be the manner in which the researcher recruits the participants. It is different to ask participants to “test an application” than to ask them to “use this helping device in the experience/activity they had already planned”.

7 Limitations

This chapter lists some of the limitations that have been identified in this thesis.

7.1 Practical difficulties

7.1.1 Time limitation

The participants had limited availability. They were asked to come for two hours slots, but then many of them had to leave. It was even worse for the second evaluation on the field site, where all 24 school children were only available for a few hours to test two different prototypes. With more time, the interviews could have been more open and conducted with more care in how the questions were formulated. There would have also been more opportunities for the participants to clarify and voice their comments. In the second evaluation in particular, the participant's answers were elicited in a group interview – while in the city, the participants were interviewed individually or in groups of two.

7.1.2 Group observation

The video and observations were not very helpful in better understanding what happened when the participants walked in bigger groups. At the archeological site in Uppåkra, where up to 6 participants could be testing the *Lund Time Machine* at the same time, one observer was not enough, especially considering that the observer also provided technical support.

7.2 Use of Activity Theory

7.2.1 Internalization

We did not use the development aspect of Activity Theory in the *Lund Time Machine* evaluation. We could have investigated the possibility of learning your environment through the *Lund Time Machine* and seeing if this kind of interaction supported the internalization of the streets and other useful information for navigation well or not. In part, this limitation was due to the prototype not being finished. A promising aspect of the next prototype is the inclusion of the exploration mode, where you can get at any moment readings about points of interest around your current position. This could possibly support better an internalization of the map through key points of interest such as the train station or the cathedral, which usually are necessary points of reference when learning to navigate a new city. In the current prototype, it is only possible to follow a predefined track, and this might be counter-productive in the user's learning of their surroundings.

7.2.2 Understanding

In the analysis of the *Lund Time Machine* evaluation, it was possible to look back at recordings and to use the interviews to better interpret them. However, the observer is not always aware of the participants' thoughts. Although the participants were encouraged to say aloud what they were thinking, they were obviously not constantly doing so. This was even less the case when a participant was following the tourist track alone.

In regard of the practical limitations, it is needed to keep in mind that the activities that we use to interpret the observations are reconstructed from our understanding. The validity of the analysis is thus not assured if the observer misunderstood something in the interpretation.

One way to overcome this limitation would be to go through the recordings with the participants right after the evaluation. Then the researcher can directly ask the subjects at each moment of the recording what their motives were and what action they were trying to accomplish.

8 Conclusion

This thesis has presented the iterative design of an audio-haptic tourist guide. Its evaluation, informed by Activity Theory, has also been presented and discussed. Some conclusions have been reached and are presented here.

First, the Activity Checklist (Kaptelinin et al., 1999) was found to be useful in guiding the researcher's focus during observation.

This was not the only tool used related to Activity Theory. When analyzing with the Activity Theory framework, the Activity Diamond presented by Hedvall (2009) was preferred, because it allowed more focus on the artifactual and natural environment compared to the collective dimension. This was found to better fit a mobile tourist guidance situation.

Some important points regarding the *Lund Time Machine* application itself can be noted. The design of the guidance presented is to give feedback when the device is pointed in the right direction. The feedback is given in vibration, with pulses that increase in frequency the closer you get to the goal. This interaction model was validated as being unobtrusive in the city evaluation of the tourist guide.

Other considerations were reached at the end of this process. The benefit of stating explicitly the evolution of the activity in the design process was discussed, linked with the idea that the nature of the subject's task evolves when given new mediating tools as stated in Rabardel and Waern (2003) and Soegaard (2006).

From the start, the hierarchical structure of activity was used for practical reasons in the evaluation. This choice enabled a common evaluation while still leaving room for individual analysis with the complement of interviews.

Identifying the relevant elements of the environment in the activity was found to be important during the evaluation. To that effect, it was considered beneficial to use the extended activity framework as formulated by Huang and Gartner (2009) to keep the whole environment in the analysis.

Lastly, the way the researcher recruits participants is suggested to have an impact on their activities during the evaluation. It is advised to consider carefully how the participants are recruited when aiming at a range of envisioned activities.

9 Future work

The work presented in this thesis will be continued. The further developments both of the *Lund Time Machine* and in other projects are presented here.

9.1 *Lund Time Machine* further development

9.1.1 Giving missing clues to visually impaired pedestrians

In this iterative process, we have identified visual clues that were in the world (like street signs) and that were used by the sighted users. Integrating this information into the prototype may greater benefit the visually impaired users, and thus include more of people from this target group in the next evaluation.

9.1.2 Develop the missing parts

The *Lund Time Machine* prototype will include the recommended elements, like the explorative scanning that lets you locate a number of points of interest around you, which was available in PointNav. This more complete prototype may allow us to evaluate in greater depth how well the participants can use it to learn their surroundings.

9.1.3 Final evaluations

For the final evaluations in the projects, when the prototypes should be fully usable, the benefit of choosing participants in a real tourist office is a possibility. It may be possible to recruit participants who already want to visit the city, or carry out the activity that the prototype is mediating. In this way, the use of the new application or device would better fit the real use case.

9.2 Activity Theory in other projects

Activity Theory was applied here in a specific case study involving mobile navigation. Audio-haptic technologies are also useful in other domains, for example to assist visually impaired children at school. The HIPP project (Hipp projektet 2011) uses audio and haptic interaction to give non-visual access to two-dimensional drawings.

It is planned to take into account the artifactual environment and the human environment in the context of the educational activity. Since the activity is mediated by the HIPP software and associated hardware, the conclusions from the current work should be beneficial, particularly concerning the tools used from Activity Theory.

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A Methods for understanding the mobile user experience

Paper A

Methods for understanding the mobile user experience

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ABSTRACT

Evaluating the user experience is often done in a laboratory. Methods for observing what happens in the wild are nonetheless being employed because they bring results that the traditional methods of evaluation do not yield. In this paper we describe and discuss methods used at our lab for understanding the mobile user experience. These methods range from quantitative to qualitative evaluation, and encompass diverse aspects of the design process. Finally we argue the need for combining different methods to obtain a better picture of real mobile usage.

1. INTRODUCTION

Observing the mobile user experience is a challenge. Situations change, and outcomes of tests are highly context dependent –eg. a person sitting on a bus will use a mobile device differently to one who is cycling. The social context also matters, since usage will not only be influenced by what you are doing but also who else is present and what your relations are. In this paper we provide an overview of different methods and discuss experiences, pros and cons of the methods we have used in our lab. Given our experiences, we argue that no single method is enough, and suggest that one needs to make use of a "smorgasbord" of techniques – both qualitative and quantitative.

Observing in the wild usually takes more effort than doing lab studies. To assess the utility of this additional work, in [1] the authors compared the evaluation in the laboratory and in the real world. Although the evaluation steps were exactly the same, the field study gave different and unique results compared to the study in the lab. The benefit of getting unique information from a field study then justifies that researchers consider the trouble of observing outside of the controlled environment of their laboratory. In the following we describe and discuss different methods used at our lab to make observations of users in the wild or at least in more real settings.

2. LOGGING

In several studies such as [2] and [3], logging has been used to keep track of what is happening during the experiment. One can log queries made to the interactive device as well as values taken from sensors. It is also possible to add some processing to recognize specific actions or usages (context sensing). In our studies we have mainly used logging as a support for the qualitative observations made during the test, but some data such as time to complete or number of turns lends themselves well to statistical analysis. The advantage of logging is that it is automatic, while the main disadvantage is that it can be difficult to interpret the recorded data. Context sensing can potentially help, but for more complex activities it is a true challenge to implement.

3. SEMI CONTROLLED OUTDOOR TESTS

To get feedback on basic components of the interface we have done a kind of test we call a semi controlled outdoor test. This type of test has a more lab type setup, where one takes care to randomize the order tasks are performed in. The test is also done on a specific location which mirrors some relevant aspects of the real world. Quantitative measures are recorded (such as time to complete, number of turns etc) and analyzed statistically. In addition an observer walks alongside (but slightly behind) the test person in order to make qualitative observations of gestures and behavior [4].

The advantages of this type of test is that it is less time consuming than setting up and performing a full scale study of mobile use. Another advantage is that one can focus on a single interaction component in a more full scale study a more complete interface usually needs to be implemented.

Problems with this approach is to know how relevant the results really are for the real usage situation, and also the lack of control over external factors like weather. It is also difficult for a person that walks slightly behind to observe all aspects of the interaction. Logging may help to some extent, but it is hard to extract more complex gestures from logs of magnetometer or gps data.

When testing GPS based applications one also has to consider the problem of GPS accuracy. Even at the same location this can vary from day to day. A workaround that can sometimes be used is to avoid connecting the GPS positions to real locations, and instead focus on how well the user is able to reach a virtual position (specified by the GPS coordinates).

4. REAL TIME LO-FI WIZARD OF OZ

Another method, as in [5] is to have a person acting as the mobile device, and observing the interaction. The questions posed by the user as well as the system responses provide valuable input early in a design process. The advantage of this method is that it is very easy to implement (no technology development needed) while the downside is that results depend heavily on the performance of the person playing the system. An additional problem is that there is a difference between talking to a person and using a mobile device.

A particular issue in our tests done with this method, was how to record the dialog without disturbing the situation too much. We ended up recording sound with a mobile phone – something which was seen to work well.

5. SIMULATIONS

When looking at mobile behavior one can also consider making use of computer simulations. In a simulation it is possible to investigate the effect of different parameters without external disturbances, and it is also possible to run very large numbers of tests. Thus simulations can be a useful tool for analyzing test results, or provide initial recommendations for certain interaction parameters [6].

The downside is that the usefulness of the simulation depends entirely on how well it is implemented. Factors important in real life may be missing, and unless the simulation design is carefully grounded in observed usage one runs the risk of getting useless results.

6. INTERVIEWS (SITTING DOWN)

To gain an insight into what happened during interaction, as well as into the context of use (skilled or novice user, intentions when using the device...) we need to ask the users. Interviews can be controlled or more open, but the researcher should avoid questions that can lead to confusion or use too technical. We often use a semi-structured interview approach: we have a set of pre-defined questions, but allow for follow up questions and discussions depending on the user answers.

The interviews can be done both before and after use, to gain insight in the context of use, the background of the user, and to obtain reflections on the test.

Interviewing is a standard technique and has been used in most of our studies, and also in many of the studies made by other researchers as mentioned in [1].

7. INTERVIEWS IN MOBILE CONTEXT

Interviews can also be done in the mobile context. We have noted that answers given while on the move are often different than those elicited when inside in a laboratory or an office. For this type of interviewing it is important to consider the recording. Just as in the previous method mobile phones or small recorders may be suitable. Video is more disturbing, but may be necessary if actions are to be recorded properly. One strength of this method is that events in the environment may trigger the discussion – something which may also be a weakness in case the external events are disturbing.

8. FOCUS GROUPS

During focus group discussions the researcher moderates the discussion while the end-users bring in their ideas. The discussion can be open or semi directed. To avoid missing important topics, or to give more concrete ideas to the group, some technology samples or prototypes can be brought to support the discussion.

Just as for ordinary interviews, we have found that bringing such a group outside is very useful. The group may talk about more technical issues in an office and then switch their focus to more situated topics when outside in the real context. Again the environment is both beneficial and problematic – it can not only trigger useful discussions.

Just as for situated interviews the documentation needs to be thought through – video is valuable, but audio may be enough depending on the context.

9. USER WORKSHOPS WITH DEMONSTRATION WALK

In participatory design, design workshops with potential stakeholders are a commonly used type of activity. The workshops are usually centered on scenarios which form the context for the prototype use. We have carried out workshops in which the scenarios are the users themselves, and their wishes and needs. After they have designed their paper / lo-fi prototype, they have been asked to act out the functionality of the prototype, and since the prototype in all cases has been navigation devices, the acting has included walking while demonstrating. This has led to a richer and more detailed dialogue around the actual functions and at what times you are interested in what kind of information. A potential problem is that users are not designers – they may find it quite hard to generate good designs, and the activity needs careful design and also often a moderator to ensure a useful outcome.

10. DIARIES

One way to get more long term and rich information about how persons use technology, or what kinds of needs they might have, is to ask them to fill in diaries over a period of time. This has been explored by eg. Gaver et al., who used it together with other sampling material in the Cultural Probes that he described in [7]. We used diaries together with scenario walks, contextual interviews and workshops as one method among others, not as a stand-alone tool. The diaries were mainly to collect travel information and to ask users about technology they might or might not use when planning or undertaking a trip. Every day had preprinted data to be filled in, such as the number and nature of trips, plus one or two preprinted questions from a larger collection of questions and also additional space to fill in any comments. In one case, the diary was filled in between two meeting occasions, in the other case after a larger workshop. The answering frequency was 100% in the first case, and only 5% in the latter, which shows that it might be better to send out diaries to be filled in before a meeting, rather than after.

11. VIDEO OBSERVATIONS OF ACTUAL PRACTICE

To have an insight into what people are really doing, it is possible to go out in the real world and try to video tape examples of use of the targeted technology. At our lab we have used such observations to obtain a better understanding of how users use their mobile phones when biking or walking. Those methods give information about what is happening in the real life. One disadvantage is that it doesn't inform the observer about the use of devices that are not yet possible to use. Another problem is that it can be really hard to catch the person to ask him or her why they did what they did.

Ethical questions can also arise from this kind of observation, and the observer should ask whenever possible if the video recorded can indeed be used.

Such video clips are also useful for bringing developers and designers closer to the complexity of real use. This type of videos provide the kind of richness which tends to be lost in methods like personas [8].

12. SIMULATED USE IN THE WILD

Most of our work has been to evaluate some aspect of interaction with a prototype that has limited, but accurate functionality in those parts that we intend to investigate. However, we have also recently carried out an evaluation sequence with a simulated functionality in context, where the test users had to perform actions that were not part of the future interaction. The task was to compare different navigation image types and decide which was most preferred [9]. The prototype was entirely without navigation functionality; instead it was the user who flipped between navigation images cued by the test leader and observer, who followed the test person. The unnecessary flipping of pictures seemed not to disturb the users much, and they were able to walk with speed. Aside from the drawbacks mentioned previously, the simulated use and the observation by following made it doubly difficult to be able to know what information the user really received. It occurred more than once that the user flipped the image at an incorrect time or accidentally flipped twice.

13. DISCUSSION AND CONCLUSION

The above discussed methods probe different aspects of the mobile usage situation. On the whole we agree with what was already stated in [10] that one needs to make use of several methods in combination in order to obtain a good understanding of the user experience. Although longitudinal methods are good for existing technology, they tend to be hard to use in the design process due to the times involved. Instead one often has to probe potential future use by shorter tests and design activities. In doing so we have found it important to use a variety of methods, and to make use of both qualitative and quantitative approaches.

A problem common in many of our studies is how to observe what the user is doing. If you are walking a little behind (which you have to in order not to influence the test person) it becomes hard to observe everything that happens. The actual activity of having to walk outdoors also introduces some specific problems:

- It isnt possible to carry out tests in all weather types
- You cant expect people to walk very far, especially not when you are working with elderly persons or persons with mobility problems
- You need to find safe test environments for persons with visual impairments
- People have different walking speeds

One particular problem we have noted is the difficulty of observing the interaction if feedback is given through earphones or vibration. In several studies we have made use of the loudspeaker of the phone just to allow the observer to gain access to the same output that the user is experiencing – but this is for many use cases quite artificial, and it could be worth exploring to have the observer get the same feedback as the user through an external device. A possible setup would be if both users have mobile phones and the user phone sends messages to the observer phone to generate the appropriate feedback.

We also note that simulations based on observed user behavior can be quite useful. Since simulations take much less time than real outdoor tests, we have found them a valuable complement when it comes to understand navigational behavior. How useful it is of course depends on the type of interaction studied, but (just as [6]) we find simulations a tool which should be considered.

In any design process the role of the user study is also to allow the users to participate in the design process. Thus, methods need to be combined in such a way as to help give the users the appropriate concrete grounding (by allowing them to experience existing technology) as well as to give tem visions and suggestions of future solutions [11]. Most persons find it hard to know what kind of future technology they want and how they think it should be designed. In fact, when faced with the question what do you want the most common answer is what can I get. Thus, it is the responsibility of the researcher or designer to work together with the users in order to explore the future design space.

To conclude: there is no single best method observing the mobile user experience. Instead one has to put together a set of probes to try to obtain an accurate understanding of the situation and the usage. Which combination is used depends not only on the kind of usage studied, but also why it is studied – are we observing existing technology, or trying to understand how possible future technology is to be designed?

14. ACKNOWLEDGMENTS

We thank the EC which co-funds the IP HaptiMap (FP7-ICT-224675). We also thank VINNOVA for additional support.

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B Pointing for non-visual orientation and navigation

Paper B

Pointing for non-visual orientation and navigation

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ABSTRACT

People who have visual impairments may have difficulties navigating freely and without personal assistance, and some are even afraid to go out alone. Current navigation devices with non-visual feedback are quite expensive, few, and are in general focused on routing and target finding. We have developed a test prototype application running on the Android platform in which a user may scan for map information using the mobile phone as a pointing device to orient herself and to choose targets for navigation and be guided to them. It has previously been shown in proof of concept studies that scanning and pointing to get information about different locations, or to use it to be guided to a point, can be useful. In the present study we describe the design of PointNav, a prototype navigational application, and report initial results from a recent test with visually impaired and sighted users.

Author Keywords

Non-visual, interaction, navigation, GPS, compass, audio-haptic, augmented reality.

ACM Classification Keywords

H5.2: Auditory (non-speech) feedback, H5.2:Haptic I/O, H5.2: Prototyping, H.5.1: Artificial, augmented and virtual realities.

INTRODUCTION

The use of navigation devices based on GPS information increased with 100% between the years 2006 and 2009 [5]. Nowadays (2010) many mobile and smart phones are delivered with pre-installed navigation applications. By combining GPS data with the information from an electronic compass (magnetometer), directional information can be displayed to a user when a device is aimed in the direction of a point of interest (POI). So far the bulk of this work focuses on adding visual information on the screen of the mobile device, of which Layar is one example (layar.com). However, there is also recent research showing how to make use of non-visual feedback, for example [1], [2], [4], [6], [7].

The soundcrumbs application [2] demonstrated that the non-visual feedback received when pointing with the device and scanning with it in different directions provided sufficient information to the user about the direction to a target. The SoundCrumbs application was an application mainly for creating trails (hence the "crumbs") and following them, and was therefore independent of map data. The display of map data in a completely non-visual use case becomes increasingly complicated with increasing numbers of map features to display. Still, pointing and scanning with a navigation device could potentially augment the reality to aid users who have limited eyesight and give them a means for obtaining an overview and orienting themselves as well as a means for navigating in unknown places. We have developed the PointNav prototype in order to explore how such an application should be designed.

THE POINTNAV PROTOTYPE

PointNav is a test application implemented on the Android platform which can provide speech and vibratory feedback. The application allows the loading of point of interest lists (via .gpx files).

Figure 1. The touch screen interaction design.

The main functionality from the user's perspective is the non-visual touch-screen interaction, the environment scanning by pointing, and the guiding to a selected target.

The touch screen contains nine buttons as shown in figure 1. You get a short vibration as you move from one button to the next. This allows you to feel the borders between the different buttons. If you rest your finger on a button the speech feedback will provide you with the name of the button. You select a button by releasing your finger from the screen (just as you do for mouse button selection in the standard windows interfaces). This design allows the user to slide her finger over the screen to find the right button without accidentally selecting something unwanted. In contrast to the accessibility design used in the Apple iPhone or in [9] this type of screen interaction requires no double tapping or special multi touch gestures.

In the scanning mode, the user points the device in the desired direction, and if the device points at a POI within a certain distance range she will get a short vibration followed by the POI name and distance (by speech feedback). The scanning angle (see figure 2) is currently 30º, and if several POIs fall into a sector, the one closest to the 0º bearing will be displayed. The last POI reported is stored and the user can select it by pressing the "Add" button and also ask for more information about it. In the real world there are often very many POIs and the user can filter these points by selecting to scan for near points (0-50 m), intermediate points (50-200 m) and far points (200-500 m).

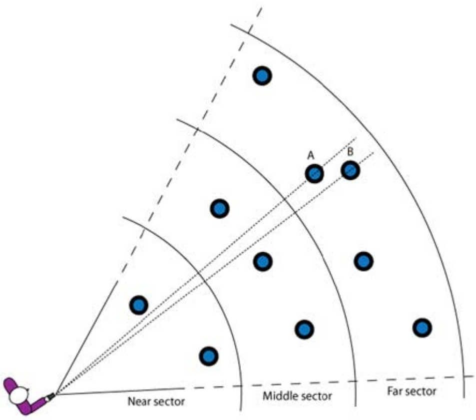

Figure 2. Scanning angle and sector ranges. The points signify POIs, and the POIs A and B in the same sector are close to each other in angle.

Since speech information about a POI takes time to display there is, in this respect, the question about how to handle the speech queuing in the case of several POIs with small angle differences (like A and B in figure 2). In PointNav the TTS is allowed to finish speaking POI names. This might result in feedback given at the wrong location, but having the speech interrupted by new speech requests can result in incomprehensible stutter due to compass and GPS jitter. We do, as yet, not employ any signal filtering strategy since filtering has been observed to result in a lag in the compass bearing which has been observed to be problematic for the scanning interaction. It is still possible that some filtering strategy might need to be adopted at a later stage.

In the guiding mode the user is guided to the previously selected point. The guiding does not make use of any routing, instead the application provides the user with information about if the device is pointing towards the target point or not. The figure 3 illustrates the guiding design.

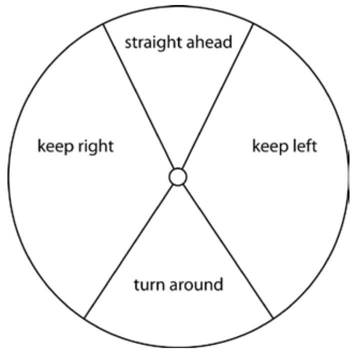

Figure 3. Guiding design. The "straight ahead" angle is 46º (to avoid decimals), the "turn around" angle is 60º and the "keep right/left" anlges are 124º.

For the design of the angle intervals we have been guided by the recommendations in [3]. In contrast with the design used in the soundcrumbs application [2] this design does not only provide information about how close the device is to the 0º bearing, but also about which direction to turn in order to point more straight at it. The speech feedback says the name of the goal, the distance to it and the text indicated in figure 3; "keep straight", "keep right/left" and "turn around". The corresponding vibration feedback used a design inspired by the PocketNavigator [8] and used a long and a short vibration for the "keep right/left" sectors (long-short for keep right and short-long for keep left). The forward direction was indicated by a pattern of three short vibration pulses and the turn back was shown as indicated by a sequence of long vibrations. The guiding stops when you are 15 m or closer to the target and the speech feedback says "arriving at <POI name>. No more guiding". In addition you get a sequence of five short vibration pulses. The 15 m distance is to some extent determined by the jitter/jumps in the GPS signal and for the test location (a park with many trees) we had observed that the 10 m used in [2] occasionally placed locations in places that were hard to reach or dangerous while 15 m appeared to work better. For all the vibration patterns described above a short vibration is 50 ms and a long vibration is 150 ms.

The start button in figure 1 was to keep the application inactive before the test, and the mute button allowed the user to silence the guiding speech information.

TEST DESIGN

The above described application was tested with five visually impaired users and one sighted user. The test was semi-informal/qualitative and was done in a park (figure 4).

Figure 4. POIs in the test area. The POIs used in the test are indicated by arrows.

Of our visually impaired users three were completely blind while two had some residual vision. We tested with 3 men and 3 women. We tested with young, middle aged and old users – the age of the test users was 14, 16, 44, 44, 52 and 80. The sighted user was the youngest of these – we wanted to test also with a sighted teenager to compare how this kind of user would react to an application like this.

To allow the users to familiarize themselves with the application the test started with a tutorial where we showed them how to find the test starting point (the topmost of the points indicated in figure 4). Once at the test starting point the user was asked to locate the fictional place "Beachstock" (at middle distance, rightmost of the points in figure 4) and go there using the guiding functionality of the application. Once at "Beachstock" the user was asked to locate "Neverhood" (at long distance, leftmost in figure 4) and then to go there. The user was not told in which distance interval the points could be found. The use of fictional POIs was motivated by a wish to avoid having users making use of previous knowledge of this park. After having found "Neverhood", the test leader guided the users to a spot near a fountain placed centrally in the park (the centrally placed white circle in figure 4) and asked the user to tell him how many POIs that could be found nearby. The users were video filmed during the test, and the test concluded with a short semi structured interview around the experience and the application. The whole test took between thirty minutes and one hour.

RESULTS

All users were able to complete all test tasks. The visually impaired users particularly liked the possibility to orient themselves using the scan mode. The guiding was also quite well liked by four of the five users with vision problems, while one user did not like it since the GPS precision is not good enough (this user had previous gps experience and thus knew the imprecision you sometimes get – "you want to get to the ATM and you end up at 7-11"). The touch screen interaction worked quite well – all users were able to learn it quite quickly, and the main problem was actually to remember which functions there were and what they should be used for. Given the short duration of the initial familiarization, users were allowed to ask for help with the touch screen interface, and everyone except the sighted user needed reminders like "the top left button" initially. All users were able to handle the final task without support indicating that they had mastered the interaction fully.

Compass jitter made it hard to select the "Neverhood" POI (the speech feedback would jump between the two nearby points), causing selection errors and forcing the users to try several times before they succeeded. In response to this, two of the users developed the strategy of turning the phone to a vertical position as soon as they heard the right name (the scanning updates only while the phone is held horizontally).

In general users kept the phone pointing forwards during guiding and followed the speech instructions. One user also developed the alternative strategy of keeping the phone pointing towards the goal even when walking in another direction (when walking around obstacles or having to follow paths that did not lead straight towards the goal).

All users had to be told about the vibration patterns. They spontaneously noticed that there was vibration, but unless told so they did not notice the different patterns. One of our blind users had used the application before during pilot tests, and this user preferred to turn off the speech feedback for the guiding. The other users were quite happy about listening to the speech, although some commented that once you got more used to the vibrations you might want to turn the speech off. One user who had tested an earlier application that made use of a Geiger counter type of vibration feedback to indicate direction commented that such a design might be more intuitive than the one we had implemented in PointNav.

The users were offered to use earphones. Four of them preferred to use these, while two preferred to listen to the phone loudspeaker. This may in part be due to the test design – since the test leader was walking nearby it is possible that some users felt it more natural to share the sound compared to if they had been on their own.

We had included one elderly user in the test. This user had no central vision, and no longer used a mobile phone. Before the onset of the vision problems this person had used one, but it was described as the "old" kind. Thus this user had no experience of touch screens, and needed longer time to learn how to use the touch screen interface (although also this user was able to complete the final task without assistance). The pointing and scanning on the other hand caused very few problems.

We were also interested in how the PointNav application (which was designed to be accessible) would be perceived by a sighted teenager and we included one such person among our test users. Teenagers can be considered mobile phone expert users, and much marketing is targeted towards this group. Since we only tested with one user from this group we can make no general statements, but at least this person reacted very positively to the application and thought something like this would be really useful. It was also interesting to see how little the application interfered with the walk – the user looked around and also talked quite a lot with the test team. Even when interacting with the screen in bright sunlight, the device was held in a relaxed position at waist height. This can be contrasted with the “hold the device in front of the face” type of interaction that tends to result from the standard touch screen interaction.

DISCUSSION AND CONCLUSION

This paper describes the design of the PointNav application and reports initial results from a user test involving five visually impaired users (ages 16-80) and one sighted teenager (aged 14). PointNav includes a combination of augmented reality scanning and guiding while earlier studies have focused on either augmenting the reality [4, 6] or guiding [1-3], [7], [8]. In contrast with [1], [4], [6] and [7] we have also tested with visually impaired users. The test reported in [2] involved only one visually impaired user, and was (as was stated above) directed solely at guiding. Our test results are encouraging – the scanning and guiding interaction is intuitive and easy to use, and also the touch screen interface worked well although users needed some time to learn the button layout. The select on release design caused no problems, and the users quickly understood how the interaction worked.

Our visually impaired users particularly appreciated the scanning mode since it provided overview and helped with orientation. The guiding allowed all test users to find the goals we had assigned, but this may to some extent be part of the test design. The kind of POIs we used (not closely tied to a physical object) and the kind of environment we were in (a park) is less sensitive to GPS inaccuracies. Judging from the user comments the orientation one gets from the scanning may be more important – in fact one user explicitly stated that GPS guiding was not good enough for his needs. Still, guiding was appreciated by several users and in fact two of our visually impaired users spontaneously expressed that they felt safe using it (one of these was the elderly test person).

Another problem we partially avoided by using a park was the kind of situations where objects in the environment block the path to the goal (an extreme example would be a cul-de-sac forcing the user to take a detour). It is clear that routing will improve the guiding in an environment where such problems are more common – but at the same time we see that for more open environments the kind of interaction described in this article (as well as in [1-3] and [6-8]) works well both for sighted and visually impaired users. It should be noted that the park was not completely open – there was one place where a ridge barred the way and our users were still able to handle this by walking around it. Still, we feel it should be the subject of future studies how these guiding designs can be combined in a good way.

ACKNOWLEDGMENTS

We thank the EC which co-funds the IP HaptiMap (FP7-ICT-224675). We also thank VINNOVA for additional support.

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C Navigation by pointing to GPS locations

Paper C

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DOI 10.1007/s00779-011-0456-3

ORIGINAL ARTICLE

Navigation by pointing to GPS locations

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Received: 29 August 2010 / Accepted: 5 May 2011

Abstract This article deals with a method for interacting with a handheld navigation application, based on using the mobile device for pointing. When the user points the device in any direction, feedback will be provided based on if the user is aiming at the next point in the track or beside it. The presented study has been performed in order to get a better understanding of how the basic parameters in this type of interaction—like the angle for pointing and the size of the target—influence the navigation performance. We have applied a dual investigation by running a computer simulation varying additional parameters such as GPS accuracy and user behavior, and also running an in-context study with 15 participants in a realistic outdoor setting with real location-based GPS data. The study has resulted in general recommendations for angle intervals and the radius of the circles surrounding the track points.

Keywords Gesture · Audio · Navigation · Pointing · Augmented reality · Non-visual · Multi modal

1 Introduction

The introduction of compasses in more and more handheld devices has opened the way for applications making use of pointing gestures to provide information about objects or locations in the real world. With geotagged information on a device which knows where it is (through GPS or other means) and also knows in which direction it is pointing (through a compass), it is possible to show the user information on important buildings, restaurants, future or past events, etc. in the direction the device is pointing (http://www.layar.com). So far the bulk of work in this direction focuses on adding visual information on the screen of the mobile device, although there is recent work making use of the non-visual channels, e.g., The roaring navigator [1], ONTRACK [2], Backseat playground [3], Audio Bubbles [4], SoundCrumbs [5], Sweep-Shake [6], Social Gravity [7], and "I Did It My Way" [8].

GPS and compass information can be used both for augmenting the reality and for navigation. As was illustrated by the SoundCrumbs [5] application and later also by Social Gravity [7] and the "I Did It My Way" [8], pointing the device in different directions and getting non-visual feedback when on target is a way of not only providing information about a target but also a way of giving information about in which direction the user should be walking. The most basic version of this kind of interaction is illustrated in Fig. 1. To provide navigation information, the application has a database of GPS locations, and the direction from the user GPS position to the GPS coordinates of the current goal is calculated. The device direction indicated by the device magnetometer (compass) is then compared with the correct direction. As long as the device is pointed in a direction inside the two border lines indicated in Fig. 1, feedback is provided. Outside this interval, the user gets no feedback at all. Each GPS point is surrounded by a circle. As soon as the user is inside this circle, the point is considered to be reached and the user is guided toward the next point in the sequence.

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Published online: 17 September 2011

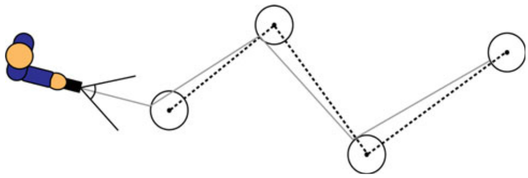


Fig. 1 The basic interaction principle

In Fig. 1, the track of GPS points is shown together with the circles around each point. The gray line indicates the path a user would follow in the ideal case of perfect signal quality and if he or she walked in a direction pointing directly toward the points. Note that also in the perfect case, the actual GPS points would not be reached, instead the user will turn toward the next point in the sequence as soon as he or she is inside the goal circle. Thus, in a world of perfectly accurate signals and GPS positions, the smaller the radius of the goal circle is, the closer the user path will be to the dotted line in Fig. 1.

In the real world, the path the user follows will be influenced by the angle interval in which the user gets feedback, the goal circle radius, the GPS signal quality, the magnetometer (compass) signal quality, and also by the strategies the user adopts. Thus, it is important to have a good understanding of how these factors influence the user performance. Some earlier works have partially addressed this (see related work below) but a better understanding of the influence of angle size on performance and behavior in a more real outdoor navigational setting is still needed. User strategies and initial results have been published in [9], and the current article reports a more in-depth analysis of the results.

2 Related work

Using non-speech sound or vibration in a handheld device to guide pedestrians in a wayfinding situation has been studied previously, but not extensively.

One group of proof-of-concept systems make use of spatial audio for navigation purposes and thus require headphones. AudioGPS by Holland et al. [10] displays the direction and the distance to a target and uses stereo together with a repeated fixed pitch tone and a repeated varying pitch tone to give the user the directional information. A Geiger counter metaphor is used to convey distance from target (more frequent tone bursts the closer to the target the user is). In gpsTunes created by Strachan et al. [11], the user's preferred music was placed with spatial audio to provide bearing and distance information. As long as the user kept walking in the direction of the goal, the music was played at the desired volume. Stahl's The Roaring Navigator [1] guides visitors at a zoo by playing the sounds of the three nearest animals. The system also uses speech recognition for interaction and speech to display further information about the animals to the user. Jones et al. [2] modify the volume of music stereo playback to guide users toward their destination in the ONTRACK system. The full sound is given in both ears within an angle of 90° around the target. Between 90° and 180°, the sound is shifted 45° to the left or right, and it is completely shifted to the left or right ear for angles above 180°. Their field trial also showed that visual distraction may interfere with audio guiding.

The Audio Bubbles concept by McGookin et al. [4] is similar to AudioGPS, but does not require the use of headphones. The context is somewhat different, in that it is not specifically targeted to navigation, but to support tourists to be aware of and locate points of interest while wandering freely. The Audio Bubbles are therefore also limited in size and have a maximum range outside which they cannot be heard at all. Backseat playground [3] does not provide navigation information—instead the audio feedback is used as information within a location-based game played in the back seat of a car. The SoundCrumbs application described by Magnusson et al. [5] enables the user to place virtual spheres of sound in a virtual georeferenced system and locating them again to support finding ones way back to a starting location, or to create virtual trails to share with others. The user can hear the soundcrumb when being near the crumb location. The volume of the sound depends on the distance and get weaker as you go further away. It is also possible to locate the next soundcrumb on the trail by pointing and sweeping a device with a magnetometer (compass) in it. When the magnetometer points in the direction of the next soundcrumb, it will be played with adjusted volume, depending on whether the user points directly at the target or beside it. In [12], a study of a system which integrates scanning the environment for information and navigation feedback into a complete system (PointNav) is reported. PointNav makes use of the already published preliminary angle recommendations in [9], in that it makes use of a central "straight ahead" angle interval of 30°, complemented by wider "keep left"/"keep right" information outside this interval.

Instead of using audio as a beacon at the target, tactile feedback such as vibration has also been used. The Sweep-Shake system presented by Robinson et al. [6] has similarities with the SoundCrumbs application, in that the user points in a direction and receives vibratory feedback when the device is pointing at the target. The targets are different in size depending on their information content (a larger target indicates more information content), and the use case described is primarily browsing and selecting geolocated information while standing still. Ahmaniemi and Lantz

[13] similarly use vibratory feedback to investigate target finding speed in a laboratory setup. The user scans or sweeps a handheld device while standing still. The study considered feedback angles between 5° and 25°, concentrating on the speed of the sweeping movement. The possibility of missing the target at high speeds for smaller angles is stated. The results show that reaching a target with a vibratory angle of 5° is significantly more difficult than with larger angles. The Social Gravity system described by Williamson et al. [7] intends to guide a group of people toward a common meeting point, called a "centroid" that adjusts its position according to the individual members of the group, using vibration feedback. The users are also here expected to scan for the target (centroid), and a 60° target indication angle was used in the field trial. Before choosing the field trial angle, a simulation was made with angles from 5° to 180°.

A combination of tactile feedback and spatial audio feedback is utilized by Strachan et al. [14] following the work with gpsTunes [11]. The user's music is modulated by sound clarity and reverb according to the changing predictions of user position with respect to a path. The vibratory feedback underlines the audio feedback, by getting stronger when there is a low probability for the user to stay on the desired path. In "I Did IT My Way" [8], this kind of navigation is investigated as means to provide navigation information in a more exploratory manner. In this study, the feedback angle is influenced by the number of possible routes to the target—the minimum angle is 60°, but this angle is increased if more alternative paths lead to the target.

A group of users who may potentially benefit greatly by navigation systems making use of sound or tactile cues are persons with visual impairments. Off-the-shelf navigation systems for blind persons make extensive use of speech output (e.g., the TREKKER [15]) and some also on speech input (the Kapten [16]), while very few also in research are making use of non-speech audio or tactile feedback. Tactile feedback is often used, however, in applications supporting near-field navigation, like obstacle avoidance and object recognition. Several commercially available systems are described by Calder in [17], where he also describes the problem of matching assistive technology to the moving target of a user's changing or evolving needs. Johnson and Higgins [18] present a tactile belt that presents distance information to obstacles that are detected by two cameras.

Tactile systems have been described as more useful than audio-based systems as they do not interfere with the user's hearing. Visually impaired pedestrians rely on the ambient sound information about their environment to orient themselves. Gustafson-Pearce et al. [19] compared a vibrotactile setup with a single ear-piece headset and showed that the vibrotactile setup generated less user error than the audio setup for simple navigation information.

3 Research questions

The present study is performed in order to get a better understanding of how angle interval, the goal circle radius, the GPS signal quality, the magnetometer (compass) signal quality and the strategies the user adopts influence the user performance. Thus, the questions we are trying to answer are:

- What is the effect of using different angle intervals?
- What is the effect of using different goal radii?
- What is the influence of the signal quality?
- What different strategies do the users adopt?

4 Outdoor tests

For the outdoor test, we used an external magnetometer (a SHAKE SK 6 device) connected via Bluetooth to a Sony Ericsson Xperia mobile phone running Windows Mobile. We initially tested an implementation also on an Android developer phone, but since both running the vibration motor and the magnet snap for the keyboard influenced the compass, we decided to use a separately held magnetometer for the test. Due to connection/software delays, the effective magnetometer update rate was not constant. The times between our data points ranged roughly between 150 and 250 ms with an average of 200 ms (measured over 500 data points from one of the log files).

5 Test design

To keep the duration of the test around 1 h, we decided to perform the test within a limited space. Most test rounds were done in a park-like area outside our department which contained open areas, foot/bike paths, trees, bushes, and some artistic installations. We had decided on this type of fairly open environment for several reasons:

- A road network would impose a limited number of possible directions making it harder to discern the effect of the angle interval alone.
- One can expect users to visit parks and open squares, and the test environment contained elements natural for that type of environment.
- This type of environment allows more freedom in the design of different trails.

To see what happens in a completely open environment, we also carried out three tests in an open field further away.

With only one goal point, users may just use the feedback to find some suitable visual landmark and then mostly rely on this landmark to navigate. Since we were interested

Fig. 2 The grid points for the test trails

in the effect of the feedback on the navigation, this was something we wanted to avoid, and thus, we created an underlying track which changed direction. We selected a design where the test tracks were based on a grid structure (see Fig. 2).

The four different tracks available can be worked out from Fig. 2. Each track started at point 1 and went on to point 2. At 2, you could turn either left or right. The same would then happen at the points 3 or 4. The track ended at one of the corner points 5, 6, 7, or 8. The turns at the points 2, 3, and 4 were made in an alternating fashion so that if you turned left at the first turning point in the first trial, you turned right during the next trial. Thus, if your first trail was 1, 2, 3, 6 and your second trail 1, 2, 4, 8, your third trail would be 1, 2, 3, 5. The same design was used for the following turn. The initial values for the turns in the sequence were assigned randomly. Since there were four tracks and eight tests, each track occurred twice, but since the order was randomized, we expect learning effects to cancel out. In addition, due to both GPS inaccuracy and deviations due to different angle intervals, the users did not walk the same way every time even though the underlying GPS track was the same.

The grid distance in the (5, 1, 7) direction was defined by a latitude difference of 0.00018 and a longitude difference of −0.00049, while the distance in the perpendicular direction (1, 2) was defined by a latitude difference of −0.00025 and a longitude difference of −0.00027 (decimal degrees). At this location, these values correspond to 37 and 33 m, respectively (using the haversine formula [20]).

Each point in the track was surrounded with a circle of an approximate goal radius of 10 m. If the user was inside this radius, the point was considered to be reached and the application would lead the user toward the next point in the sequence. Thus, all points had to be visited in a sequence and you would not find the goal unless you had reached all the previous track points. When the user was within an approximate goal radius of 20 m of the goal waypoint, the phone started to vibrate slowly. When the user was 10 m (or closer) to the target, the goal was considered reached and the phone started to vibrate quickly.

As described in the previous section, the interaction was designed so that the user got information about in which direction to go by pointing the device in different directions (as was done in [5, 7, 8]). If the device was pointing in the right direction, audio feedback playing a wave file (the sound of waves against the shore) was played. The volume did not change—the sound was either on or off. The direction was considered to be right as long as the device was pointed to a direction within a specified angle interval as shown in Fig. 1.

The angle intervals tested were 10°, 30°, 60°, 120°, 150°, and 180°. The order in which these were presented to the test person was randomized. Before the actual test, a practice round at 30° to allow the user to familiarize himself/herself with the equipment (and also to make sure the GPS reception had some time to stabilize) was carried out.

Initially, we considered testing both audio and vibration for the direction feedback. In the vibration case, the audio would instead have been used for the goal information. The pilot test indicated that the feedback mode was less important for the kind of things we were observing—and since audio made it possible for the observer to understand what was happening by listening to the feedback (we played the sound in the phone speaker for this purpose), we decided to limit the test to sound feedback for the direction and vibration for the goal information.

The users were observed during the test by an observer walking slightly behind (not to disturb the navigation) and to the side (to be able to see what the person was doing). After the test, they were asked about which strategies they used for small and large angles, how much they felt they needed to concentrate, or if they had any other comments about the interaction design. The test application logged time, GPS position, and magnetometer heading. It also logged when the user passed different waypoints and when the goal was reached.

6 Test users

The test was pilot tested by three persons to check the equipment and the setup. Early in the test, we found that some users made use of the distance information printed on the screen for debug purposes, and after this, we covered this information with a rubber band. The two users who had

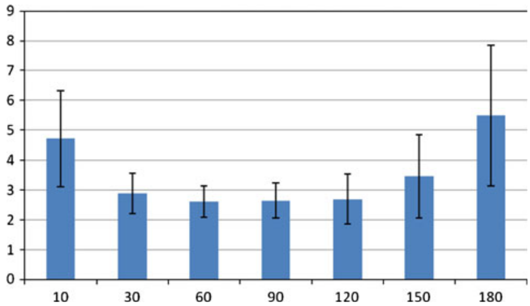


Fig. 3 Time to complete for the different angles. *Error bars* indicate the standard deviation (SD)

made use of the distance were removed from the test series and we added two persons to bring the total number of actual tests up to 15. Of these users, 6 were women and 9 men. The age range was wide—our youngest test user was 13, while the oldest person who did the test was 70.

7 Results

If we start by looking at the time to find the goals in Fig. 3, we see that the 10° angle interval and the 180° angle interval take longer. Statistical analysis using ANOVA showed significant differences ($P < 0.0001$).

A Bonferroni test showed significant differences with a confidence level of 95% between 10° and the angle intervals 30°, 60°, 90°, and 120°. 180° was significantly slower than all other intervals except 10°.

Figure 4 summarizes the resulting trails from our park-like test area.

In addition, we did three tests in an open field to see what happens in an environment free of obstacles. In Fig. 5, we see the resulting trails (all these pictures were made with GPSVisualizer, http://www.gpsvisualizer.com/).

If we look at the trails in Figs. 4 and 5, we can pick up some general features. As expected, the more narrow angles lead to more precise route following, while for the

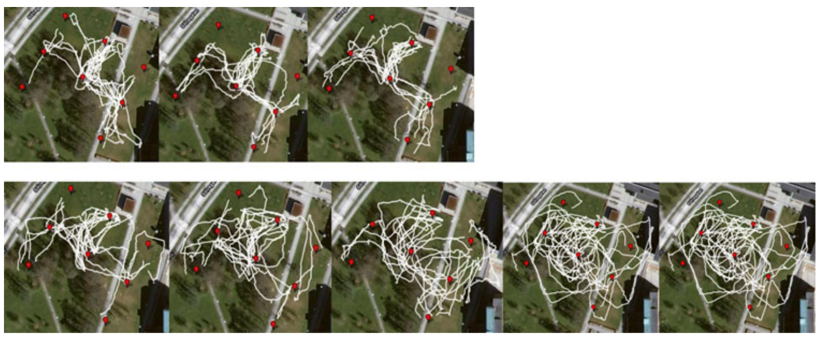


Fig. 4 Trails for the angles 10°, 30°, 60° (*top row*, left to right) 90°, 120°, 150°, and 180° (*bottom row*, left to right)

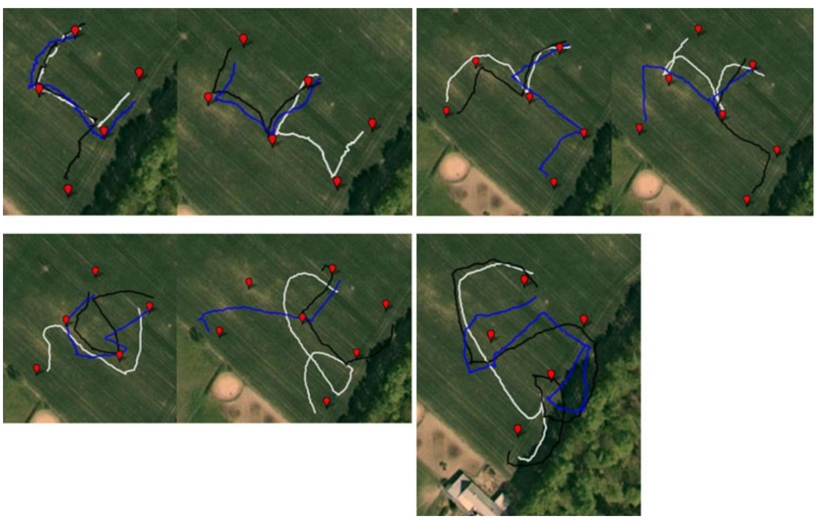


Fig. 5 Trails for the angles 10°, 30°, 60°, 90° (*top row*, left to right), 120°, 150°, and 180° (*bottom row*, left to right)

wider angles, people would stray more and would even occasionally loop/walk in circles for a while.

For the finding of the appropriate direction while standing still, we saw three main types of gestures. The first, which basically all users made use of, was to hold the device out in front of the body, keeping the arm and hand position fixed relative to the body, and walk around on the spot (sometimes in a small circle). A second gesture which was used both while walking and while standing still was the arm scan. In this gesture, the arm was moved to the side and back again. This gesture occurred to one side only or from side to side. The third type of gesture was hand movement only—the user moved the hand by flexing the wrist. Also this gesture was used both standing still and while walking. In addition, two users also scanned by keeping the hand and arm still, but instead walking in a zig-zag/serpentine fashion forward. One user also tried to scan by moving the device with the fingers (keeping the hand in the same position).

For finding the direction while standing still, all the three main gestures were used. Some users preferred the whole body rotation only, while some started with the arm pointing and only made use of whole body rotation if this did not give any result. The hand pointing was mostly used for the narrow angles (10° and sometimes also 30°).

In general, our users would keep walking as long as they heard the audio feedback. When they lost it, they stopped and checked the direction. The only exception was the 10° angle. As was noted already in [13], narrow angles make targets easy to miss, and for this angle, it was really hard to keep a steady signal. This led either to the person stopping a lot or to keep walking a while without signal and then stopping to check whether he or she was walking the right way. Some users also tried to use arm or hand scan while walking to keep the signal, but given the noise in the signal, the limited update rate and the delays present this tended to work badly leading instead to a complete loss of signal.

For the wider angles, we saw that we had two basic types of users. One group was more analytic and explored the width of the angle interval and then tried to walk toward the middle. The other group walked as soon as they felt they had a steady signal. The difference between the groups was most clearly seen in the 180° condition; although some of the more analytical users also had problems with this angle interval in general the analytical strategy made users better able to cope with the wider angles. In the analytical group, we would often see the user trying to check the limits of the angle interval by doing a sideways scan (while walking) to find the border. The less analytic users would still tend to avoid the borders of the angle interval. Due to noise/jumps in the magnetometer signal, the sound would start "hiccupping" near the border. All users made use of this info, although not everyone

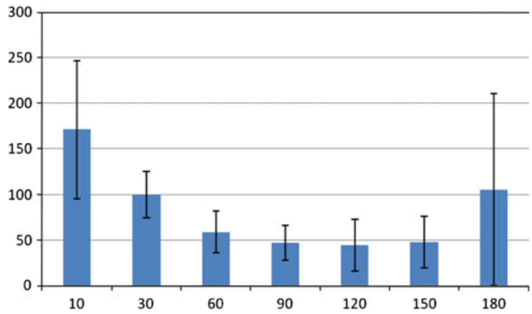


Fig. 6 Number of times the user lost the signal for different angles (*error bars* give the SD)

realized this was useful right from the start. While scanning standing still, this meant that the user would keep moving the device until the signal was steady (and often a little further) which meant that also the less analytic users would avoid walking right along the borders of the angle interval. While walking, the hiccup would either trigger a stop to scan a new direction, or the user would try to re-orient by doing an arm scan while walking.

The number of times the user loses the signal (Fig. 6) is influenced by the user strategy adopted. If a user scans the interval, he or she will lose the signal also due to scanning with the device, and not only as a consequence of walking too far in a particular direction.

In general, users expressed that they felt more "secure" with the wider angles (although they did not like the 180° which was said to be too wide). The 10° made users feel insecure, and they walked noticeably slower in this condition. We did not explicitly test cognitive load, but we did probe this by trying to talk to our subjects. Both from the responses to this and also from answers to explicit questions, it was clear that the narrow angles were more demanding. Particularly the 10° angle required a lot of concentration from the user. One user said "you have to concentrate so hard that you almost forget where you are". All users disliked the 10° and thought it was too narrow. With wider angles, people were more relaxed and would often start talking spontaneously with the observer. They also commented that with larger angles you did not have to concentrate that much, but could relax and enjoy the walk.

7.1 Test of circle radius

In order to get a better understanding of the effect of the circle radius on the navigation, we also did a single follow-up test at the angle 90° comparing the radii 1, 2, 5, 10, and 20 m.

The test user was instructed to walk as soon as there was a signal, and to stop and scan as soon as the signal was lost.

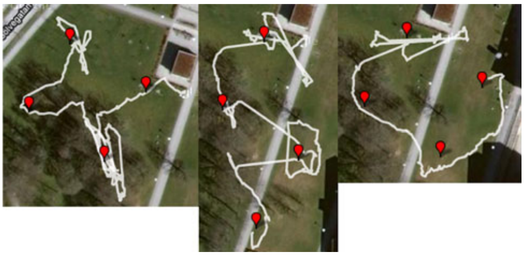


Fig. 7 Trails for 1, 2, and 5 m circle radius

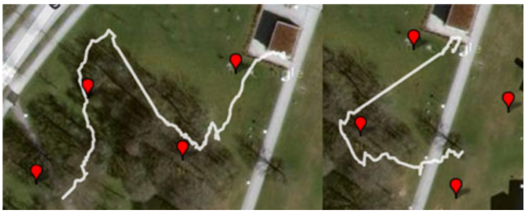


Fig. 8 Trails for 10 and 20 m circle radius

For the small circles (Fig. 7), we had a lot of problems with jumps in the GPS signal while the cases with larger circle radii (Fig. 8) were less affected.

The 20 m circles resulted in quite poor track following, but since the track was not visible to the user, this condition was actually preferred—the test user stated this was the easiest condition. Given the fact that the amount of GPS jumpiness was observed to change between different days and that "hunting the jumping point" is something which both takes time and is frustrating, we decided against running a longer test series on the circle radius.

8 Simulated tests

In order to get a better understanding of how different parameters influence user performance, inspired by Williamson et al. [7], we decided to complement the above test with computer simulations. In the outdoor test, we had identified two basic user strategies: (1) those who tried to find the center of the angle interval and (2) those who started walking as soon as they had a good signal.

To get an overall simulation of average behaviors, we simulated navigation toward a single point assuming the user will chose a random direction within the interval that produces positive feedback. To get a simulation of the kind of behavior resulting from walking as soon as you have a signal, we also looked at the worst-case scenario where the user walks in the least advantageous direction possible.

For the overall simulation, we assumed a user walking in a random direction within the angle interval, changing direction only when the feedback stops. Although some users adjusted their direction while walking (by scanning during walking), they did not in general change direction until the feedback indicated this was necessary.

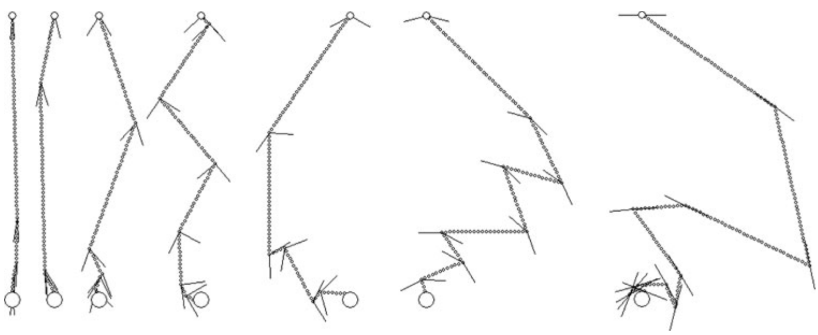
Figure 9 shows trails for 10°, 30°, 60°, 90°, 120°, 150°, and 180° (these were the angles used in [9]). Although the goal was surrounded by a circle, the feedback was generated from the central point in the circle (corresponding to a GPS point in real life). Thus, also the smallest angles led to corrections, even though these might not be needed to actually take the user into the goal area. This way it may actually be advantageous for larger goal areas to have a slightly wider angle interval since the possibility of being able to get to the target without having to make corrections can be larger.

The simulation was run 100 times in each condition. The proportions were selected to correspond to a distance between start and goal of 35 m with a step size of 0.5 m. To see the effect of the size of the goal circle, we looked at goal radii of 1 and 10 m. The result of the simulations can be seen in Fig. 10.

The average number of steps it took to reach the goal can be seen in Fig. 11, and the average number of turns is found in Fig. 12.

As was expected, the increase in goal circle size is comparatively more beneficial for the wider angles. We

Fig. 9 A selection of random tracks for the angles 10°, 30°, 60°, 90°, 120°, 150°, and 180° (*left* to *right*)



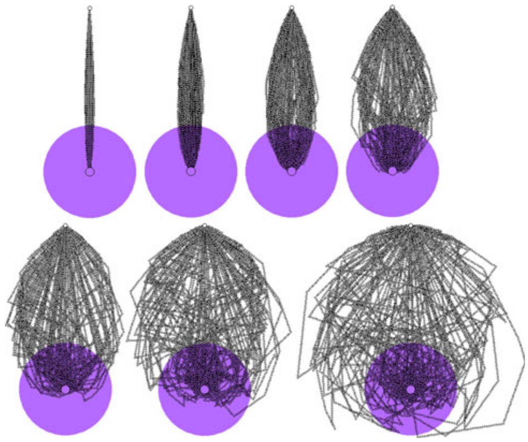


Fig. 10 Simulation results for the angles 10°, 30°, 60°, and 90° in the *top row* and 120°, 150°, and 180° in the *bottom row* (increasing angles to the *right*). The large transparent area indicates the goal area in the 10 m radius condition

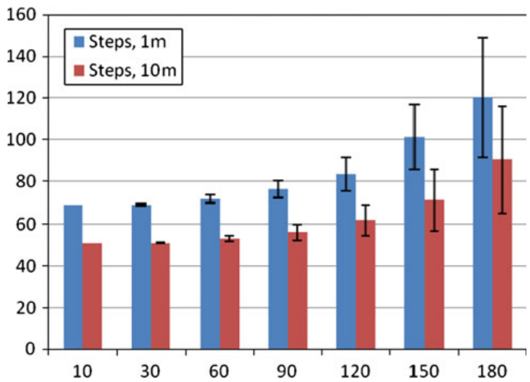


Fig. 11 The number of steps for different angles in the 1 and 10 m conditions (*error bars* indicate the SD)

also see that there is little difference between the angles 10°, 30°, and 60°. A small increase is seen for 90° and 120°, while 150° and 180° appear less suitable to use.

For the worst-case scenario, it is clear that if the angle interval is 180° and above, the user will never reach the goal. At 180°, the user will walk in a circle around the target and larger angles will produce an outwards spiral. Smaller angles will result in an inwards spiral ending at the target as is shown in Fig. 13.

In the simulation, we have used a finite step size, assuming that users do not adjust their direction "in stride" but only after a step. With this assumption, the step size influences the trails—since we look at a worst-case scenario, the signal will be lost immediately and thus the simulated user actually takes the step outside the feedback

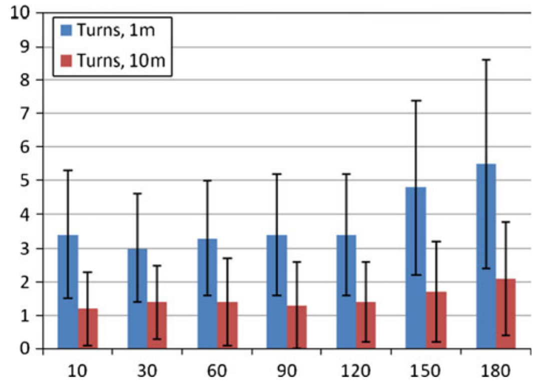


Fig. 12 The number of turns for different angles in the 1 and 10 m conditions (*error bars* indicate the SD)

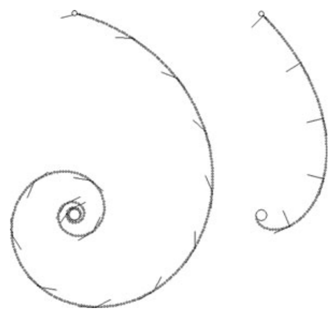


Fig. 13 Worst-case trails for 150° and 90°. The angle interval is indicated at regular intervals

angle. In the 180° case, this results in a trail that is not a perfect circle, but rather a trail spiraling slowly outwards. For the 150° case in the picture, the effect is that instead of spiraling into the exact center, the trail will end in a small circle. Thus, for a wider angle, a large step size and a small goal area can result in a trail that circles the goal without ever reaching it.

The increase in the number of steps in the worst-case scenario for a 1 and 10 m goal circle is shown in Fig. 14. Even though the underlying strategy is quite different, we see the same type of results for the more narrow angles: 10°, 30°, and 60° produce similar results. The problem with the wider angles is more pronounced than before, although it can to some extent be mitigated by using a wider goal circle. It should be noted that the above described results apply to any navigation where the user keeps a fixed angle deviation with respect to the direction pointing straight at the target.

In the real world, there are several problems that can change this picture. As is discussed in [21], there are both heading and position inaccuracies. The compass does not

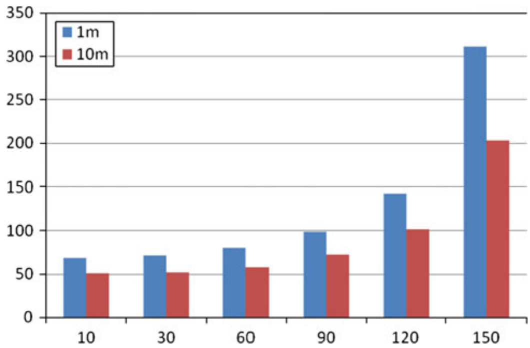


Fig. 14 Number of steps to reach the goal with a fixed angle deviation in the 1 and 10 m conditions

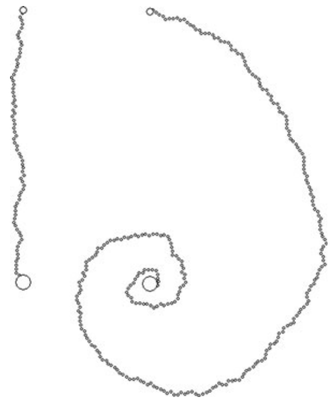


Fig. 15 Trails with 40° angle deviation. One trail using the random interval approach with a 10° angle interval (*left*) and one worst-case trail for 150° (*right*)

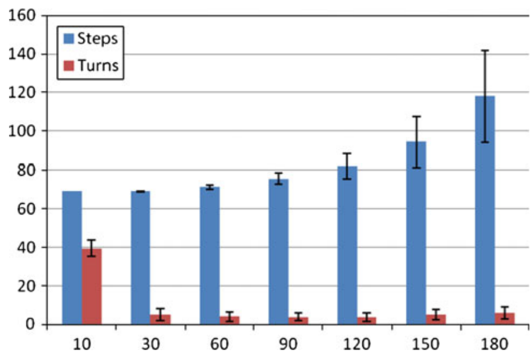


Fig. 16 The number of steps and turns for different angle intervals given a 10° angle deviation and a goal radius of 1 m

produce an exact heading—it fluctuates and if the device is swept sideways there are also delays. For this type of application, a constant GPS deviation obviously creates a problem since it will lead the user to the wrong position in the real world. For the results of the test in [9], however, it does not have any influence since success was measured with respect to the measured GPS position, not the real-world position. There is, however, a GPS signal problem that may have an impact and that is the fact that the GPS position sometimes fluctuates (at our location as much as 10–20 m has been observed).

To investigate the effect of angle deviations and position fluctuations, these were added to the simulation. For the angle deviation, we added a random deviation to the actual direction. This was done at each step in the iteration. Since the GPS jumps we had observed appeared to be less frequent, and furthermore had manifested more as discrete jumps between two positions, they were implemented as a 50% possibility to jump to another position every *N*th step in the simulation. We implemented this as a jump in the goal position—in real life, it is of course the goal that stays fixed and the user position indicated by the GPS device that changes, but the relative effect is the same.

As expected, the angle fluctuations had most effect on the narrow angle intervals. The simulated trails do not look that different (see Fig. 15 where angle deviation of ±40° was used to make the visible effect appear more clearly), but the number of turns increases for the smallest angles. How severe this effect is depends on the amount of angle fluctuations present—we report numerical results from a simulation with a 10° maximum deviation to each side (larger deviations will have a greater effect on the narrow angles, but will also push the effect upwards in the angle range). As before, we ran 100 trials in the simulation.

Figure 16 reports the results of the simulation for a small goal radius (corresponding to 1 m). Although the number of steps are not much affected, the number of turns (which are the points where the user looses the signal and has to re-orient) increases drastically for the 10° angle interval. For the 10 m radius condition, the average number of steps for the 10° angle interval goes down to 51 and the average number of turns to 29 (the overall trend for the other angles is given by Figs. 11, 12).

The overall trend in Figs. 11, 14, and 16 agrees with the results for time to complete in the outdoor test (Fig. 3). We see longer times for the narrowest angle, then several angles with lower completion times followed by an increase in the widest angles.

When we compare the number of times the user loses the signal in Fig. 6 with the simulation results, we have to take into account the fact that the SHAKE updates about 5 times every second. In addition, there is the scanning behavior. If a user scans the interval, he or she will lose the signal also in this process, and not only as a consequence of walking too far in a particular direction. Another factor influencing this number is if the user uses a strategy closer to the worst-case simulation alternative—for this strategy the signal is lost quite frequently. And of course—the simulation included only one goal point. The outdoor test involved three. The overall picture still agrees with what can be inferred from Figs. 12, 14, and 16: larger values for the smallest angles, then several angles with a lower number of turns (loss of signal) followed by an increase in the largest angles.

To round off this section, we end by looking at the effect of the GPS jumps. In Fig. 17, we see trails from the angle intervals 10° and 180° for a goal radius of 1 m. To see the effect clearly, we turned off the angle disturbance. We exaggerated the effect by using a jump distance of 20 m and allowed for a potential jump at every 4th step (if there was a jump or not was determined by the random number generator).

Figures 18 and 19 show the result of the above-described disturbance in a simulation including 100 trials. The trial was run for 1 and 10 m goal radius. The 1 m result shown in Fig. 18 implies that for a small goal radius, a disturbance where the GPS location jumps really influences navigation times.

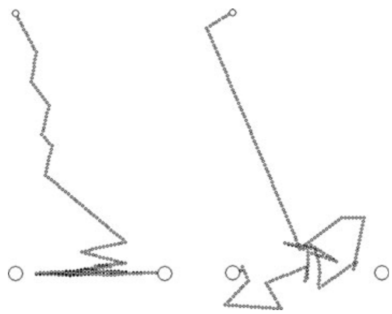


Fig. 17 Trails showing GPS jump effect. 10° to the *left* and 180° to the *right*

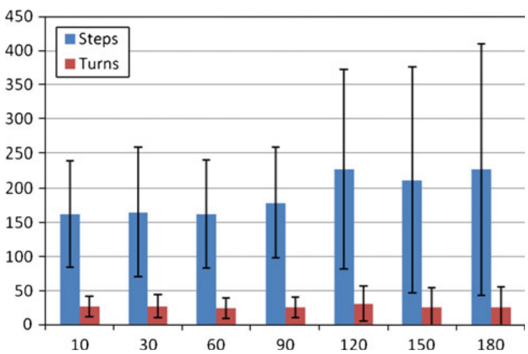


Fig. 18 Number of steps and turns for a goal radius of 1 m (given the described GPS jump effect)

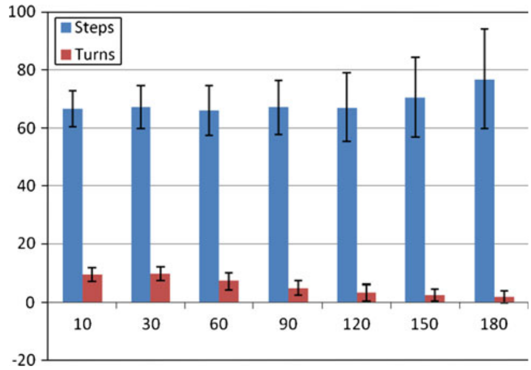


Fig. 19 Same as Fig. 18 but with a goal radius of 10 m

Figure 19 on the other hand (10 m goal radius) is much closer to the undisturbed condition shown in Fig. 11. The fluctuation in goal position will lead to somewhat larger average step numbers particularly for the smaller angles (similar to the disturbance caused by an angle deviation). For the larger angles, it appears that the effect is actually somewhat advantageous—if the simulated user is near to the goal and the goal jumps, there is a probability the goal will jump so that the current position is inside the new goal area. Since Fig. 10 shows more trails surrounding the goal for 150° and 180°, and our simulation was run for a sideways shift of the goal position, we expect this effect to have more impact on the widest angles.

Thus, given the kind of disturbance where the GPS position jumps, small goal circles can be problematic, and the result from this simulation indicates that larger goal circles should be used. This is in agreement with the results from the outdoor test.

9 Discussion

In Figs. 4 and 5, we see both the kind of turns appearing in the random simulation and curved path indicating a more continuous update of the direction (cf the worst-case simulation). This is in agreement with the observation in the outdoor test that some users kept scanning as they were walking, while others tended to walk as soon as they got a steady signal (see also [9]).

Both the computer simulations and the outdoor tests indicate that navigation performance should be fairly insensitive to the angle interval used. For small angles, an increased sensitivity to fluctuations in the magnetic compass influences the results, while at the other end of the spectrum, it is the fact that a very wide angle interval will cause many deviations and on the average leads the user to walk much longer than necessary that is problematic.

Assuming each turn (loss of signal) causes a delay corresponding to at least one step, we see that on the overall level the results of the random simulation agrees quite well with the picture we get from the outdoor tests. Although the simulation does not capture all the details of the interaction such as the user scanning for a signal, or possible specific strategies used when the angle interval is very narrow or very large, it is clear that it does provide support in the process of interpreting the data generated by the outdoor tests. Furthermore, if we add the worst-case simulation, it adds considerable strength to the conclusion that angles up to 90° (and possibly even 120°) can be used in this type of interaction.

Thus, we feel we have now an even stronger position for the conclusion made in [9]:

- If it is important to get exact track following one should go for more narrow angles. This depends to some extent on the equipment at hand but we would recommend 30°–60°.
- If you want a design that puts small cognitive load on the user, it is better to use wider angles. We recommend 60°–90° (or even 120°) for this purpose.
- In general, people walk slower if the angle is too narrow. If you are targeting applications where the user wants to walk quickly or may be even run (e.g., jogging applications), wider angles are preferable.

The 60° used in [7, 8] agrees with these findings. The fact that the 10° angle is difficult is very much depending on angle deviations in the signal. Given a discrete sampling rate, it is actually easy to miss the goal completely (the risk of missing the target if it is narrow is pointed out in [13]). Although faster and more precise equipment may make smaller angles easier to deal with, the simulations still show that the narrow interval also forces more exact navigation along the way. Thus, we expect using a narrow angle would lead to more cognitively demanding navigation even if the angle deviations are smaller.

We also looked at the effect of the goal radius. Since the direction in the interaction does not depend on the goal radius, but only on the position of the center point, the radius does not really influence the navigation between the points. What it does influence is how much “fine tuning” is needed before a point is reached. And, in the case of GPS jumps, too small circles become a problem since the GPS location may shift before the user actually reaches the point. Given the GPS quality observed at our location, we would recommend a circle radius of at least 10 m.

It is interesting to note that as long as the track is not tied to objects in the real world, there is no way for the users to know how well they follow the underlying track. What they will notice is if they lose the signal a lot, if they have to walk back and forth several times or even walk in circles to actually locate a position. Thus, they will prefer wider (but not too wide) angles and also wider goal circles. When leading users along roads or to real world objects, the GPS accuracy will influence performance. In a city type environment with narrow roads, reflections may cause deviations that make you appear to be inside a house (or even on the other side of it). Thus, also from this perspective, care needs to be taken not to make these circles too small.

Distance information or at least some extra notification when there is a change of direction in the track was not provided in the current design. This type of feedback was indeed provided in the SoundCrumbs [5] application where the user would hear a sound at each crumb location. Since the purpose of the present study was to see how well users were able to follow changes in the track without knowing where the turning points were, track point location feedback was removed for all points except the goal. Near to the goal, you would get vibratory feedback (slow vibrations when 20 m away and fast vibration on target). One may consider adding more elaborate distance cues, but care needs to be taken in order not to interfere with the navigation. As is commented on by Williamson et al. [7], in many cases, a simple interaction is enough.

The audio used in the outdoor tests (a sound of waves against a shore) was well liked. One further advantage of using a continuous sound was the “hiccupping” that happened near the borders of the angle interval which provided extra information. In a sense, the continuous nature of the sound source made it easier to discern changes in signal. This agrees with the observation in [22] that changes in data are better mapped using continuous feedback—in this case audio. In the case of Geiger counter type designs (such as was used in [10]), you will miss this information. In cases where you want to mask irregularities in the signal this could be used to your advantage, but in the present case, the border information is quite valuable. If you use discontinuous feedback, we would recommend the feedback is explicitly designed to provide similar information.

In this study, we used only sound on or off as feedback since adding different sectors in the angle interval would introduce more factors that might influence the results and we wanted to focus on the basic influence the width of the interval. This does not mean that it is not a good idea to vary the feedback to give the user the advantage of having both a more precise direction combined with the advantages a wider angle provides. One example of such a design can be found in [5] where a central interval of 30° with 100% volume was followed by an interval out to 90° where the volume was 40%. Outside this the sound played at 20% level all the way up to 180°. Another example is PointNav [12] where a central “straight ahead” sector was complemented by wide “keep left”/“keep right” sectors.

10 Conclusion

The present work was performed in order to get a better understanding of the influence of angle size and track circle radius on navigation performance. We have made use of a combination of computer simulations and outdoor tests in order to be able to understand the influence of different effects.

In the user tests, we observed three main scan gestures: the whole-body scan, arm pointing, and hand pointing. Users tended to keep walking as long as they had a signal and stop to scan for direction if they lost it. Some users scanned also while walking. For narrow angles, this was done in order to keep the signal, while if it was performed for wide angles, the scanning would be to check that the user was still heading roughly toward the middle of the angle interval. We have seen two basic types of strategies for dealing with the interaction: we have the analytic strategy where one checks the size of the interval and then tries to head for the center, and we have the direct strategy where you scan until you get a signal and then head in that direction.

Both user tests and simulation results indicate that the range of angle intervals that can be expected to work is quite wide—although very narrow (e.g., 10°) and very large intervals (e.g., 180°) are likely to create problems. Among the angle intervals that appear to be working reasonably well, we still find some differences. Narrow intervals provide more exact track following but may be slower and require more attention/concentration from the user. Wide angle intervals result in less exact track following, but allow users to walk faster and be more relaxed. Thus, there is no single preferred angle interval—instead this depends on the task. If exact track following is important, we would recommend an interval of 30°–60°; while we recommend an interval of 60°–90° (or even 120°) if lower cognitive load is important. The 60° used in [7] agrees with these findings. The task dependence of our recommendations indicates that angle interval is a variable which should be possible to customize, and the usefulness of wider angles supports the approach in [8] where wider angle intervals were used when there were many possible ways of reaching the goal.

Looking at the radius of the circle surrounding the track points, we note that these should not be too small. Given the GPS quality observed at our locations, we recommend a radius of at least 10 m. This is a recommendation which depends on GPS signal quality, but looking at the worst-case simulations, it is also clear that it helps the user deal with wider angle intervals, implying that very small circles should be avoided unless they are deemed really necessary.

Acknowledgments We thank the EC which co-funds the IP HaptiMap (FP7-ICT-224675). We also thank VINNOVA for additional support.

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D A real-world study of an audio-tactile tourist guide

Paper D

A real-world study of an audio-tactile tourist guide

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Abstract

This paper reports on the in-context evaluation of an audio-tactile interactive tourist guide – one test was done in a medieval city center, and the other was done at an archaeological site. The activity theory framework was used as a perspective to guide design, field-study and analysis. The evaluation shows that the guide allows users to experience an augmented reality, while keeping the environment in focus (in contrast with the common key-hole like experience that on-screen augmented reality generates). The evaluation also confirms the usefulness of extending the vibrational feedback to convey also distance information as well as directional information.

Keywords

Navigation, multimodal, augmented reality, non-visual, inclusive

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1. INTRODUCTION

The small screen on mobile devices poses a well known problem. By making better use of additional (non-visual) modalities, it is possible to create applications where the user can keep attention on the environment also "on the go". More modalities also help users who have problems accessing information through a specific channel – a design relying only on visual on screen information will not be possible to use for persons with vision problems. In the present paper we describe an inclusive tourist application (The Lund Time Machine) which allows users to be guided along a historical trail and experience sounds from the past. We report the results from a qualitative outdoor study.

2. STATE OF THE ART / PREVIOUS WORK

Current navigation systems in mobile phones are based on screen interaction. The user is usually expected to look at the map to find out where to go (e.g. Google Maps). The interest in non-visual modalities to guide the navigation is increasing in the research community, explained in part by the need to reduce the load on visual attention in mobile situations [20]. Several systems have been devised using sound as guidance. An early attempt was the Audio GPS[7]. The Swan project [30] gives auditory feedback about routes and context aimed for visually impaired persons. The ONTRACK [9] system uses 3D audio and music to guide the user, while the Soundcrumbs

[12] uses chosen audio tracks of varying volume according to the user's phone bearing. Audio Bubbles [16] gives auditory feedback about near-by landmarks. Others have explored vibrations to convey the information. Sweep-Shake [23] uses vibration feedback also to let users get information on close-by points of interest. It was then evolved to support users' navigation in "I did it my way" [24]. The Tactile Wayfinder [21] explores the use of a vibrating belt to give directional information. PointNav [11] gives both orientation and navigation support through vibrations and speech feedback. For more exploratory navigation, different kinds of soundscapes have been created, by communities or artists. The Urban Sound Garden [28] and the Tactical Sound Garden [27] are two examples.

When designing for mobile usage, the context in which the application or device is used will impact drastically on the user experience. To cover this explicitly, the concept of "situation induced disabilities" has been introduced [25, 26]. When an augmented reality application is intended to be used "on the go" it is clear that one situation induced disability is the difficulty looking at and attending to the screen (since you have to attend to/look at your environment in order to avoid obstacles, people etc). Not attending to your environment may even be dangerous [29]. Despite this, the bulk of mobile augmented reality applications developed rely primarily on screen-based presentations. That this is not unproblematic is exemplified by [2] where the authors report "Paradoxically the game encourages looking at the screen more than the surroundings". Even "Backseat playground" [1] which makes use of audio for most of its interaction use on-screen visual elements for feedback, and the authors report that this drew the eyes of its users towards the screen rather than to the surrounding environment. Another problem often occurring in visual augmented reality is the difficulty of having a smooth juxtaposition of virtual elements on the real world image. GPS, compass and other sensor inaccuracies causes the virtual parts of the image to move around in an unconvincing way [2, 29].

Concerning mobile observation, there has been a number of evaluations done in the wild or in the field, outside of the controlled laboratory, in mobile contexts of use. Diverse methods have been described for example in [13]. Their pros and cons are worth taking into account when choosing a method of evaluation. Direct observation by following the participants is a way to see what really happens, and let the observer get a full sense of the meaningful events during the test. However, the observer's presence can disturb the users and a human observer can miss quite a lot of what is really happening. Logging and recording, to recreate the experience later on can be used as in [8]. Those methods give a perfect but partial rendering of the experience, and they still require a long time to be analyzed afterwards, and much equipment and organization during the evaluation. Those methods, complemented by traditional interviewing, would give a quite complete picture of the experience. Usually, a trade-off between available equipment, participants and time need to be done in order to get a good understanding while keeping the evaluation manageable. It has been shown that It's worth the hassle [18].

3. DESCRIPTION OF THE LUND TIME MACHINE

The "Lund Time Machine" (LTM) is a tourist guide application developed for Android 2.2. It uses GPS positioning and compass orientation to guide a tourist along a trail by tactile guiding (vibrations), and displays relevant information at the points of interest. The information given is of the kind a human tourist guide could tell about specific points of interest in a city. During navigation, one tab with a map of all points (Figure 1, left picture) and another with the list of points was displayed. The current distance to the points was also displayed for each point in the list. When arriving within 15 meters of a point of interest, an information screen was displayed and a sound file with recorded speech was played automatically. A picture of the place was also displayed on the screen (Figure 1, right). Along the trail, ambient sound sources were played back at specified locations. At some of the points of interest, users could choose to answer a multiple choice question. The questions were related to the place and the results were given at the end of the trail.

Figure 1: Screen shots from the tourist guide

By using the mobile phone as a scanner (pointing with it in different directions), the participant will get feedback in which direction to walk. When the phone is pointing in the direction of the next point of interest, within an angle of 60 degrees as recommended in [14], the phone vibrates with 3 short bursts. As the user gets closer to the target, the pulse trains of 3 bursts are repeated more often. The pattern of 3 bursts is always played until its end, to avoid getting borderline effects when exiting the 60 degree target angle. The pattern starts anew when the user goes outside the target angle and then re-enters it again. The calculations of the frequency of bursts is based on the actual distance to target, but also on a distance zone, so that the frequency increase in part becomes "stepwise" (see Figure 2). The vibration pattern design was iteratively and systematically evaluated before the contextual evaluation reported here.

An alternative guiding behavior can be chosen by the user: the tourist guide incorporates an audio Geiger, that plays sounds with different timbre and volume, as is described in [15]. To let the users benefit fully of the ambient sound, only the vibration Geiger was used during the reported evaluation.

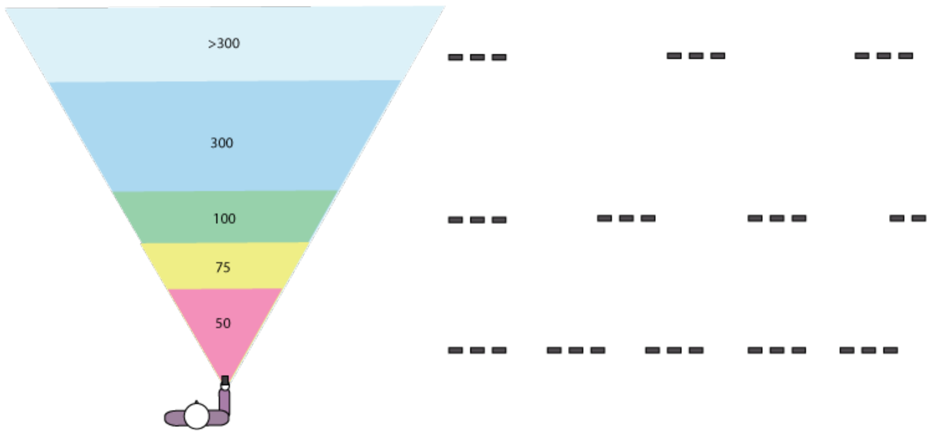

Figure 2: Haptic patterns and distance zones

3.1. Sound windows from the past

In this application, the main purpose of the location based sounds was to communicate context. The sounds that could be heard were like "open windows from the past" being sound clips with sounds that could have been heard at this location in the past. On the medieval market place, the user would hear animal sounds; when passing by a house, where in medieval times there was a pub, pub noise and music could be heard. In the streets, different horse and carriage sounds would be heard. The sounds were played back in mono, but were location based, which meant that they would increase in volume when nearing the sound window. Playback in mono was deliberately chosen, to allow users to use only one earphone, and to possibly lessen sound artifacts from GPS instability. The volume increased from 0% at a radius of 10 meters from the GPS location in the archeological site and 30 meters in the city to 100% at a radius of 6 meters.

4. METHODOLOGY OF THE STUDY

The evaluation was carried out in multiple steps. As a first proof-of-concept, informal tests were conducted in the area near the lab in the late stages of development where at least 5 different persons were involved in the tests. Then, three pilot tests were conducted in the city center of Lund. The final evaluation took place in the city centre in Lund, where the participants walked one of two trails or on an archaeological excavation site from Viking times – Uppåkra, which lies just south of Lund. In the first location, the participants were 6 elderly persons (68 to 74 years), and 2 visual impairment experts, one of whom had a visual impairment. On the second location 5 elderly persons (67 to 78 years) and a school class of 24 10-year-old children were involved. For each test, the participants were given an introduction to the demonstrator. The participants were instructed how to use the demonstrator, by scanning, following the vibrations and answering questions (see description of demonstrator above). The users had a phone each (in all cases but the test with the school children, where they were walking in pairs), and earphones to hear the sound clearly.

4.1. Activity theory in evaluation procedure

To guide the observations and strengthen the rigor of the analysis, we decided to make use of the activity theory framework. Activity theory as described in [10] considers the human action in the context of his or her interactions with the surrounding world and the other humans. When acting towards a goal, the person is mediating his or her action with artifacts or elements of the world, as well as with other humans.

Usually when evaluating interaction, the focus is on the device and how the user interacts with the device. Since what users do in a concrete activity is not limited to the interaction with the device, we tried to take the interactions with the surrounding world and the human context into account. The evaluation had as one of its aim to apply activity theory into the iterative design and evaluation of our navigation application. To achieve this, The Activity Diamond [5] was used as a conceptual model when designing the research activities and later on as an analytical construct guiding the analysis of the results.

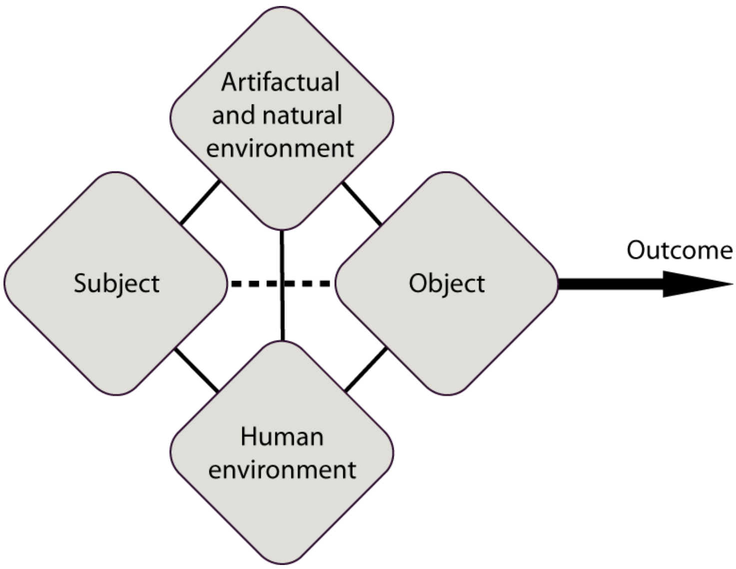

Figure 3: The Activity Diamond : The participant's activity mediated by human and artifactual environments

The Activity Diamond is a conceptual model that portrays a human activity system [3], where the subject-object relation is mediated and thus influenced by the artifactual, natural, and human environments. The model is based on four interrelated sets of factors and is situated in time and place. Conceptually, the Activity Diamond captures an activity system that is changing and developing over time. This means that it can cover both historical development and instantaneous snapshots of an activity system.

The four sets of factors are:

(1) The subject in the model, which is often an acting individual, but can also be a group of people such as a family. In our case, the subject was a test participant.

(2) The object of an activity, which is related to the will and needs of the subject. It is determined by the motive behind the activity [10], such as getting better grades, learning to read, or developing and producing a multimodal tourist guide. In our study, the motive was slightly artificial for the participants, and differed between several of them. The envisioned activity was to follow a guided tour with the device. As a real guided tour, the users would follow a trail and get information on points of interest along the way.

It is possible to distinguish a hierarchical structure in human activity: "Activities are composed of actions, which are, in turn, composed of operations. These three levels correspond, respectively, to the motive, goals, and conditions." (figure 3.4 p.64 in [10]) We did not enforce a motive, but the participants were all given the same goal - to follow the trail and get information at the points of interests. This sequence of actions was assumed to be the same for real tourists in Lund, whatever their motives might be. The hypothesis was that with several people having a common goal, it was possible to evaluate how the device can be adapted to better mediate the interaction with the environment, in a way that was adaptable to different motives.

(3) The artifactual and natural environment, which consists of material and immaterial artifacts and nature. Artifacts are everything human-made, such as computers, languages, symbols, legislation, along with their respective affordances [19], and resistances (i.e., the ways in which the artifact may enhance or impede functioning). An example of a factor in the natural environment is sunshine, which sometimes can make it hard to see what is on the screen of a computer or phone. A busy street environment that people have to attend to, as well as points of interest, are also part of the artifactual and natural environment. The impact of the artifactual and natural environment is described in more detail in the result section.

(4) The human environment, which is the people or groups of people influencing the activity at hand: family, personal assistants, work colleagues; larger sectors of the population that are involved in or otherwise affect attitudes, norms, and expectations associated with an activity. Here, the human environment consisted of the other participants, the observer and the other people wandering in the city. Considering the whole activity required to observe not only the interaction with the device, as is often the focus in such an evaluation, but also what happened around it in the real world. We thus chose to conduct the evaluation in a real environment with a diversity of users, so that the actions of the users were as similar as possible to the targeted tourist experience.

4.2. Town and field, real-life context

The evaluation took place in context. The Lund city environment is a small scale city, with a medieval city center. The tests were carried out during the day in a normal busy city environment. Cars and people were passing by, forcing the participants to pay attention to their surroundings. In the second site, Uppåkra, there was on the contrary no distraction, except the other participants. There were no remains in the field, and the participants could only discover the points of interest through the device that was handed to them. The content of the tourist guide in both cases – historical city and archaeological finds – had been collected and narrated by archaeologists.

The content consisted of 2 different city trails based on sculptures as points of interest, and the historical information about people or places connected to this sculpture. By choosing less prominent sights, also test participants living in Lund could discover something new. In the archaeology field, only one trail was created, with a collection of finds.

Figure 4: Testing at the archaeological site in Uppåkra

4.3. Observation and recording

During the test, one observer followed the participants, part as a technical support, while also ensuring the safety of the participants, in case the device use would have made them unaware of the surroundings. The main task was to observe the participants and what happened during the interaction, as well as to do the video-recording. During the trail following, various recording occurred. In the city evaluation, the participants were walking either alone or in pairs. The participants were video filmed from a distance and the conversation between participants was recorded. The participants were asked to walk in pairs in order to get natural "think aloud" from their conversation. In the field evaluation (Uppåkra), the participants did not get audio-recorded, because the group was too large. Usually three to six participants would walk in the field at the same time, making it difficult to follow each one individually. In those cases, the interviews were most helpful to gain insights into the participants' experience. The main observations gathered from inperson observation as well as video and audio recording are described in the results.

4.4. Interviews

The interviews were conducted after the evaluation in Swedish. The quotes reproduced here are translated by the authors. The interviews always started with a NASA RTLX subjective workload rating (without pairwise comparisons) [4, 17]. As the navigation method (scanning with the mobile phone) was new to participants, it was used as a measure to assess whether users experienced a high amount of cognitive load or annoyance using it. A questionnaire, designed to determine the visual, hearing and mobility abilities of the participants, as well as their previous experience with smartphones and GPS devices was also issued. If time allowed, a Santa Barbara Sense of Direction Scale (SBSOD) [6] was answered by participants, in order to get a more precise rating of their sense of direction. The main interview consisted in structured and semi-structured questions to elicit participants view on the tourist guide application. The different user groups were asked the same set of basic questions, but the elderly user group had a more detailed interview, as the children were expected to tire faster. The common questions were:

- What are your general/spontaneous comments to the tourist guide?
- What (parts) were easy to use?
- What (parts) were hard to use?
- What was the one most difficult part to use?
- Is there anything you would like to add? What?
- Is there something you would want to remove? What?
- Did you experience any problems and how did you solve them?

The additional questions for the elderly participants consisted of qualitative questions, also asking them e.g. about how much they focused on the surroundings compared to how much they focused on the tourist guide application.

Due to slight differences in the set-up and the number of questions, the three different user groups (8 in the city, 5 elderly in the archaeology field and 24 children in the archaeology field), have been treated separately in the analysis. Additionally, the recordings from the semi-structured interviews were partially transcribed and used alongside the notes from the interviewer to extract the most important subjective results. The observations from the observer together with the video recordings were used to obtain a better understanding of what happened during the trail. When the technical recordings allowed, the video from behind and the sound from the participant's speech were merged. In that way, the observer could reconstruct the dialogues of the participants while seeing what happened. The reconstructed video was then analyzed using Lignes de Temps [22] to mark important events in the timeline. Those observations were correlated to the interview results.

5. RESULTS

In this section we will present the results of our evaluation. First we present the information on the test participants gotten through a detailed questionnaire, reflecting their diversity. Then a section on the global results given by the inspiration of Activity Theory that framed our analysis follows. After this, the detailed results are given in several sections.

5.1. A diversity of users

The participants were asked to give some details about their visual, hearing and sensory-motor abilities, as well as their previous mobile phone and GPS usage. The scales were from 1 for normal ability to 4 or 5 for no ability (e.g. complete blindness) As the guide was aimed at a diversified population, the age span was deliberately chosen. The declared visual ability of elderly people is to be contrasted with the declarations of school-children. The sight decreases normally with age, and some problems that seem to be normal when being older might not be seen as vision problems, and thus still rated under "full vision" by the older participants. When asked about a rating of their vision, while answering the best item "complete vision" one participant stated: "It is quite good, for my age."

Group	1 – Adults	2 – Schoolchildren
Gender	4 male - 40% – 6 female - 60%	9 male - 37.5% – 15 female - 62.5%
Average age	66.8	9.5
Age span	43 to 78	9 to 11
Highest completed education (average & spread)	From high school to 4 years university education. Most had a specialized education for their diverse professions.	All in the same school class. Primary education – 10 years-old.
Visual ability (1 to 5 scale)	Mean 1.4 ; no color blind	Mean 1.04 ; one color blind
Hearing ability (1 to 5 scale)	Mean 1.6 ; 60% with musical exp.	Mean 1 ; 52% with musical experience
Motor ability (1 to 4 scale)	Mean 1.2 ; 90% right-handed	Mean 1.13 ; 77% right-handed
Mobile phone experience	80% had one for more than 2 years. Half of those had used touch screens.	92% had a mobile phone. Only 2 declared using a touch screen.
GPS experience	60% never used a GPS. Otherwise, it was mainly used for unknown routes in cars.	71% never used a GPS. Among the other, it was mainly used by their parents in cars.

Table 1: Demographic information of test participants

5.2. Participants sense of direction

In addition to the basic questionnaire, six out of the ten adult participants filled in the Santa Barbara sense-of-direction scale, and all of them were asked a single question about self-assessment of their sense-of-direction.

Overall, people did not use the lowest ratings for their sense-of-direction, but we find that the participants are quite well distributed between the highest rating (very good sense-of-direction) and the neutral rating (neither good nor bad). When comparing these data to the requests for specific help (for example routing) expressed in the interviews, no correlation between routing preference and good/bad sense-of-direction rating was found.

5.3. Activity Diamond framing results and analysis

The observer and the video from behind enabled us to have an understanding of what happens on a moment-to-moment basis. It was possible during the analysis to look at the videos and pick up moments when the participants made use of the surrounding artifacts (for example the street names) to mediate their actions toward the goal of following the trail. Activity theory was used during the analysis, in order to guide the interpretation of the data.

The audio-recorded conversation of the participants, in the case of the city evaluation, was especially helpful in understanding how participants used the human and artifactual environment to mediate their actions toward the goal, since they would discuss about what they were currently doing or trying to do. For example, a participant who couldn't read the questions and text on the screen repeatedly asked the accompanying participant to read to her what was on the screen. In another case, a participant was pointing to something, and the audio recording made possible to hear the participant say the street name she was pointing to, thus explaining what video alone could not have.

The trails and content of the tourist guide was devised to appeal to the participants, even if they were not regular tourists, so that their experience could reflect more one of a tourist in the activity of visiting than one of a test participant testing an application or discovering a new technology. In most of the cases, the interviews and observations showed that we succeeded.

"I found out things I had no idea about!"

Only two participants seem to have clearly had their main motive to test the application. In one case, this was reflected in their behavior by an increased scrutiny of the application. This was obvious in the interview when the participant had a tendency to answer not with their own experience, but with general statements. When asked about the importance of a component of the application, the participant said :

Participant : So it is... for whom? [. . .]

Interviewer : It is always for you.

P: It is always for me? Yes, for me. . . It is then not so important. But I can see, for people- that there is an advantage. It must not only be for me...

In another case, a participant, that had already discovered the content earlier, walked the trail without stopping at any point to listen to the information.

The users were also diverse in their previous experience with GPS and smartphones, and were recruited mostly following their age group (elderly people and school-children), so that their motives could match more those of a diversity of tourists. Unlike a guided tour with a guide, you could take as long as needed and do the circuit independently, but you could obviously not have a human interaction with its full flexibility with a human guide. On the contrary, one participant told us : "You get the info without effort - the guide tells you – like having a personal guide that you can ask to repeat [. . .] instead of rushing on to the next thing."

5.4. Interaction without occlusion – participants' focus

In visual augmented reality, the user needs to look at the screen to get the additional information. An audio and tactile modality lets the user interact more freely, since the device is not a barrier between you and the world. Through both the interview and the observation, we tried to get a sense of where the focus of participants was directed, so that we could confirm this hypothesis about nonvisual augmented reality. All users but one expressed to have focus on the environment:

"I had time to look in the shop windows" / "I looked at the ducks on the big square. And the alcoholics on the bench by the art museum. . . "

Although one user (who unfortunately also suffered from technical problems with the GPS) said:

"You focus quite a lot on the vibrations. If you walk with a map you look around more to identify buildings on the map – so you have to look around more than you did with the vibrations. . . .but at the same time you can think about other things – I remembered that I had forgotten my library card. . . ."

(a) Man hole cover (b) Participants walking

Figure 5: User focusing on an element of the real environment

From the observer point of view, it was possible to see where the participants directed their gaze. In Uppåkra, where the environment was poor in content (a field of grass), the participants had naturally more focus on the device. In the city environment, they were alternating between the screen and the buildings and roads. At a POI most participants could look at the real building when one was present. When in pairs, the participants could also interact with each other while following the vibrations. In the Figure 5, the participant was walking and he stopped to focus on a man-hole cover decorated as a Swedish coin. This was not at all something mentioned in the application, and this focus was a spontaneous observation made by the participant. Some participants would rely more on the environment than on the guiding vibrations. One participant even walked along the street in a wrong direction for one or two minutes before changing and coming back after checking the vibrating angle with the device.

Figure 6: User holding the phone lightly and pointing

Some users focused more on the screen than expected. One user particularly used the written distance information to understand better if she was nearing the target or not. Despite the guiding voice, which read exactly the text on the screen, some users preferred to read themselves also. The interviews gave us a more global view on this matter. When asked directly, all except one of the participants in the city-environment evaluation answered that their focus was equally on the device and the surroundings or more on the surroundings (and other people) as opposed to focus on the device. One participant stated clearly : "The vibrations allowed you to look around."

5.5. Trail following through vibration

The participants could all follow the trail and complete the visit of all the points of interest. In the archeological site, the participants could only rely on the vibrations. In the city interviews, when asked about the easiest to use parts of the application, the vibrations were cited by all participants. Overall in the interviews, the participants rated the vibrations to be both very important and fun or easy to use.

"It was easy to find the direction"/ "The vibration guiding was practical – and pleasurable" / "The vibrations felt good. . . in Lund it feels natural to point like this." / "If you turn a paper map upside down you will walk in the wrong direction. A paper map doesn't vibrate. [to show you where to go]" / "Good if you are alone in an unknown city - more discreet than a big paper map."

Only one participant found the vibrations of less importance, but she felt the distance coding was appropriate. "It" burns" when you are near. (it is) good."

The in-context field evaluations of the LTM demonstrator took between 10 minutes and 45 minutes for the completion of the tourist trail. The time differences are explained in part by the fact that the tracks were different in length. Another factor for the difference in time is the length between two points, and the varying time spent listening to information and answering questions at the points of interest.

5.6. Sound windows

The reception of ambient sounds was also positive, although seen as less important than the vibrations :

“It was a little strange with all the animals.” / ”Cozy sounds – nice to listen to! I liked the horse sounds.” / “I liked that the sounds were so real – when I heard the cows I started looking around to see where they were. . . .”

Some felt the historical dimension of the sounds :

“You feel a bit as if you are moved to the middle ages” / “The sounds are important for the experience. You get a feeling of the history.”

Comments showed another rather important effect: the sound windows could also be used to enhance the awareness of the current reality:

“It was good there was horse [and carriages] sounds– they reminded me that there could be traffic”

5.7. Low Effort/Cognitive load

To assess the level of cognitive load and general effort required by this type of navigation, we asked the participants to rate their effort through a NASA-RTLX test, with a 7-point scale (from low = 1 to high = 7). All tests were given within 15 minutes of the actual walking with the phones.

The tests were given just after the evaluations in the centre city. On the field, it was not possible to fill them in between the two tested applications. The adults were asked to distinguish their answers to relate only to the Lund Time Machine evaluation, and thus given two NASA-TLX tests. The children were asked the questions for the two evaluations as a whole, rating the effort for the global experience.

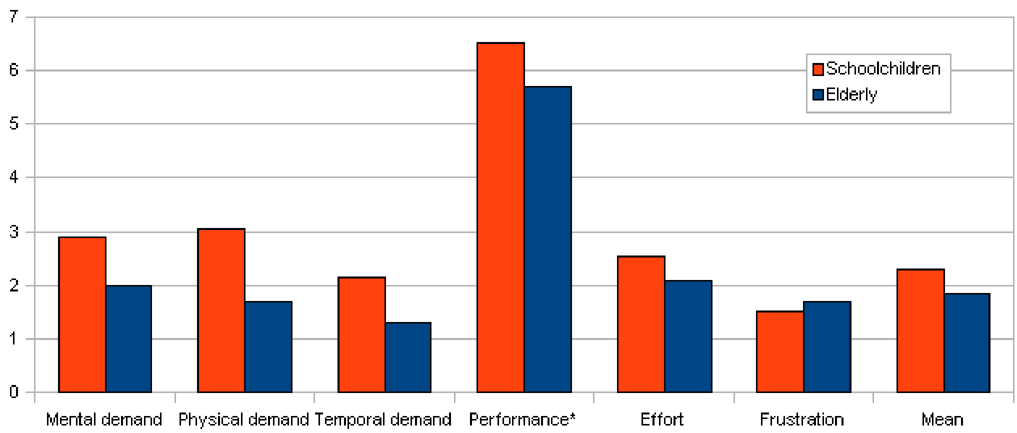

Figure 7: NASA-TLX aggregated answers

The performance question was reversed (indicated by * in figure 7), but the mean takes this into account. The mean adapted to a 100-scale is of 32.73 for the schoolchildren and of 26.37 for the adults. Globally, the values indicate a low demand related to the time dedicated to the demonstrator use. This low effort can be correlated with the possibility to focus on the environment, which both indicates that the Lund Time Machine enables to be guided with less effort and more freedom to explore the surroundings.

Some comments also confirm this: “I didn’t think it was hard at all.” / “This was just fun!”

5.8. Possible improvements

5.8.1. Directions and Routing

In the Lund Time Machine, the direction to follow is given without routing, as the crow flies, to the next point of interest. This means that in a constructed environment, the LTM vibrations might guide you toward a wall.

In the city environment evaluations, we have observed two different reactions toward the guiding behavior :

P1 : “You had to think one step further – aha – it may be on the other side of the house. You feel the impulses pointing you in a direction, but when you look there is a wall.”

P2 : “No, I had no problems with that – I am used to think around corners.”

Some people will naturally go around the buildings that are in the way, having no problems understanding the given directions. This kind of guiding allows the participants to walk different routes to reach the same points, encouraging free exploration of the city.

For some other participants, this lack of routing was seen as a difficulty. In several occasions, the participants would walk as close to the wall as possible, before turning to the observer and ask for what to do. Maybe the distance information might have helped here, since repeating that the target might be far away and that it was possible to go around buildings seemed enough to help the participants to continue walking in those cases. Obviously, this problem doesn’t appear in an empty field.

5.8.2. Soft keys and touch screen interaction problems

The reactions to the screen interaction were a little different for the two different age groups. The school-children rated the use of buttons and the information on screen as both important and satisfying, positioning them just behind the vibrations in terms of preference.

For the elderly, the screen interaction revealed several difficulties. The most frequent comment was that the text presented on screen was too small. Usually it was also read aloud, but the questions were only displayed on screen, and were identified as one non-accessible element.

We were using a Nexus One with Android 2.2.1. When confronted with a dry environment, pressing and clicking the buttons seemed to become harder: “The screen was not very responsive”. The problem was exacerbated with the group of elderly persons. The soft buttons below the screen were also problematic, because they were too close to buttons on screen, and were not giving feedback when pressed by mistake, which lead to unexpected changes of focus outside of the application. Getting back from this was not always easy: “The back button is not obvious, if you are not used to it.”

Most tests were conducted in a very sunny weather. Some participants had difficulties: “To read on the screen was hard – I had to go and stand in the shade” (Figure 8).

However, some users seemed to like to read on the screen, also while listening to the text. For example: ”The images were quite important when you were unfamiliar with the place”. The users used it: ”I looked at the screen to compare the images to the houses.”

Figure 8: Seeking shade to read screen

6. DISCUSSION

The main non-visual interface components (the vibration interaction and the sound windows) proved to be both usable and satisfactory to the majority of the users. Although the using a pointing gesture in combination with vibration feedback is not new [23], [24], [21], [11] the distance coding was novel – and the results of the test shows that not only direction but also distance is important.

For the elderly group, the use of the touch screen was the main problem, but they could still follow the guide and get access to the historical and cultural information within the guide. Taking into account the different preferences by users, this calls for a stricter adherence to the cross-modal ideal. One the one hand, we need to communicate that the product is usable without the screen, while making all parts of the application usable through gestures, audio and vibrations. On the other hand, we would also need to redesign to make use of the screen in the best possible way, allowing users to zoom and scroll text and pictures and to use good contrast. Varying the placement of application specific buttons to avoid accidental soft key activation may also be one way of improving the functionality.

Half of the participants in the city requested routing as an addition to the application. At the same time there are participants who prefer to explore and discover alternative routes - there are after all users who do not like to use a GPS because it is “no challenge” (as one person said in the interviews). We interpret this as a sign that both possibilities should be made available to the user. An intermediated position could also be to design the trails using so called “via-points” without historical information. Displaying the distance information in a more obvious way – maybe by speech - could also help.

Most of our users were able to keep their focus on the environment – in contrast with [2] our users are looking at ducks, houses, manhole covers, alcoholics etc. Although the screen is still useful, our results indicate that anyone interested in enhancing (and not occluding) the reality needs to carefully consider which modalities to use. One unexpected effect was the fact that the sound windows also could be used to alert users to current day dangers (such as traffic) – this is something which should be considered explicitly in future designs.

Another positive result from using sound windows is that these are less sensitive to signal jitter/disturbances. In contrast with [29], [2] we had no complains about jumping virtual elements.

When observing how the users relied on the outside environment to follow the trail, we noticed that some users were focusing on specific information like the street signs around them. One aim of this application was to be more accessible for visually-impaired people. Integrating the elements that are not visible to them in the world – like street signs, high buildings in the far as point of reference – could give them this missing information that has been useful for users in the present evaluation.

In this evaluation, an activity theoretical approach through the Activity Diamond was successfully used to coherently analyze the human, computer-mediated, interaction taking place in the participants' real-world human, artifactual and natural environments. Activity theory has been largely and fruitfully applied to the domain of Computer Supported Cooperative Work (CSCW) (p.85 in [10]), but to a lesser degree in other domains of Human-Computer Interaction. Our results show that it is a framework well suited for the design and analysis also of augmented reality applications.

Although we took steps to ensure that the participants' would have motives close to those of real tourists, the envisioned motive of visiting the town as a tourist was slightly artificial for our users. In a future study, we would aim at taking real tourists maybe from the tourist office, who already have this motive, and propose to them to test our application while doing as they had planned.

7. CONCLUSION

The interaction method using scanning and pointing to navigate proved useful to follow the trail while still enjoying the tour. We add to the previous work [23], [24], [21], [11] by providing a vibration coding that gives both direction and distance information.

The Lund Time Machine was successfully used to guide users in their navigation in both a town and field environment, enabling the users to enjoy an augmented city environment without too much distraction from the device (in contrast with [2]). Looking at our results we suggest that for interaction "on the go" the kind of non-visual designs we have tested are particularly useful and that on screen elements are more suited for interaction where the user is standing or sitting (as is indicated by users having to go to specific locations to be able to read on the screen at all). We hope our results will encourage a more wide spread use of non-visual interaction within the augmented reality community.

The results indicate that activity theory is a useful framework also outside of the cooperative domain – and suggest that it is particularly fruitful for the design and analysis of augmented reality applications, where there is a need to consider real-world human, artifactual and natural environments. Other elements of the interaction have been identified through the activity-based evaluation as sources of improvement. We see that both routing and "as the crow flies" has advantages – and suggest that future tourist applications allow users to choose. Other elements that support the interaction in the real world, like street names, could also be considered.

Our issues with the touch screen finally, shows that possible alternative modes of input should be made available. The application implements some limited gesture recognition (allowing users to shake the device to press the "next button"), but this should be extended in future versions of the application and is something that needs to be considered by anyone designing for a wider range of users.

8. ACKNOWLEDGMENTS

The authors are grateful the European Commission which co-funds the IP HaptiMap (FP7-ICT-224675). We also want to thank VINNOVA for additional support.

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The main purpose of this thesis is to show in a case study how it is possible to inform, with Activity Theory, the design and evaluation of a pedestrian navigation system that uses audio-tactile feedback.

The case study consists of an iterative design process that results in a tourist guide application used in a mobile phone. The interaction with the user is mostly through the audio and haptic modalities. The mobile phone is used as a scanning device and guides the user by means of vibrations. An auditory ambiance and recorded speech information also enriched the augmented reality experience. The tourist guide was evaluated in the real context of its use. This interaction proved to be an unobtrusive way to guide tourists to points of interest in the city.

During the evaluation, several tools from the framework of Activity Theory were used. The evaluation benefited from the following: the Activity Checklist, the Activity Diamond, the hierarchical structure of activity and the extended activity framework.

Activity Theory was chosen so that more than just the interaction between the user and the device/technology would be included in the evaluation. Other elements of the artifactual and natural environment were also taken into account, as well as the human environment, the object of the user's activity and the user's motive. Activity Theory provides a solid theoretical background when analyzing the subject's behavior toward the technology, offering a better understanding as to how it is possible to improve the mediating technology.

Other important factors for the design process have also been identified and are discussed as well.

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Certec is a research and educational division in the Department of Design Sciences at Lund University.

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LICENTIATE THESIS CERTEC, LTH
ISBN 978-91-7473-216-0
DECEMBER 2011
Delphine Szymczak
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