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Haptic, Audio and Visual Interfaces for Maps and Location Based Services

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4 Executive Summary

D2.2 is the second and last deliverable produced from work package 2 (WP2). WP2 is one of the largest in Haptimap, with most partners having some time allocated to it. In total it comprises of 15 person years of effort across its four subtasks. The major role of WP2 is to expand upon the findings of WP1 and develop and evaluate techniques where the problems identified can be improved. From this, feedback into WP1 and WP4 in the form of guidelines and specifications of potential HCI toolkit modules to allow others to use the results we have produced. The amount of work carried out in WP2 is too large to fully summarise here, but we will outline the key areas and how these relate to the requirements laid out in the DoW and objectives therein.

WP2 contains four subtasks, each responsible for a key area of the investigations. Subtask 2.1 is the largest subtask with most number of partners and is responsible for investigating the perceptualisation of geographical information and interaction design. When D2.1 had been delivered at General Milestone 3 (GM3), we stated in the DoW (p56) that “we will drop prototypes that are not effective, and concentrate efforts on the effective ones for the final year”. Rather than develop prototypes, we have been developing techniques that are embodied in multiple prototypes. This brings a key benefit in that it has allowed us to investigate differences in situation, device and context. However, we did drop some of the techniques we were developing at GM3 and continued with those that were more effective. The techniques that we dropped are discussed in D2.1 more fully, and our work since on the remaining techniques is discussed in Section 5.1. Primarily this has concerned providing an awareness of people, facilities and landmarks around the users current location. We have investigated these through both audio and tactile feedback as a means of communicating distance and direction to users. This is a key means of presenting information on the move, as it doesn’t require the user to interact with a screen. We have found that what is presented is also important and have developed and evaluated techniques for locating friends, cycling (D2.1), navigation and landmark finding. Our work since GM3 has more fully investigated the requirements of using audio and tactile navigation in this way so we can provide clear guidelines. As useful as such techniques are, unless a user can control them they are likely to prove of little use. Our second strand of subtask 2.1 investigates how map based data can be presented non-visually through both touch screen (virtual tactile) and force feedback and other haptic means. We have developed a range of different techniques to allow virtual haptic exploration or tangible user interfaces to allow planning and interrogation of the map based geographic environments. Our work on augmenting touch screen devices with haptic feedback however is relevant given the need for non-visual interaction and the increasing popularity of touch screen mobile devices that require vision for interaction. We have spent time investigating how this can be non-visually accomplished through the use of tactile feedback as the user moves his or her fingers over the touch screen. Our most recent joint work has shown how a standard map application can be modified with tactile interaction to allow a visually impaired user to interact with it (see Section 5.14). Many of the prototypes we have developed have reached a capability and maturity that they are being further developed as demonstrators in WP5.

Presenting information though, is not very useful if we don't know what information to present. The work of subtask 2.1 has shown that there is a more limited channel of communication available when using non-visual techniques so we must be able to determine what information is likely to be useful when navigating or directing the user with the techniques developed in subtask 2.1. The work of subtask 2.2 completes this role. It provides an ontology to determine what the best landmarks are in the creation of routing and navigation instructions. The use of this will allow designers to determine what the best landmarks are to successfully navigate a user and present that information through the techniques developed in Subtask 2.1.

Our work discussed in subtask 2.3 fulfils two roles. Firstly, in order to present useful information we must be able to determine the situation of the user. If the user is walking, the landmarks and other features that are relevant may be different to cycling or other scenarios. Subtask 2.3 has investigated several different sensor technologies and can provide algorithms and filtering techniques to allow us to determine with high accuracy the situation the user is in, we can then provide appropriate feedback, e.g. indicate a shortcut or park bench to a cyclist. In cases where users are being directed by our techniques or we otherwise know the destination of the user, we have been able to detect when the user makes a mistake and the behaviour that goes with this. In such cases we can provide stronger or clearer navigation instructions. E.g. moving from simple tactile cues to a spoken direction based on the ontology developed in subtask 2.2. This might be useful for a visually impaired user who has low familiarity with an area, and could be used to provide some "hand holding". Feedback can be provided when appropriate, but switched off as the user became more confident reducing the possibility of annoyance.

Finally, the techniques that we have developed in support of Subtask 2.1 have been using standard hardware, such as tactile belts (D2.1) or low fidelity motors in the mobile devices (see Section 5.11). Subtask 2.4 has been investigating ways to better support these techniques through new hardware innovations. As much of the techniques developed in Subtask 2.1 have involved lo-fidelity direction and awareness, hardware to support these has been developed. Initial work on lightweight graspable wristbands has been developed to provide small tactile bands with a high density of pins that can provide a directional tactile sensation (at least in the major cardinal points). This provides a much simpler and more usable device than the more common tactile belts (such as used in D2.1), and are devices that can be easily integrated into other wearable parts such as watches. Other work allows us to create mobile tactile refreshable displays that could be incorporated into mobile devices, allowing a tactile display for use by visually impaired users or in-pocket interaction such as illustrated by the techniques in PocketMenu (see Section 5.11).

The work contained both here and in D2.1 contribute significantly to the objectives O2 and O3 in the DoW. Building on the results of D1.1 in O1, we have developed a number of novel ways to deliver information multimodally (O2) and considered how the context of the user and activity that he or she is undertaking affects this (O3). In conclusion the subtasks and partners in WP2 have collaborated successfully to create a set of techniques that complement each other and allow the deep embedding of accessibility into mainstream applications to the benefit of both special needs users and mainstream users. These techniques cover both desktop and mobile applications, with some, being able to be used across both. We have extensively evaluated these techniques with different types of users and scenarios, so we can be confident on the validity of our findings. We have also extensively

published the work we have carried out. Appendix A shows the list of refereed papers that have been published based on the work of WP2. We have published at international conferences and other forums. This highlights the quality and significance of the work carried out.

In order to make the findings of our work as easy to apply as possible, we have largely structured the findings in this deliverable into a series of technical reports. Each contains a background and justification as well as guidelines for incorporation into Deliverable D1.4 and a proposed module that could be developed for inclusion into the Toolkit of WP4 as an HCI module. In addition, some of the prototypes that we have developed (notably Pocket Navigator (D2.1), and NiviNav (see Section 5.13) have been directly passed to WP5 (see D5.1) for re-implementation as demonstrator applications. In addition, work on Audio Bubbles (see Section 5.4) has been incorporated directly into the Virtual Excavator demonstrator application of WP5. We therefore expect the techniques developed and the results obtained in WP2 to continue to be relevant through the remainder of the project.

5 Task 2.1 – Perceptualization of Geographical Information and Interaction Design

5.1 Summary of Subtask 2.1

Of all of the Subtasks in WP2, Subtask 2.1 contains the most number of partners and as such, the most resource. As stated in the Document of Work, the purpose of subtask 2.1 is to develop prototypes and carry out investigations into perceptualisation and understanding geographical information as well as investigating appropriate interaction designs that can be used to interact with such information. In D2.1 we identified four broadly important areas: Multimodal augmented reality, marking and augmenting the environment, non-visual map access and bridging visual and non-visual representations. As stated in D2.1 we have begun to consider that multimodal augmented reality topic and marking and augmenting the environment have been merged so we can consider them as being similar. Our work since D2.1 has begun to consider more fundamental encodings of information in both tactile and non-speech audio modalities. In doing so we have discovered that almost any sort of information can be encoded in the cues, but effective distance and direction encoding is the most important. The forth topic, bridging visual and non-visual representations is important, but we have not further investigated it as a topic in itself. There is an important need to be able to relate visual maps to non-visual representations, but our prior work has shown that visual indication of direction on the map is a suitable way of achieving this. Therefore our focus in the work of D2.2 is compressed from the many rich approaches determined in D2.1 to multimodal augmented reality and non-visual map access. The reduction to two topics clarifys the objective at GM3 where we intended to concentrate work in the most useful areas that we had identified. As with D2.1 we have arranged this section concerning Subtask 2.1 into a series of technical reports. Again, this is due to the same reason; much of the work of this subtask has already been published in conferences oor journals. A list of such publications is included as appendix A.

5.1.1 Multimodal Augmented Reality

Multimodal augmented reality refers to making the user aware of features or services within the environment that may not be in visual sight. Either they are too far away or the user is visually impaired. Visual augmented reality, such as overlaying signs on a video image of a mobile device is useful, but in many situations, such as driving, cycling or navigating through busy crowds it is impractical. From D1.1 we identified that this was a key user requirement and a considerable amount of effort has gone into the investigation of this topic. From GM3 we identified that it was important to further understand the issues surrounding both the fundamental presentation of distance and direction as well as the scenarios in which users may wish to employ such awareness of the environment. Our work since D2.1 therefore covers both of these for audio and tactile feedback. The more fundamental aspects are covered in the following reports:

Further Exploration with Audio Bubbles (Section 5.4)

Pointing Angle and Circle Radius Size for Tactile Wayfinding (Section 5.6)

Intuitive Vibration Pattern Coding of Distances (Section 5.7)

Evaluations of the Tactile Compass (Section 5.8)

The application based research is covered in the following reports:

Friend Sense (Section 5.9)

A Non-Visual Orientation and Guiding Application Based on Pointing Gestures (Section 5.12)

Natch – Reducing Navigation Information to the Necessary (Section 5.10)

NiviNav - A location-based game for mobility training and fun (Section 5.13)

5.1.2 Non-Visual Map Access

The other area that we have concentrated on is non-visual map access. This is distinct from Multimodal augmented reality as rather than try to provide awareness of facilities or features nearby the user's current location, which may or may not involve a map, this seeks to make existing map and map based data accessible to users non-visually. In this way we are covering the best ways of allowing a user who may be blind or partly sighted to browse or plan using a map. Again we look at lower and higher level approaches and have employed a range of modalities. These range from furthering the investigation into non-visual tangible user interfaces (discussed in D2.1) to the creation of virtual environments that allow users to train in a 3D model of the environment in safe location. We have also investigated how users could access the map when using a mobile device, with cross partner work from OFFIS and LUND to expand the non-visual work from D2.1 to create a virtual tactile map that can be felt on a mobile touchscreen. Work such as this complements the developments in Subtask 2.4 in creating a refreshable tactile screen. In addition, this work also illustrates how non-visual touchscreen interaction can be used to create non-visual interfaces that have wider uses than just creating accessibility for non-sighted users. This highlights the value of the project aims that deeply embedding accessibility can bring benefits to all users, not just those for whom such benefits were initially proposed. The fundamental interaction techniques are discussed in the following reports:

Symbol Displacement for Improving Legibility in Mobile Applications (Section 5.2)

Pocket Menu (Section 5.11)

Non-Visual Tangible User Interfaces (Section 5.16)

The more applied techniques are discussed in the following reports:

Soundscapes for Planning a Hike (Section 5.3)

TouchOver Map (Section 5.14)

Virtual Navigator (Section 5.15)

In conclusion Subtask 2.1 has provided clear benefits and advancement onto new areas of perceptualisation and interaction with geographic information. It has directly influenced other subtasks and many of the techniques that have been developed in this subtask have been so successful that they are being reimplemented as demonstrator applications for WP5 (e.g. the tactile compass from D2.1). The addition of guidelines and the toolkit HCI modules proposed mean that future researchers and developers will be able to take up our findings with confidence and apply them to successfully deeply embed accessibility into mainstream mapping applications.

5.2 Symbol Displacement for Improving Legibility in Mobile Applications

5.2.1 Introduction

From D1.1 we found that users want their devices to be as intuitive as possible to use and easy to understand (D1.1/Appendix D). Users expect flexible interaction and a good resolution from the screen.

The clarity of visual mobile maps can be handled by using static raster images that cartographers have designed with respect to legibility, the purpose of use and degree of generalisation. However, map applications nowadays allow flexible scaling of maps and use of vector data. Thus, to maintain the clarity of the map it should not be necessary to download map data every time the map scale changes. Downloading data might not even always be possible. Consequently, the mobile applications should be able to perform efficient cartographic generalisation on downloaded vector data sets to provide a flexible view of the geographical features.

In community-based services, for instance, the simplest form of communicating real-time spatial information related to specific places or events to other users is, to use Points of Interest (PoIs). The alternatives to make PoIs understandable for visually impaired users include for instance modifying the size, representation and colour of symbols. Figure 1 shows an example of utilising such methods. The major difficulty still remains: the overlapping symbols.

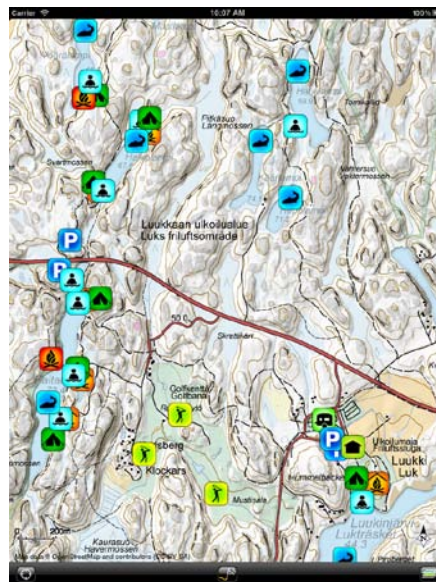


Figure 1: Alternative methods to increase legibility of map symbols include enlarging the size of the map symbols and adding distinguishable colours to the map symbols. Additionally, displacement of symbols is needed to get rid of overlapping symbols.

As the number of symbols on maps increases and the maps allow intelligent zooming, the overlapping of symbols needs to be resolved by automated cartographic generalisation methods. Displacement is one of the methods used to resolve the competition of space between overlapping or too close symbols by shifting them on the map, but without violating spatial relationships (McMaster and Shea, 1992). The method introduced in the present study is developed to display visually pleasing and legible groups of Points of Interest on mobile maps (Figure 2). In the following paragraphs the method is briefly described and discussed, and more detailed report is given by Kovanen and Sarjakoski (2010).

5.2.2 State of the Art

In the era of the Internet and performance-based mobile devices, the real-time generalisation methods have become essential (Sarjakoski and Sarjakoski, 2007). According to Foerster and Stoter (2008) displacement is the most important generalisation operator, when importance is weighted based on how often the operator is applied and how dominant role it has. Displacement algorithms especially for point map symbols are presented in the studies of Mackaness and Fisher (1987) and Harrie et al. (2004). These methods are related to the displacement methods for buildings, but also to map labelling as Harrie et al. (2004) states.

Mackaness and Fisher (1987) use the least squares adjustment theory to create clusters of points. The clusters are resolved locally using some method, such as radial enlargement. In this method first the centre of gravity of the cluster is calculated. In case of a constant point priority, the centre of gravity becomes the geometrical centre point. Thereafter the centre can be moved to respond to map elements other than the points. Finally all the points are moved radially away from the centre. The amount of movement is defined by the initial locations of the points, the size of the symbols and the variation of the method. In case of proportional enlargement the magnitude of movement of each point is relatively the same, in comparison to the other points, as the initial distance to the centre. In a Gaussian case the movement gradually decays towards the boundaries of the cluster.

The grid algorithm implemented by Harrie et al. (2004) starts from the initial location of a symbol. If that location is not suitable, then the algorithm moves to the North direction and begins to rotate clockwise around the initial location in a spiral manner. The symbol icons have a shape of a square in their study, but could be extended to rectangles. At each candidate location a disturbance value is calculated for the grid location taking into account important cartographical points and possible overlapping situations with already placed symbols. If no overlapping occurs and the disturbance value is less than a threshold value defined a priori, then the search is finished and the symbol is placed at a new location.

5.2.3 Study Description

The motivation for our study is that no suitable symbol displacement and grouping algorithm has been published to be used on a client-side that is not all the time connected to a server and where the scale is free to change. The hypothesis of the study was that it is possible to implement an on-the-fly client-side displacement algorithm for mobile maps that follows the map generalization principles used by professional cartographers. In addition, we made boundary conditions for the algorithm,

such as the algorithm has to work with off-line multi-scaled maps, the algorithm has to be fast but resource economical, and that symbols may have priorities or be added and removed.

The study was performed iteratively. In each iteration the algorithm was redesigned, its hypothesized problems were documented, the algorithm was implemented for simulation, and finally the performance-related bottle necks, visual flaws were searched and general functionality was tested. In the last iteration round the algorithm was brought from the simulator into the real usage environment.

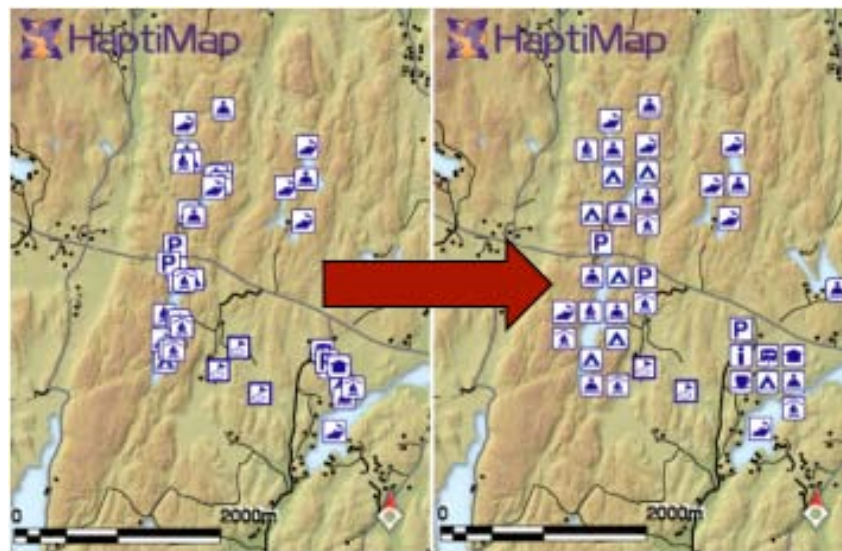


Figure 2 Effect of the displacement algorithm on real data on Points of Interest

To empirically validate the concept, we implemented a displacement algorithm that aligns symbols into vertically and horizontally aligned small groups in case when the symbols are overlapping each other on the map. Thus, the algorithm is suitable for symbols that are represented by pictorial or geometric symbols, but not for all kinds of discrete areal geometries, such as building features. The symbols do not need necessarily to have a rectangular shape, but in that case a minimum bounding rectangle calculated around the symbol is used as the geometry of the symbol. The symbols are displaced one at a time sequentially in such a way that the new symbols never overlap the previously displaced symbols. Duplicates of symbols are been omitted from the symbol groups.

We developed the algorithm with a low computational complexity in order to allow the method to run not only on real-time servers performing the generalisation process, but to integrate the algorithm into a mobile environment. To decrease unnecessary complexity, we decided not to take other types of map features or text into account during the displacement. The method thus may make the interpretation of the map features under the placed symbols more complicated; however, the procedure is justified, based on the following points of views. First of all, modern mobile applications allow the user to hide thematic foreground map layers, such as symbols for restaurants, whenever necessary. If the symbols are at a layer of their own the user is able to hide them. Secondly, Point of Interest maps are typically meant to emphasise the symbolic aspects of a dataset

and not the underlying topographic data (Edwardes et al., 2005). Nevertheless, the method can be extended to take for example other cartographic point symbols and text labels into account.

Some previously studied algorithms involve a degree of randomness, which can cause the visual appearance of the map to change every time when the displacement is repeated. Similarly without sorting the symbols in our algorithm before performing the displacement, the layout could change every time the displacement was repeated. This creates a need to sort the symbols according to some kind of rule, like Easting or Northing before the symbols are displaced.

The developed algorithm is object-oriented. The map objects do not directly know their local environment; instead, a centralised object called 'displacer' is responsible for storing the displaced locations of the map objects. The displacer creates groups in which it puts initially overlapping symbols, but it does not select candidate locations for the symbols inside the groups. The selection of the candidate positions is performed by a 'rover' that is related to the group. The rover is aware of all the symbols' locations already in the group.

The displacer stores references to the displaced geometries to a tile tree (MX-CIF quadtree). After the still un-displaced symbols have been sorted, the displacer is responsible for going through each of the symbols. It performs the detection of the overlap/proximity and validation, but not the calculating the vectors of the displacement. The first task of the displacer is to find from the quadtree the closest symbol to be a displaced symbol, if such exists. If the symbols do not overlap each other and are separated at least by a predefined Euclidean buffer distance, a reference to the geometry of the symbol is added to the quadtree and the next symbol is processed. Otherwise, the displacer adds the new symbol to the group of the closest symbol. The rover of the group is then asked to calculate a new candidate location for the symbol until a suitable location is found, or the symbol cannot at all be added into the group. Searching the closest symbol of the candidate from the quadtree validates the candidate position. If the closest symbol is from the same group, then the rover is notified that the last candidate was suitable and a reference to the candidate geometry is added to the quadtree. Otherwise, the rover is asked to return a new candidate location.

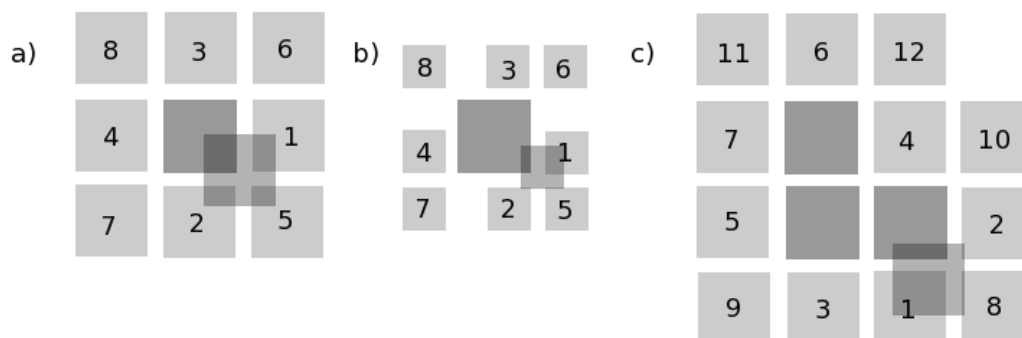


Figure 3: Order of candidate locations returned by the rover. The already placed symbols are presented in dark grey in the centre of each sub figure. The original location of a new overlapping symbol to be displaced is represented as a rectangle with opaque colour. The candidate locations are in light grey and the numbering follows the order in which the candidate locations are suggested by the rover.

The first candidate location inside a group is defined by the angle between the most conflicting symbol and the symbol to be displaced. The location is chosen so that the minimum bounding rectangles of the symbols are aligned horizontally or vertically, and the movement should be as small as possible. The principle is visualised in Figure 3. A special case in finding the first alternative occurs when the symbols have the same centre point. In this case the first alternative is chosen to the east of the original location.

If the candidate location is not suitable, then the next alternatives are found by circulating the boundaries of the group. This is quadrated with the use of a spiral search approach presented by Harrie et al. (2004). To find a candidate location as close as possible to the original location around the group, the algorithm goes through the boundary of the group alternating with clockwise and counter-clockwise rotating. Only '4-neighbours' are used as suitable candidate locations to create a visually satisfactory result. After the displacer has accepted a candidate location, the rover updates the boundary of the group.

The displacement could be used as such, but the map is given better legibility if the use of displacement is combined with other generalisation operators. For instance, the aggregation operator could be used to combine symbols of semantically similar features. If a symbol has already been displaced and another similar one is added to the same group, then the latter one will be hidden.

Some map symbols are in a certain context more important than others. According to Ware et al. (2003) the important symbols are more sensitive to modifications than unimportant. The presented algorithm takes the importance of the symbol into account at the sorting phase before the displacement. At this phase the symbols are not only arranged according to their Northing or Easting direction, but also according to their priority. All symbols are first arranged according to their priority so that the most important symbols are first placed on the map. In the following step all symbols with an equal priority are arranged according to their coordinate values so that they always are displaced in the same order.

5.2.4 Results

The developed algorithm is integrated in an in-house-built mobile application written in Objective-C and running on the iPhone OS 3 to validate the usefulness of the algorithm. The data used for the experiment is real and has not been generalised in advance. The Level of Detail, at which the data is made visible on a respective mobile map, has been defined in advance. The Points of Interest are visualised as geometrically squares. The number of symbols shown at a single moment is between 0 and 100. The higher number is reasonable for small displays with many symbols. In addition, artificial data was used to test the unusual situations such as adjacent symbols with diverging sizes, and exceptional dense distribution. Figure 4 represents a sample of the test data on three different scale levels. On the upper row the symbols are shown in their original location, on the lower row they are shown after applying the displacement algorithm.

The main result of the experiment is that implementing a client-side displacement algorithm for mobile maps is feasible. The efficiency of the developed algorithm was determined to be around 50

ms per rendering which makes the algorithm usable even if it run every time the scale changes. The experiment shows that the symbols are visible in their full size after displacement.

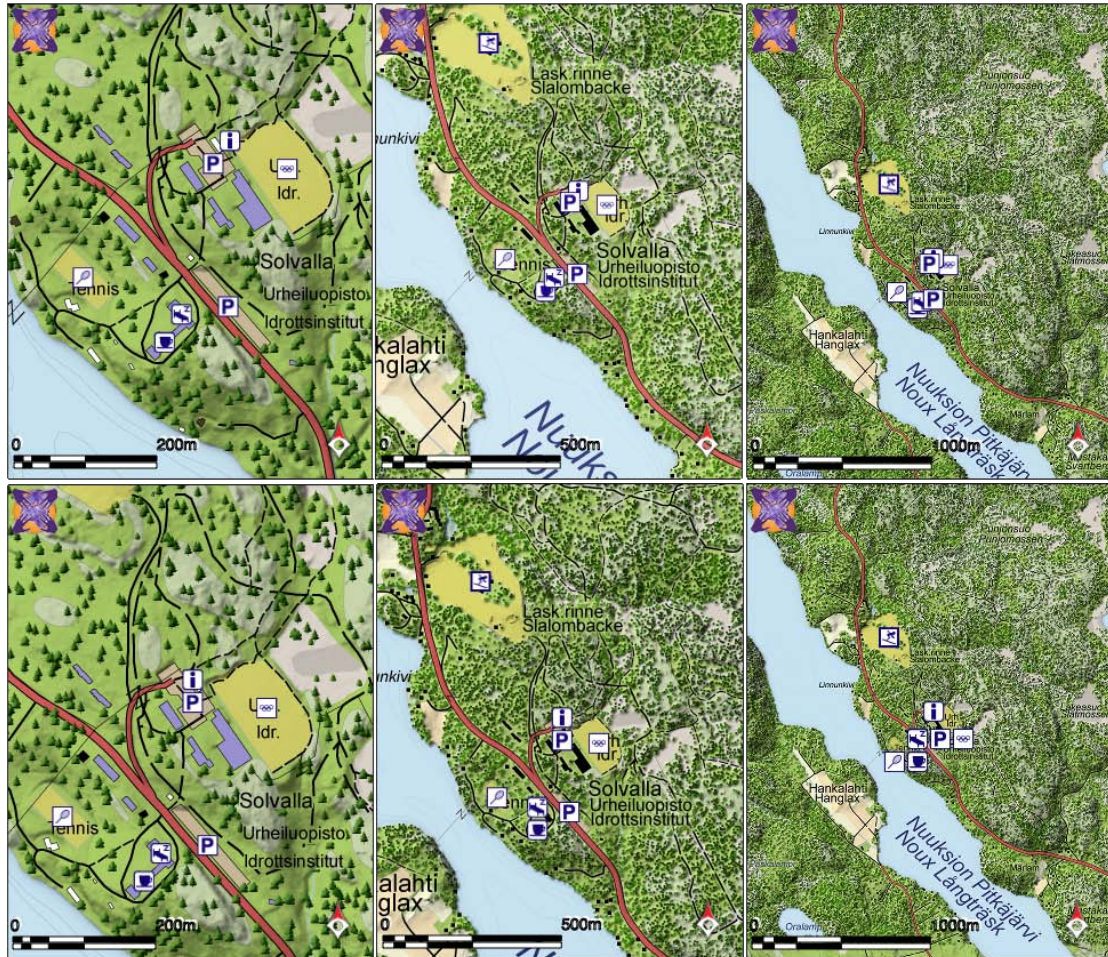


Figure 4: Three maps (top row) representing original symbol data on top of a background map at three different scales. The lower maps represent the results after applying the displacement for the symbol data.

5.2.5 Discussion

Currently all symbols are displaced using a single displacer object, thus, the data structures may become large and the length of the search paths long. An interesting alternative to test is to partition the search space into smaller parts, like using street networks as Sester (2005) suggests.

Similarly to Harrie et al. (2004) we believe that the icon displacement does not need to take line segments or polygonal areas into account, however, cartographic points and labels should be taken into account in the future versions of the implementation. The algorithm is implemented to allow this at the point when the rover returns a candidate position for validation. Before comparing the candidate to the closest symbol, the displacer could validate the minimum bounding rectangle of the candidate against the important symbol points, such as building corners.

Symbols having initially a conjoint centre point should optimally be handled differently as the algorithm currently performs. An alternative could be to perform a pre-processing before the actual displacement in which the symbols of the same location are displaced around the location. In case of two symbols, both symbols are moved the same distance away in opposite directions. Similarly, the points that are aggregated should undergo the validation of the linkage rules. The grouping of symbols with different sizes is also currently possible, but the results can be in many cases better if all the symbols of a group are of the same size. One possibility is to apply magnification or scaling down to the symbols that significantly differ in size from the rest of the symbols in a group.

5.2.6 Guidelines for D1.4

The following guidelines can be derived from the work:

The presentation of icons representing points of interest are problematic when placed close to each other: In cases where multiple POIs are close to each other and overlap, interpretation by the user can be confusing. A displacement algorithm to displace POIs from the real locations, is likely to improve map interpretation and understanding. This is especially the case if screen-reading technology (such as Voice Over on the iPhone) is used, as this reads out features under the user's finger. Therefore multiple overlapping features are to be avoided.

Use a displacement algorithm for close together POIs: In cases where POIs must be placed close together, use a displacement algorithm to move POIs to be better laid out. The algorithm suggested in this section is both robust and time efficient for use on mobile devices.

Be careful not to set the displacement factor too high: If the displacement factor (the distance between the actual and visualised POI) is set too high, confusion may arise to the location of the POI. In such cases, some overlapping of the POIs may be necessary.

To improve the visual accessibility, the problem of overlapping symbols on small display maps has to be resolved. One possible solution is to use the developed generalisation algorithm, as described above.

5.2.7 Proposed Toolkit HCI Modules

A module could be implemented to group map symbols and remove cluttering from maps. The input of such a module could be a list of the identifiers of the symbol geometries stored in the internal data storage of the toolkit. In addition, the module would require knowledge about the symbols to use, thus, one alternative is to provide symbols of a common size and their geometrical extent, while another option is to provide the sizes and map resolution (or geometrical extents) of all the symbols, to the module.

A question is whether the module should store the displaced locations to the internal data storage of the toolkit as new features, or whether the module should maintain its own internal data structure, i.e. the quadtree, or both. The output of the module could be a list of references, in which the

identifiers of the symbols that have not been displaced would be the same as in the input. Alternatively, the module could provide the new locations of the symbols directly.

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5.3 Soundscapes for Planning a Hike

5.3.1 Introduction

Perceptualization through multiple channels is one of the key principles identified in the HaptiMap Description of Work and in D1.1 as well. Sonic tags were found as an alternative to communicate spatial information of the unknown environment, to be used not only during a hike but also when planning a hike or exploring in advance the area to be visited.

As stated in D1.1, visually impaired people use ambient sounds as landmarks. In the answers of ‘User needs questionnaire’ several users commented that they use existing audio information existing of the environment along their routes. To remember customary routes, many users make use of visual and sonic landmarks. This speaks for the presentation of the sonic landmarks of the environment in the audio realistic form in maps.

When including an audio channel into the cartographic presentation, the question arises: what kind of spatial information can be transmitted through sound? In this study we have focused on embedding real world sounds from a national park environment in a digital map. With sound it is sometimes possible to communicate such spatial information that it is not conceivable to be communicated through visual channels. Notably characteristic soundscape of a location is something that non-sonic maps do not transmit, for example a soundscape of the ocean shore where waves are crashing on shore. We have been experimenting with embedding soundscapes into hiking maps (Laakso and Sarjakoski, 2010a; 2010b) to serve stationary users who want to plan their hike in advance. A brief report of this study was also given in the HaptiMap’s deliverable D2.1, here the study is completed with new examples.

5.3.2 State of the Art

The possible use of sound in maps has been recognised by many authors, for instance Krygier (1994) presented a variety of sound forms and a wide range of possibilities for using them in geographic applications. The concept of soundscape was introduced by Schafer (1977, 1994). He described the elements of a sonic environment and defined the soundscape as (p. 274):

“Technically, any portion of the sonic environment regarded as a field for study. The term may refer to actual environments, or to be abstract constructions such as musical compositions and tape montages, particularly when considered as an environment.”

However, as cited by Cartwright (2009) and Porteous and Mastin (1985), there is an early example in which Granö (1927) did pioneering work on creating an agricultural soundscape that illustrated cartographic representations with acoustic sensations of human activity, birdsong and grazing cattle on the island of Valosaari in Finland. According to Cartwright (2009), the theory of using soundscapes is generally attributed to Granö (1927).

The potential of soundscapes in cartography has been discussed by Théberge (2005). He recognised the figure-ground relationship in environmental sound and its possibilities for maps. He also emphasises the overall sound design and the good quality of the sound components to be used. Théberge continued with the concept of cyperc cartography, which Taylor (1997) originally presented. The use of soundscapes in enriching our multisensorial reading of space, as well as the role of sound in cartography is increasingly discussed by Caquard et al. (2008). In this study, a profound analysis of sound in film theory is used to explore the potential of sound in cartography. Also, Brauen and Taylor (2007) discussed the motivation for introducing multisensory information into mapping projects. They presented a framework for incorporating sound into visual maps by relating it to the example of an atlas project.

Rice et al. (2005) confronted the design of map interfaces within the context of visually impaired users in a research project entitled ‘Haptic Soundscapes Project’. They used special interfaces with haptic and auditory feedback. The sounds they used were different kinds of auditory cues, speech and tones with varying frequencies.

Research on computer technology, particularly in the field of auditory displays, has studied how to transform visual information into aural information. MacVeigh and Jakobson (2007) presented a study on auditory display in GIS. They used a simplified raster image in which three different sounds are integrated into a layer and at each point a value for each sound is calculated and played. This is a good example of a sound-covered map and could help visually impaired users to hear which objects are within a particular hearing range. Another example of auditory displays comes from Dingler et al. (2008), who studied the learnability of sound cues for environmental features.

Sarjakoski et al. (2009a) discussed the importance of sound for map use experience on ubiquitous maps. The augmented sound elements may even support aesthetic and entertaining aspects of interactive maps. As stated by Peterson (2007), multimedia cartography may contribute to the joy of discovering something new about the world. The sounds from the real world of a certain location are something we rarely can learn about without actually being there ourselves.

Although researchers have conducted studies on the use of sound with maps, very few publicly available web or mobile applications yet exist. It is a challenging task to develop sonic maps that would provide the users with additional information that is fit for use, and not only for amusement. Most of the aural applications are aimed at visually impaired users, even though sound within maps; for example, a soundscape-type aural image of a location could communicate interesting and important information to many kinds of users.

5.3.3 Research Questions

In this research we want to investigate what are the possibilities to use sound in communicating spatial information. Our aim is also to study later on what are the benefits gained by different user groups, both sighted and visually impaired users. A central question is whether real world sounds would bring significant additional value to the visual map representation.

5.3.4 Study Outline

The study consists of two experiments of embedding sound into hiking maps. In the first part of our study we explored the possibilities to attach soundscapes into hiking maps. For the presented sonic maps, the recordings were made with an audio recorder during wintertime and early summer. An audio recorder Olympus LS-10 was used to obtain recordings of adequate quality (24bit / 96kHz linear PCM recording). The field-recorded soundscapes for specific locations are stored in the web-based map service. The map data is delivered and displayed for the user on the web map or on the mobile map. When the user chooses the option ‘Show soundscapes’, play button symbols are overlaid on top of the background map into the locations where soundscapes were recorded. In addition to the audio response of the button, a small text box appears containing some additional information about the recording. In the text box a short description of the soundscape and the time and place of the recordings are given (Figure 5). For the summertime ‘Hiking’ map shown in D2.1, the following recordings were made: a chorus of birds singing in the forest in spring, a creek full of gurgling water, water cascading over a dam, people having a break by the camp fire, footsteps on a wooden bridge and a woodpecker drumming on a tree.

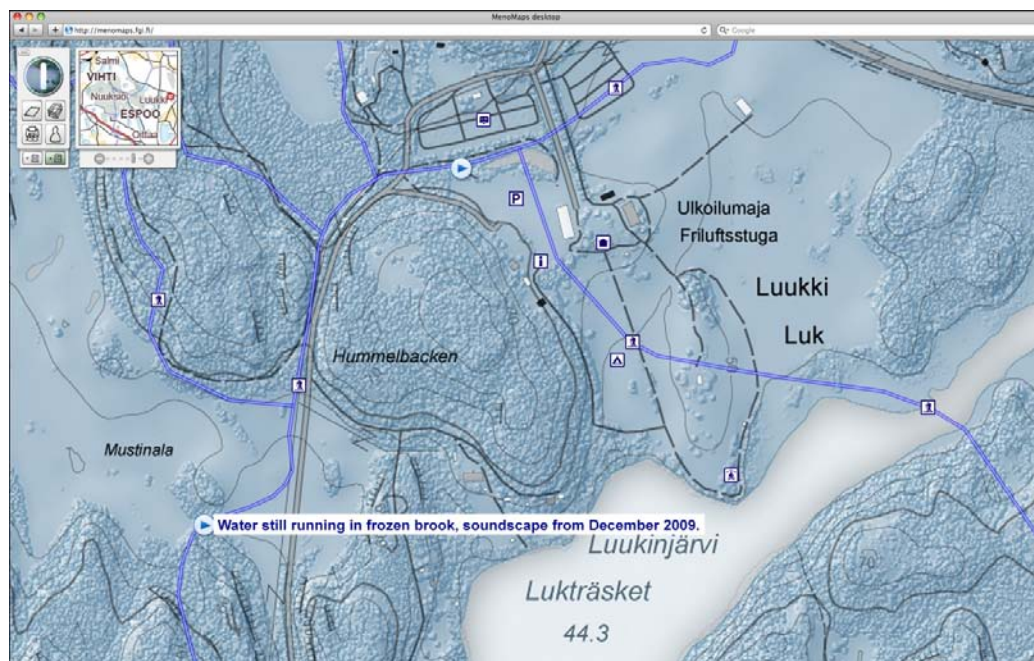


Figure 5 The soundscape map over Nuksio National Park with the ‘Skiing’ theme.

When the user chooses the ‘Skiing’ option in the map application, the background map is a winter map with a white and grey-blue ‘snowy’ colour scale on top of the visualised terrain model (Oksanen et al., 2011). The background map is overlaid with additional information, such as skiing tracks, and the buttons with winter-theme soundscapes appear. These are recorded in wintertime, in snowy, very cold conditions. The recorded soundscapes presented for the winter include squeaky footsteps on snow during a heavy frost and running water under the ice covering a brook (Figure 5).

In the second part of our study, we covered the whole map area with corresponding natural sounds. We first carried out an intensive map generalisation of the background map. We emphasized the walking routes with thicker lines having generalised simplified forms and gave special attention to the colours. In the field, the walking routes are marked with small signs attached to trees by the path with specific colours, which restricted the colour choice. Water areas were also enhanced. The detailed information on the map, such as contour lines, was faded out into the background by increasing transparency in colour. We did not want to delete the topographic information on the background entirely, since it may serve the accompanying sighted person. After the visual generalisation, we added the sonification.

We completed this aspect of the sonic map using Adobe Flash CS3 software. We integrated the various areas and separate objects of the map into invisible buttons. Thereafter, we attached the sound files to these buttons. After that, the sounds could be listened to through a mouse-over function. The user may explore the map with a pointer (mouse, finger or other device) and in every location hear a sound related to the object (Figure 6). The sounds that we used in the sonification were as follows:

- the forest areas: the on-site recorded sounds of the forest (singing birds, wind in the trees)
- the water: a gurgling brook (from one on-site brook, the same sound used in all of the water areas)
- the paths: walking footsteps on a dirt path
- the roads: the sound of passing cars
- the map symbols and the text are read out loud

In this implementation the display used could be a large and bright touch screen. With a large screen the visual objects are easier to distinguish and, if using a finger or hand as a pointer, the touch and adjustment is more intuitive and easier to make. This map (Figure 6) is aimed for weak-sighted user or for users with some other visual impairment.



Figure 6 The sonic map of the Nuksio National Park for visually impaired users. The sound of various map objects can be explored through mouse-over actions or by hand on a touch screen.

5.3.5 User Testing

Limited user testing has been conducted for the soundscape maps (Flink et al., 2011). Many of the users were delighted with the possibility to get some idea of the sonic environment of the area, but some of them were unsure of what purpose the soundscapes would serve. In particular, the users were not motivated to use soundscapes on mobile maps. There were some suggestions given about the ways in which the soundscapes could be improved. Some users suggested other kinds of icons for the buttons that could be more easily recognised. There should also be information about the length of the recorded sound file. Many of the users wished for more current sounds, for example sounds for every season should be included.

5.3.6 Results

Sounds on maps can serve all kinds of map users by providing essential and additional information, depending on the usage situation. For users who are unable to go on a hike, the real world sounds from nature that are embedded in the map mediate the true atmosphere, and thus provide a sort of accessibility to nature. People who are visually impaired but not totally blind will benefit from a map with embedded sound effects which have primarily been designed for the visually impaired (Magnusson et al., 2009; Sarjakoski et al., 2009b); especially when maps are displayed on large touch screens. With sonified maps, visually impaired users can familiarise themselves with the area in advance and also find sonic landmarks to obtain help in recognising places.

One of the main points that arose from the user testing was the actuality of the soundscapes on the map. This calls for even more granulated division of seasonal soundscapes. In the forest, the

soundscape of a location is different during every season, whether spring, summer, autumn or winter, but also at different times of the day. However, certain time dependent cues can be distinguished, such as sounds produced from snow in winter and seasonal differences in birdlife. It is also possible to find spots where the aural image is stable enough to serve as a sonic landmark, for instance through the year running water in a brook.

5.3.7 Discussion

The primary use of the presented soundscape map applications is to serve stationary users when planning a hike or users who are unable to visit the actual place. With a sonified map a visually impaired user can familiarise him/herself with the area in advance and find sonic landmarks in order to get help in recognising places when later visiting the area. While providing the first steps in developing new kinds of sonic maps, further development is still needed. The preliminary user tests showed that people are fond of having the possibility to get in advance an idea about the atmosphere of the environment they will visit. The users also preferred to have current sonic information about the environment, for example information about a particular season of the year.

Objects that can be regarded as sonic landmarks, meaning that they have more or less the same aural image all the time, are relatively rare. Some places with constantly running water may be referred to as such. A continuous sound map of a route could help visually impaired users in navigation. However, since stable sonic landmarks are infrequent, a route map based only on soundscapes would not be so helpful but instead it should be completed with other auditory means, such as earcons, auditory icons and speech (Kovanen et al. 2010).

5.3.8 Guidelines for D1.4

From the work, the following guidelines can be determined:

Sonic landmarks can provide an overview of a geographic environment: The ability to quickly pass over the map and gain an auditory sense of what information is where, was found to be useful. Audio is particularly effective in this regard and may be combined with the touchover map (see Section 5.14) to provide detailed tactile roadmap with auditory area information.

Sonic landmarks may provide a bridge between planning and real world: The sonic landmarks that we have investigated are primarily for use in static planning applications. However, these could be combined with other techniques (such as AudioBubbles in Section 5.4) to provide markers in the desktop planning with embodied auditory localisation in the real environment. In such a way providing a non-visual “you are here” marker.

More generally sonic landmarks seem to be important information in orientation and their presence in maps, also in audio form, is worth emphasizing. It is likely that the usefulness of the HaptiMap service could be developed further by providing not only a mobile application but also a web application that can be utilised indoors for planning a hike or a visit to an unknown environment.

5.3.9 Proposed Toolkit HCI Modules

Different types of audio feedback should be provided to the user on demand. A request for feedback may be based on finger gestures, such as tapping on a map symbol. However, soundscapes or sonic landmarks should not be given immediately after pressing a map symbol. Instead, a description of the soundscape or sonic landmark should be first visually shown and played in audio, through text-to-speech, to the user. The description should be, for instance, “Pressing this symbol again plays you the sound of a water stream located at the site”. Not until a second finger gesture is made to the same spot on the map, does the playback of the actual audio file begin.

The described functionality should be implemented by adding to the HaptiMap toolkit mantle layer, a module that is called whenever a user touches a map (or map object) with a certain gesture (the gesture is free to choose). The module creates a request to the HaptiMap toolkit internal data storage for a PoI located near enough to the target location. Next, the module checks whether the PoI contains a predefined attribute value presenting a reference (URL) to an audio file. If such exists, then the module verifies if the PoI is the same one that was selected previously, and what sub module was. Consequently, the module needs to store is the identifier of the last selected PoI, and a reference to the last sub module.

If the PoI is not the previously selected one, then the module has to send a request to a sub module responsible for visualizing and playing the description of the PoI (let this be called a first responder). The interface of this first responder has to be able to handle three different calls: describe, is_active, deactivate. From these the module calls describe. The call activates the repeating of description and the first responder returns. The module stores a reference of the first responder.

If the PoI is the same as the previously selected one, then the module first calls the first responder to check if the PoI is still active. If it is active, then the deactivate interface method is called, else the activate method is called. If the deactivate method is called then the module advances to call third module (let this be called second responder), which is responsible for playing back the sound landscapes or sonic landmarks. The module stores a reference of the second responder. The interface of this module can be identical with the first responder.

5.3.10 References

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5.4 Further Exploration with Audio Bubbles

5.4.1 Introduction

In D2.1 we provided an initial study into the use of Audio Bubbles, three dimensional auditory spheres that could be geo-located to allow users to locate physical or virtual landmarks in the environment. The initial prototype study indicated that Audio bubbles could be useful, but did not provide a full investigation into how to apply them or the tradeoffs in their use. Additionally, other work such as Soundcrumbs (see D2.1) showed the use of dropping Audio Bubbles to allow users to “backtrack” their route was also useful. These two studies raised important questions, discussed below, in how Audio Bubbles should be designed.

5.4.2 State of The Art

Much research has already been carried out to investigate the role of auditory beacons in navigation for both sighted and visually impaired users. The earliest of this work was carried out by Holland *et al.* (Holland, Morse & Gedenryd, 2002). Their AudioGPS used stereo panning to indicate bearing information and the repetition rate of a beep sound which varied as distance to the landmark was varied. However no evaluation of this system, was carried out. More recent work has considered how different types of audio could be used to present navigational information. Strachan *et al.* (Strachan *et al.*, 2005) developed the gpsTunes system. Here, the stereo balance of music was layered to indicate the bearing of a waypoint along a route with the volume of audio increasing up to a set level as the user got to that point. As with AudioGPS, a gps system was used to determine position, but with the addition of a magnetometer that allowed more fine-grained and interactive determination of target bearing as the user could effectively employ active listening to determine direction. gpsTunes also allowed users to browse the environment for all of the waypoints on a route by using the magnetometer to “scan” the environment. On evaluation of gpsTunes with four users navigating a route around a sports field, Strachan *et al.* found that less variability in direction occurred with those users who employed the scanning technique. Similar work is reported by Jones and Jones (Jones *et al.*, 2008), their ONTRACK system used a more formal experimental process to assist a user in navigating around a built environment. Stahl *et al.* (Stahl, 2007) used 3D audio of animal sounds to indicate the distance and direction of the enclosures of those animals in a zoo.

This work, and our own study from D2.1, show that the use of 3D sound for navigation is useful, most of the work that has been carried out considers the use of only virtual landmarks. These have no physical prominence in the environment and act as waypoint or turning points. Location of physical landmarks is an important part of wayfinding and from work on tourists we know that even with a map, this is difficult (Laurier & Brown, 2008). In cases where there is more than one landmark, multiple auditory sources could be annoying or confusing if concurrently presented. We therefore believe that sound would be more useful as the user became closer to the landmark. However from our study in D2.1 there are several things that we do not know:

- What is the best radius to start presenting audio to the user?

- Does the prominence of the landmark affect when the audio should be presented?
- What is the impact of the use of 3D audio to navigate and locate physical as opposed to virtual landmarks in the environment?

5.4.3 Study Description

Whilst the research discussed indicates that Audio Bubbles can be useful, we do not have sufficient understanding to create a toolkit module that can be used by developers. The impact of radius, landmark prominence and the collocation with physical landmarks – rather than virtual - is unknown. To that end we developed a study to investigate the impact of both radius and landmark prominence on the time and distance taken to locate physical landmarks.

The study was carried out as two smaller studies. Each involved 12 participants aged 17-30. All reported normal hearing and vision. No participants from the first study took part in the second. In both studies, participants primary task was to navigate around a local botanical gardens and find and photograph six named physical landmarks. In study 1 three of the landmarks were classed as prominent (they could sufficiently recognised as distinct from 20 m away) such as signposts or small buildings. The other 3 landmarks were non-prominent such as named bushes or shrubs. In the second study four non-prominent landmarks were used with two prominent landmarks making up the six. In order to find the landmarks participants were equipped with an iPhone 3GS and an external Qstarz GPS unit (The GPS unit in the phone proved to be unsatisfactory in pilot testing). The phone ran a custom application (see Figure 7) which provided a map showing the user's current location as well as the location of the POI that the users was attempting to locate. This was augmented by a 3D auditory space that the user could listen to with a set of Senheiser HD25 headphones. The GPS unit determined the user location in the auditory space and the orientation controlled by the digital compass in the iPhone. At the same geo-location of the point of interest an audio bubble containing the sound of bubbling water was located. The diameter of this bubble was varied depending on the condition the user performed and we discuss this further later on. The user had to use all of the aids available to navigate along the physical paths towards the landmark. When the user was sure that he or she had found the landmark, they were instructed to photograph it. The participant was then walked to the correct landmark and the next trial started. We logged GPS position, accelerometer traces and the steps taken per trial (via a pedometer attached to the user's hip). We also logged the time taken and distance from the landmark when the user took the photograph.

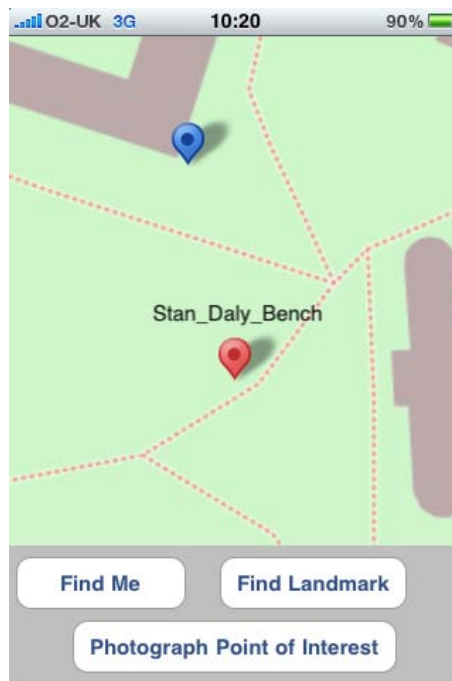


Figure 7 A screenshot of the application used by participants

As discussed participants undertook three conditions in a counterbalanced order. A different set of six landmarks were used for each condition and these were also counterbalanced. Participants undertook different conditions in each of the two parts of the study. Each condition varied by the diameter of the Audio Bubble. In study 1 the radius was either 15m, 30m or 15m plus the GPS accuracy measurement (We assumed that bubbles should be larger when GPS reception was poorer). In the second study we compared 30m (for comparison with the results of study 1), Always on (Bubble radius was the size of the park), No Audio (There was no audio presented, participants had only the visual map).

After completing each of the trials, participants were informally debriefed and paid £15 compensation for their time. Each participant took approximately 90minutes to run.

5.4.3.1 Research Questions

The study tried to answer the following research questions

- RQ1: What is the difference in locating prominent and non-prominent landmarks?
- RQ2: What is the effect of the AudioBubble radius on time and distance to find landmarks
- RQ3: What are the tradeoffs in applying a quantitative study in the real world.

5.4.4 Results

Figure 8 shows a graph of points of interest that were identified across all conditions. Accuracy was high in all cases and an ANOVA on these results failed to show significance ($F(2,12)$, $p > 0.05$).

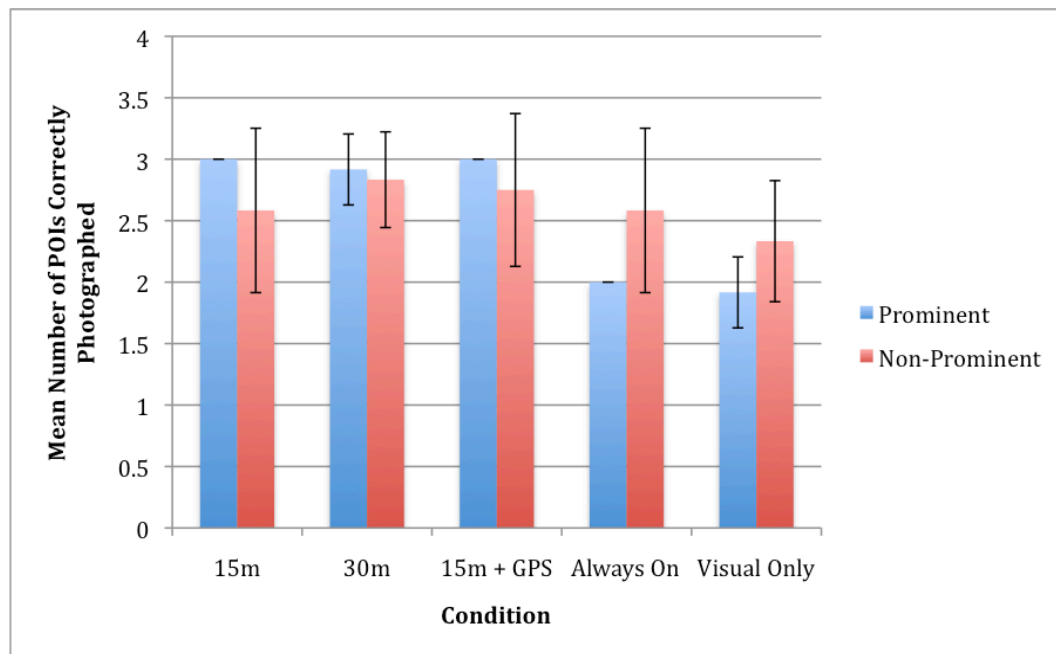


Figure 8 Graph of POIs correctly photographed for all conditions. Shown with standard deviations.

Figure 8 shows a graph of the mean distance participants were from the landmark when they took the photograph to end a trial. An ANOVA on these data showed significance ($F(2,12) = 23.2$, $p = 0.0001$). Post-hoc tukey HSD tests showed that participants were much further away from the prominent landmarks than the non-prominent landmarks. Notably, in many cases the participants photographed the prominent landmarks before entering into the sphere of the audio bubbles. In such cases there is little need for additional homing to support the user. Audio bubbles are most likely to be useful when attempting to location non-prominent points of interest.

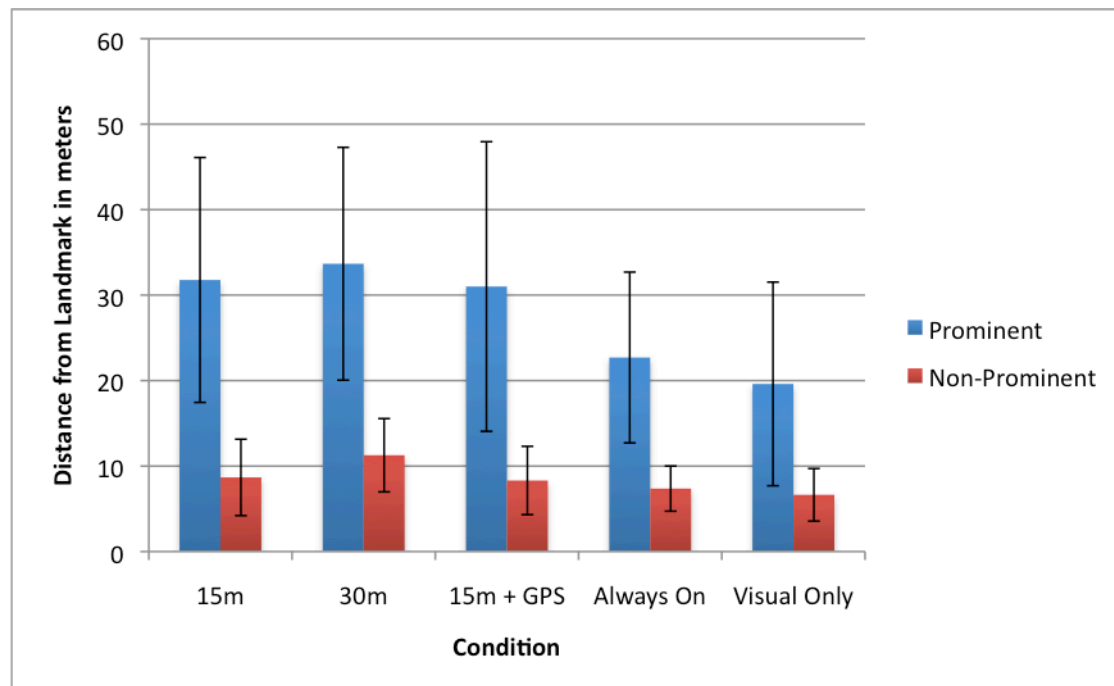


Figure 9 Mean distance that participants photographed the landmark. Shown with standard deviations.

One of the key measures we wanted to make in both of our studies were how long finding the landmarks took and how far participants had to travel to find them. In a navigation study both of these measures are key at determining the usefulness of the technique under investigation. In a classical lab based study such measures are fairly trivial. Time can be measured using instrumented software. In simulated systems distance can also be trivially measured, as there is no uncertainty in user movements (Pielot, Krull & Boll, 2010), such as would be caused by any real world positioning system. An additional issue with our studies were that participants had to find real landmarks in the park. The location of landmarks was already fixed - in some cases for hundreds of years. In a practical sense incorporating new landmarks in cases where we desired was impractical. This meant that unlike in a simulated environment, the distance between the trial start point and the landmark varied, making it impossible to directly compare the distance and time taken.

To overcome these issues we developed two new metrics to describe the distance and time taken as a proportion of a pre-determined time and distance. The intention is to put each measure on a consistent scale to allow for different routes to be compared. Proportion of Optimal Distance (POD), as its name suggests compares the distance that the participant travelled as a proportion of the optimal distance between the start point and the landmark position. In our case the optimal distance is the shortest path length between the start location and the landmark. This allows for comparison between routes of varying length, although our experience is that routes should be made as similar in length and complexity as possible. POD also provides a useful independent benchmark of the system under evaluation, as a “perfect” navigation system would tend towards the optimal distance a user would travel if the route was well known and often traversed.

To calculate the POD we used the readings from the accelerometer as a baseline measure. The graph shown in Figure 10 shows the POD for all participants. An ANOVA on this data showed

significance ($F(2, 12) = 1.45$, $p = 0.034$). Post-hoc Tukey HSD tests showed that participants were significantly more optimal when identifying prominent rather than non-prominent landmarks. Not other results were significant.

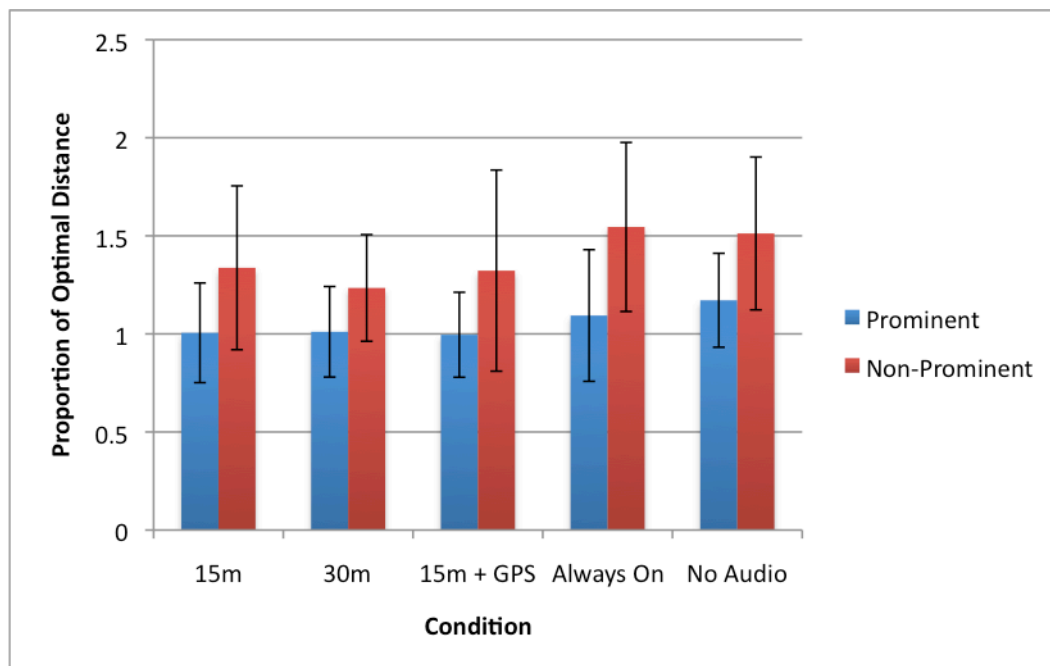


Figure 10 Graph showing POD for both prominent and non-prominent landmarks across all conditions. Shown with standard deviations.

Related to distance is the time taken, and for the same reasons as with distance we converted this to the Proportion of Optimal Time (POT). Optimal time was calculated as the time that a participant would have taken to walk the optimal route based on the mean speed walked during the baseline-measuring phase. The graph of Figure 11 illustrates this. An ANOVA on these data again showed significance ($F(2,12)=0.9876$, $p = 0.034$). Post hoc Tukey HSD tests again showed that prominent landmarks were more optimal in time than non-prominent ones. No other results were significant.

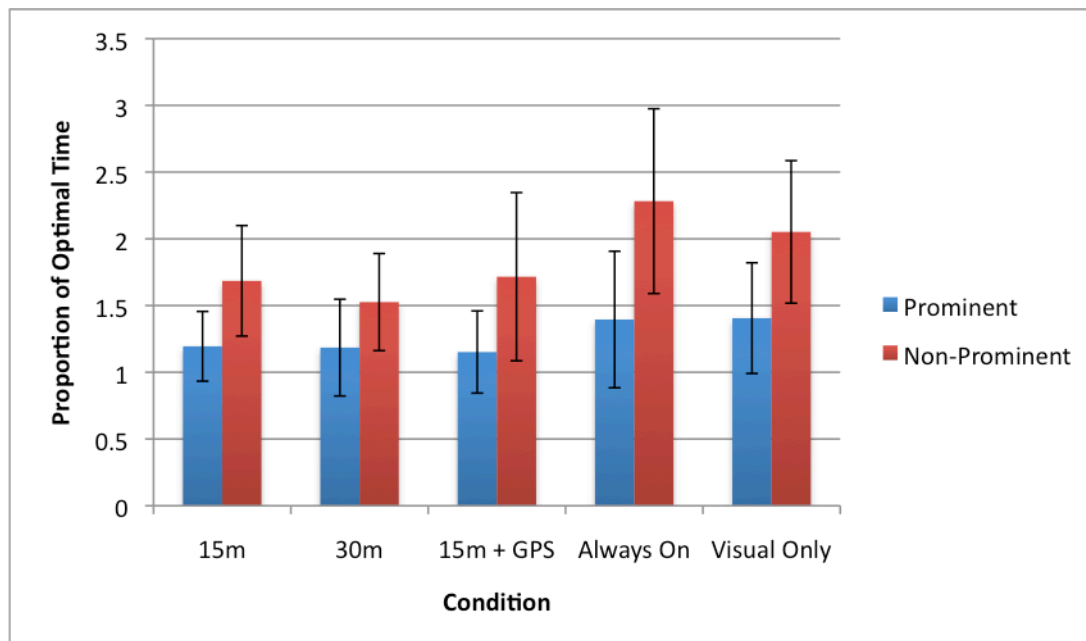


Figure 11 Graph showing POT for both prominent and non-prominent landmarks across all conditions. Shown with standard deviations.

Both of these results can best be explained as participants took photographs of prominent points of interest from a much farther distance than non-prominent points of interest. This resulted in the significant variation in POD and POT. More importantly, the mean values for the 15m and 30m conditions, show that on average participants would not have heard the audio when searching for prominent landmarks.

A further issue with distance is how to measure the distance walked. In our studies the optimal distance was measured with the aid of Google earth, but determining how far the user has walked is more problematic. In the audio study we compared three different techniques. Our first technique, and the most simple was to interpolate the position updates of the GPS device. We cumulatively added the distance between successive location events from the fixed start location to the end of the trial. Whilst this is simple, it is not without problems as we incorporate GPS errors in the recording of distance. The impact of these errors is largely dependent on the quality of GPS reception and, we believe the consistency of such variations. If we seeks to compare two techniques, gross variations in GPS accuracy when testing one technique will have greater impact than if those variations appear in both. Care must therefore be taken to measure the horizontal accuracy of each GPS position update. In our study we used a high quality external GPS unit. Accuracy was high and consistent through all trials, but this may not always be the case. Goodman (Goodman, Brewster & Gray, 2004) proposed the use of a pedometer. This is a small clip on device that counts the number of steps the wearer has taken. We calibrated the pedometer by having the user walk along a path of known length six times. By counting the number of steps taken we could calculate the mean distance per step. Readings of the pedometer were then taken at the start and end of each trial and the step length used to calculate the distance travelled. Pedometers are a cheap way to determine the number of steps the user has taken, but they must be seen at regular intervals during the study, so if the user is wearing a long coat or clothes that do not allow optimal placement of the pedometer, this can pose

difficulty. The third technique we employed was gait analysis (Strachan & Murray-Smith, 2009). The devices that we used, as with most current mobile devices, contain an accelerometer which can measure instantaneous force applied. The forces applied during walking can be analysed to determine the number of steps that a user took. In this way the same information as was generated by the pedometer can be collected in an automated way - rather than needing to read the pedometer at the start and end of a trial. However, more work is required to post-process the data to generate the step counts. Accelerometer analysis does however offer a significant advantage over both the previous techniques in that it allows instantaneous speed to be determined, allowing determination of points where the user slowed down during the trial which may offer deeper understanding of user performance (Williamson et al., 2010). The results of all of these techniques across all participants is shown in the Graph of Figure 12.

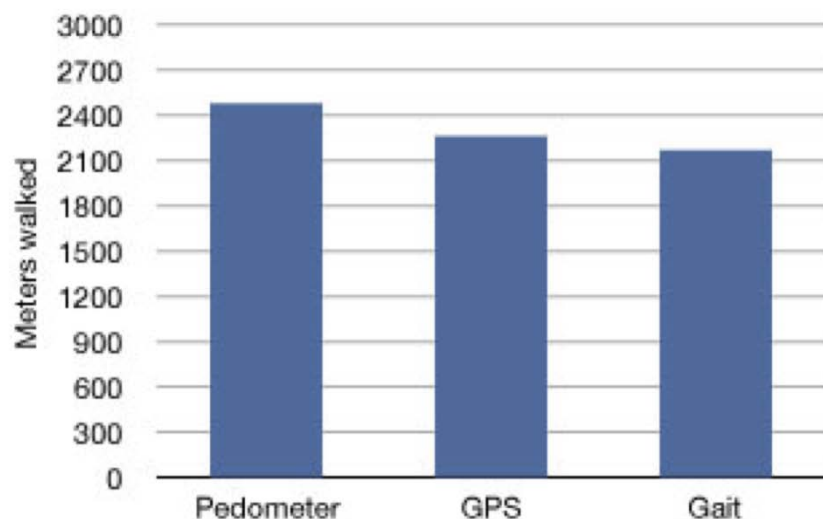


Figure 12 Graph showing the calculation of meters walked for all participants as measured by the three measurement techniques.

5.4.5 Discussion

Across all conditions performance was good. Participants were able to find and photograph landmarks with a high degree of success. Although the audio bubbles failed to show a significant increase in performance, we believe this may be due to the collocation of the audio with a physical landmark (something that has not been investigated before). This means that even small GPS errors when close to the landmark will indicate a much greater error in the direction to the point of interest. We observed this in many instances, where participants would search on the wrong side of a path because the audio indicated it (due to a small gps error). In conclusion, without a much more precise location system audio bubbles are unlikely to provide a strong quantitative improvement in landmark homing when searching for physical landmarks.

However, as with previous research audio bubbles are likely to be useful if the physical landmark does not exist, and in this case the diameter of the audio bubbles are unlikely to have an effect on

user performance. The majority of participants also preferred the Audio Bubbles, most at about 30m diameter. They felt that they got hints as they moved closer to the landmark.

In conclusion we believe that audio bubbles can be useful, but require a very precise navigation system to allow them to work properly. When GPS accuracy is low, it may be more effective to remove the 3D element and allow users to search visually, the audio providing only gross warmer or cooler cues depending on distance. However, in cases where no physical visual landmark is being searched for, or that landmark is large, they may provide effective cues. Because of this, they are being incorporated into the Virtual Excavator demonstrator.

5.4.6 Guidelines for D1.4

GPS is not always good enough: Whilst participants liked the Audio Bubbles, our use of even a high quality GPS device caused significant issues where the participant was close, putting the user on the wrong side of the landmark and this being indicated to move in the wrong direction. Audio Bubbles should be switched off when the participant is close to a landmark or the feedback provided should be scaled to the quality of location available.

Not all landmarks are the same: Participants were significantly faster to detect and photograph prominent landmarks than non-prominent ones. It is therefore important to consider how prominent points of interest are before providing extra assistance for their locations.

Quantative outdoor users studies are possible (with considerations): In evaluation of Audio Bubbles we used a quantative outdoor usability study where users found pre-existing landmarks. We were successfully able to create metrics that allowed both success or failure to be adequately measured, but also to deal with the variations with the distances between start locations and landmarks. The development of POT and POD allow this to occur. However the variations between the three measurement techniques for distance (accelerometer, pedometer and GPS interpolation) mean further work is required to validate our approach.

5.4.7 Proposed Toolkit HCI Modules

We propose that a set of modules should be built into the toolkit to allow the creation and management of Audio Bubbles. These should include creating an audio bubble with a sound file, geo-location and audible diameter. The ability to activate or deactivate an Audio Bubble and allow the audio to loop or be played only once before automatic removal.

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5.5 User Evaluation of the Memorisation of Vibrational Patterns Transmitting Spatial Information: Use of VIFLEX

As in our study described in D.2.1, a 2DOF haptic platform (called VIFLEX), developed in a previous project has been used to develop and to test a number of perceptual metaphors for presenting spatial information. In the previous study, we mainly tested understandability. In this study, memorisation was tested. The motivation of this study was the following: in order to navigate effectively memorisation of vibrational patterns is as important as their correct understanding. We investigated both short- and long-term memory of haptic stimuli.

5.5.1 State of The Art

Haptic memory, both short- and long-term, is much less investigated than visual and auditory memory. The few studies that have, to date, attempted to explore haptic memory primarily concentrated on short term memory (STM, Gallace & Spence, 2008). The results of these studies, in which stimuli have mainly been presented to the fingertips, suggest that the immediate memory span for tactile stimuli following brief (i.e., 100 ms) presentation varies from 3.5 to 7.5 stimuli. It has also been observed that tactile STM performance declines to its lowest level of performance within 45 s of stimulus presentation (e.g., Bliss, Crane, Mansfield, & Townsend, 1966; ; Gallace, Tan, Haggard, & Spence, 2008; Gilson & Baddeley, 1969; Mahrer & Miles, 1999, 2002; Miles & Borthwick, 1996; Miller, 1956; Rabinowitz, Houtsma, Durlach, & Delhorne, 1987; Hillstrom et al., 2002). However, there is still a very limited body of knowledge on haptic memory.

This study was supposed to be a contribution in this direction. The main objective was thus to test the short- and long-term memory for abstract vibrational patterns presented on the VIFLEX.

5.5.2 Study Outline

Twenty-four CEA employees (16M/8F) participated in the study. Their age range was from 19 to 54 years. Some of them had technical background and some of them were administrative personnel. None of them was well-acquainted with the tested device. Ten abstract patterns presenting geographical information (e.g. big roundabout, small roundabout, Y-junction, door behind, staircase, vertical barrier, error) were learned by the test participants.

An example of the visual presentation of such an abstract pattern is presented in Figure 13.

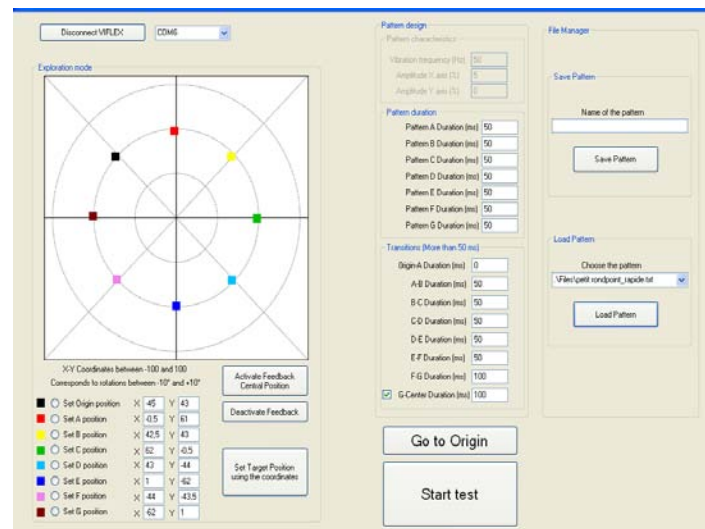


Figure 13 Visual representation of an abstract vibrational pattern presented on the VIFLEX

The recall of the abstract vibrational patterns was tested immediately after the learning process and 48h later. The procedure was the following. The test participants were presented with a list of 10 pattern labels indicating the meaning of each pattern, as well as the corresponding vibrational stimulation played twice. Then, participants were given some time to take notes or to reflect on an eventual memorisation strategy. After this reflective phase, all the patterns were played once again to reinforce the association with their labels.

After this phase, immediate recall was tested. This was done by presenting the patterns in a random order, with a 2s interval after each pattern presentation. This phase was followed by a debriefing on correct and incorrect memorisation. The most difficult to remember patterns were replayed.

Participants' long-term memory was then retested 48h after the first test. The procedure of this long-term memory test was the same as the one used for the short-term memory test.

5.5.3 Major Results

The number of correctly recalled patterns ranged from 2 to 10, both for the short- and long-term memory test. On the average, participants recalled correctly 7 patterns immediately after the first learning phase. The recall performance was a little bit better 48h after the first test. 8 items were then recalled correctly. See Table 1.

Table 1 Items for which the best recall performance was observed. The percentage indicated the percentage of correct recalls.

	Short-term memory	Long-term memory
Error	87.5%	87.5%
Big roundabout	83.3%	83.3%
Y-junction	83.3%	91.2%
Vertical barrier	70.8%	75%
Stairs	66.7%	66.70%

Beware uphill slope	66.7%	75%
Small roundabout	62.5%	75%
Door behind	62.5%	83.3%
Porte à droite	58.3%	95.8%
Beware downhill slope	54.2%	54.2%

Immediately after the test, participants recall best the patterns presenting an erroneous action or decision, a big-roundabout or a Y-junction. The patterns presenting a vertical barrier, stairs and uphill slope are also recalled correctly in the majority of the case. The pattern indicating a downhill slope and a door on the right are less well recalled compared to the others.

Fourty-eight hours after the first test, the results are different. The pattern for which the best performance is observed is the pattern indicating door on the right. The Y-junction, the big roundabout and the error message are still well recalled.

5.5.4 Discussion

The results of the study on the memorisation of vibrational patterns presented on the VIFLEX are very satisfactory. Thus, around 80% of the presented patterns were correctly recalled by the majority of test participants. This tendency is observed both for short- and for long-term memory.

In addition, patterns based on visual analogies (such as the roundabouts or the Y-junction) or on vibrational dynamics (such as the error message) allow better better learning and recall. These results suggest a connection between visual, haptic and sensorimotor memory, which should be investigated in future studies.

As for the patterns which provoked an unsatisfactory performance, we can note that they are not distinctive enough and are often confounded with similar patterns (e.g. uphill and downhill). However, when participants reflect on their erroneous recalls, their performance improves greatly. An example of this tendency is the pattern presenting a door on the right. This shows the importance of high-level cognitive processes for perceptual learning, memorization and recall.

5.5.5 Guidelines for D1.4

A number of design guidelines can be derived from this study:

Simple and universal visual analogies are a very good support for the design of intuitive and easy-to-remember patterns. They should preferred to abstract associations, which are less easy to grasp at first sight and will take more time to learn.

Simple, easy-to-perceive and itegrated shapes for the tactile patterns should be used. The study showed that shapes such as circles and lines are easier to perceive than more complex shapes, for

which the user has to make an almost conscious cognitive effort in order to build a mental representation of these shapes.

Patterns should be easily distinguishable from each other in order to limit the possible confusions. Patterns that are similar are likely to be confused and lead to increased error recognition rates.

The intensity of the tactile stimulation (frequency or frequency and amplitude when these are related) should be used in order to transmit alerts. The length of the stimulation can also be added as a possible parameter to manipulate, i.e. short bursts could be used to indicate alerts and messages with mandatory character

When users need to recall haptic patterns, the limitations of the span of haptic memory should be taken into account. Our study showed that the span of both short-term and long-term haptic memory ranges from 3 to 7 patterns, if these are designed according to the guidelines above. In this sense, interface designers should not overload user's haptic memory with more than 7 patterns.

5.5.6 Proposed HCI Toolkit Modules

Support for the ViFlex already exists within the toolkit. However, we propose a further module to allow the patterns that we have determined to be effective to be easily presented by developers. This should work at both a high level (so the developer does not need to worry about the forces sent to the ViFlex) but also at a lower level, to allow our patterns to be combined with other stimuli that may be being transmitted via the ViFlex. In this way the developer can easily use the patterns developed, but have more flexibility when needed. At least the patterns that showed high memorability (>60% recall) should be included in this module.

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5.6 Pointing Angle and Circle Radius Size for Tactile Wayfinding

5.6.1 State of The Art

One basic question for the pointing type of interaction is the angle interval in which the user gets feedback. Some earlier works have partially addressed this (see state of the art in (Magnusson, Rassmus-Gröhn, Szymczak, 2010) and D2.1). User strategies and initial results have been published in (Magnusson, Rassmus-Gröhn, Szymczak, 2010), and the current article reports a more in depth analysis of the results reported in (Magnusson, Rassmus-Gröhn, Szymczak, 2010) and D2.1.

The investigated interaction is illustrated in Figure 14. The application has a database of GPS locations and the user is guided towards the next location in the sequence by audio or vibratory feedback. 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 towards the next point in the sequence.

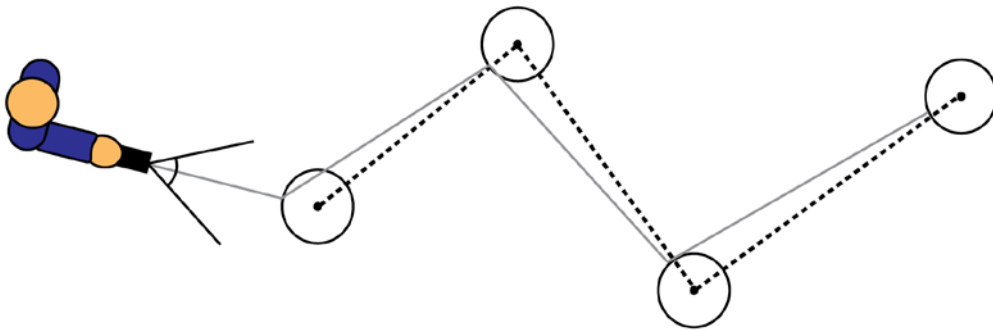


Figure 14 The interaction principle

In Figure 14 the track of GPS points is shown together with the circles around each point. The grey line indicates the path a user would follow if he or she walked in the direction pointing directly towards the points. The angle interval around this direction which will also generate positive feedback is indicated in front of the device.

5.6.2 Research Questions

Based on the previous investigations we sought to answer the following research questions about angle size and landmark size in wayfinding:

What angles are suitable for pointing based guiding?

What is the effect of changing the circle radius around the GPS location?

5.6.3 Study Outline & Results

Inspired by (Williamson, Robinson et al, 2010) we decided to implement a simple computer simulation to gain a better understanding of the interaction. We had seen in (Magnusson, Rassmus-Gröhn, Szymczak, 2010) that two basic user strategies existed: 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 we simulated navigation towards 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 behaviour 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.

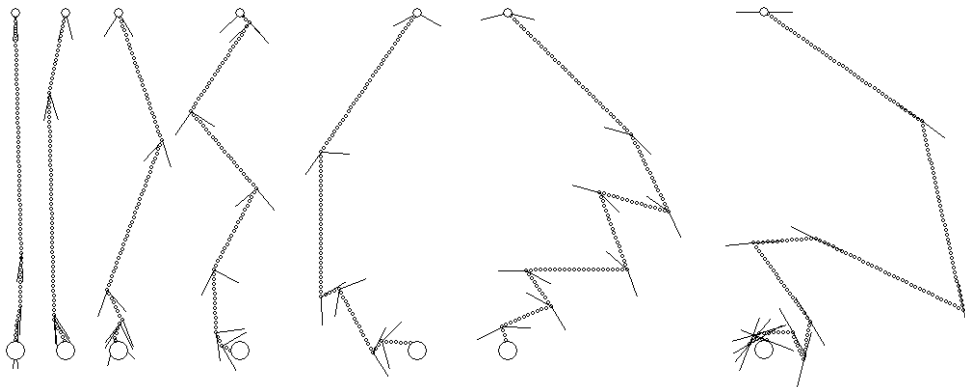


Figure 15 A selection of random tracks for the angles 10°, 30°, 60°, 90°, 120°, 150° and 180° (left to right).

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 (Magnusson, Rassmus-Gröhn, Szymczak, 2010)), they did not in general change direction until the feedback indicated this was necessary.

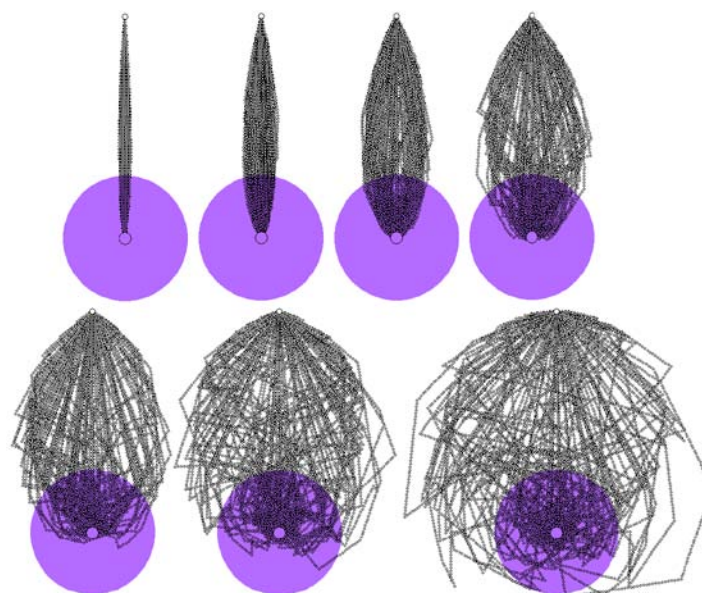


Figure 16 Simulation results for the angles 10°, 30°, 60° and 90° in the top row and 120°, 150° and 180° in the bottom row (increasing angles to the right). The large transparent area indicates the goal area in the 10m radius condition

Figure 16 shows trails for 10°, 30°, 60°, 90°, 120°, 150° and 180° (these were the angles used in (Magnusson, Rassmus-Gröhn, Szymczak, 2010)). 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 1m and 10m. The result of the simulations can be seen in Figure 3.

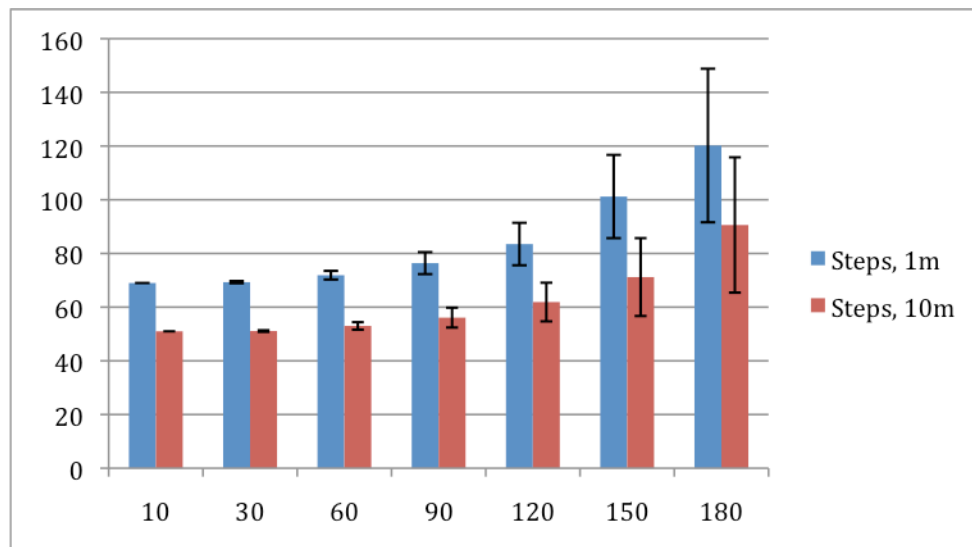


Figure 17 The number of steps for different angles in the 1m and 10m conditions (error bars indicate the standard deviation).

The average number of steps it took to reach the goal can be seen in Figure 17, and the average number of turns is found in Figure 18.

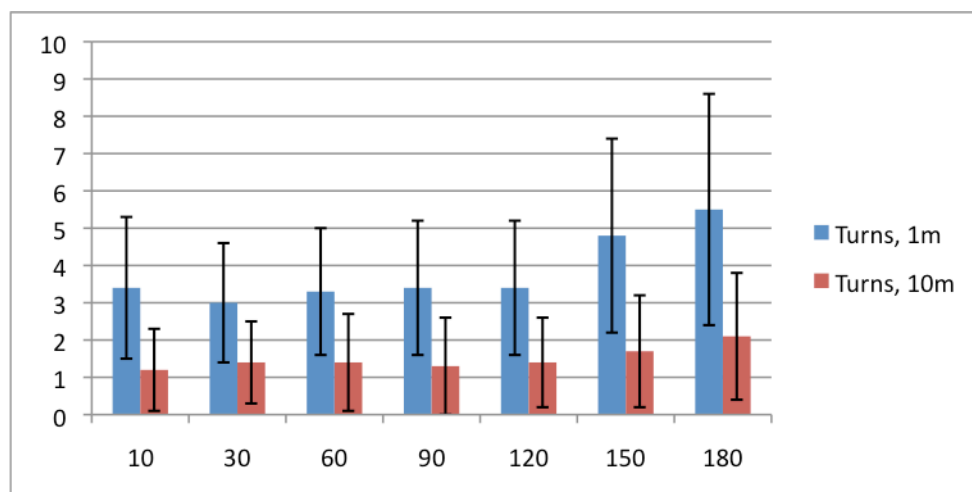


Figure 18 The number of turns for different angles in the 1m and 10m conditions (error bars indicate the standard deviation).

As was expected the increase in goal circle size is comparatively more beneficial for the wider angles. We 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 Figure 19.

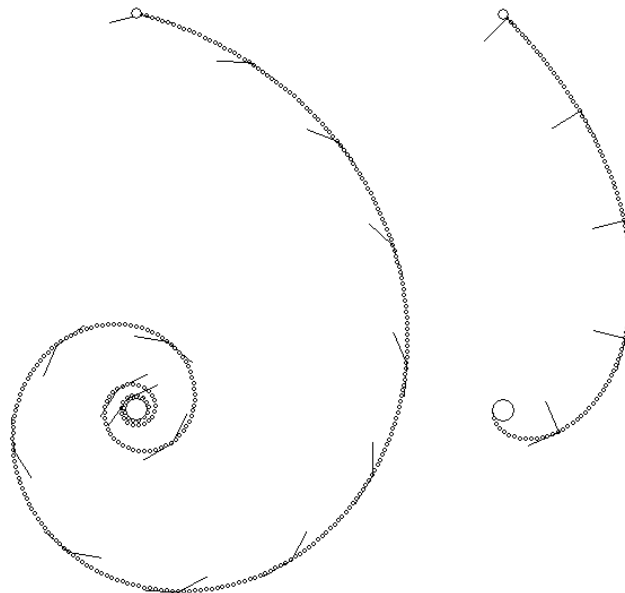


Figure 19 Worst case trails for 150° and 90°. The angle interval is indicated at regular intervals.

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 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 in to 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.

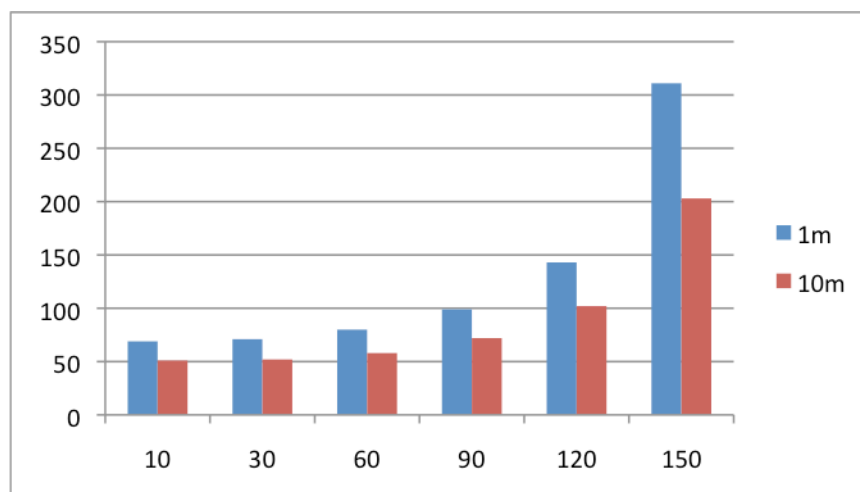


Figure 20 Number of steps to reach the goal with a fixed angle deviation in the 1m and 10m conditions

The increase in the number of steps in the worst case scenario for a 1 m and 10 m goal circle is shown in Figure 9. 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 (Strachan, Murray-Smith, 2009) there are both heading and position inaccuracies. The compass does not 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 (Magnusson, Rassmus-Gröhn, Szymczak, 2010), 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.

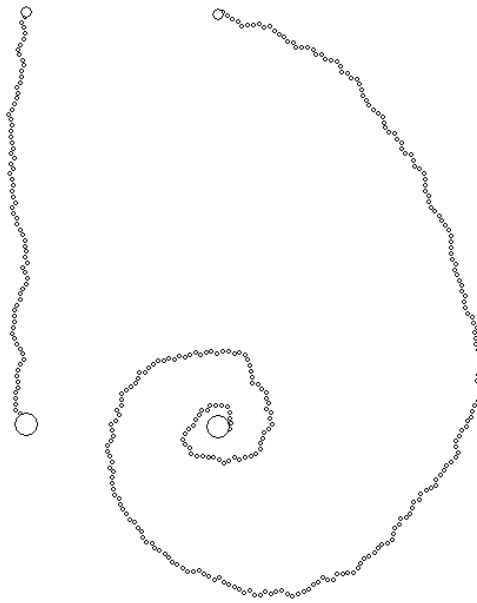


Figure 21 Trail with 40° angle deviation. One trail using the random interval approach with a 10° angle interval (left) and one worst case trail for 150° (right)

As expected the angle fluctuations had most effect on the narrow angle intervals. The simulated trails do not look that different (see figure 8 where an angle deviation of $\pm 40^\circ$ 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° degree 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.

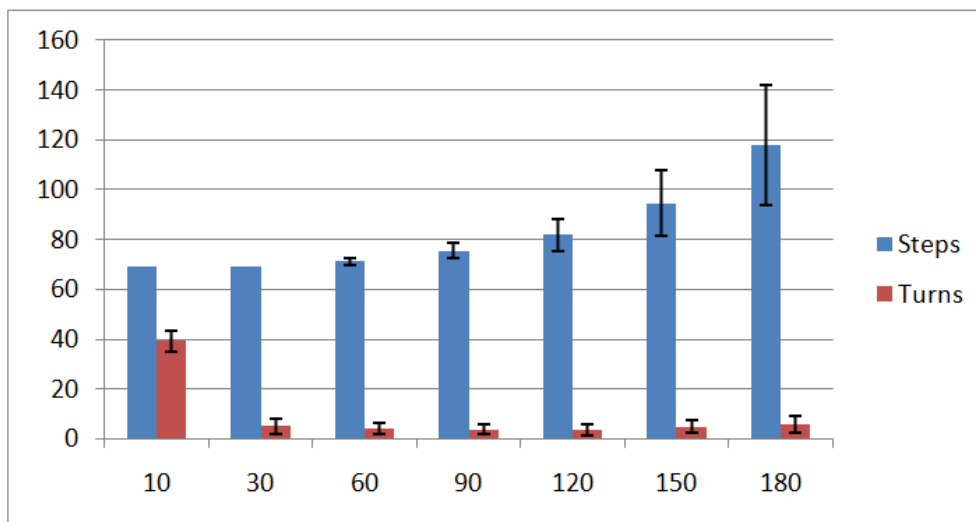


Figure 22 The number of steps and turns for different angle intervals given a 10° angle deviation and a goal radius of 1m

Figure 22 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 loses 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 Figures 4 and 5).

To round off this section we end by looking at the effect of the GPS jumps. In Figure 23 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).

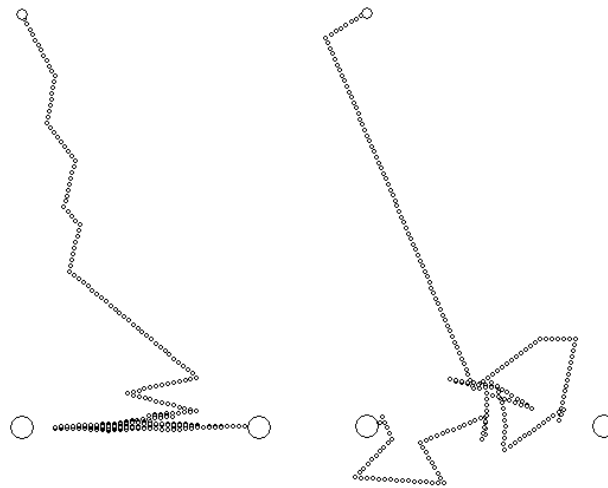


Figure 23 Trails showing GPS jump effect. 10° to the left and 180° to the right

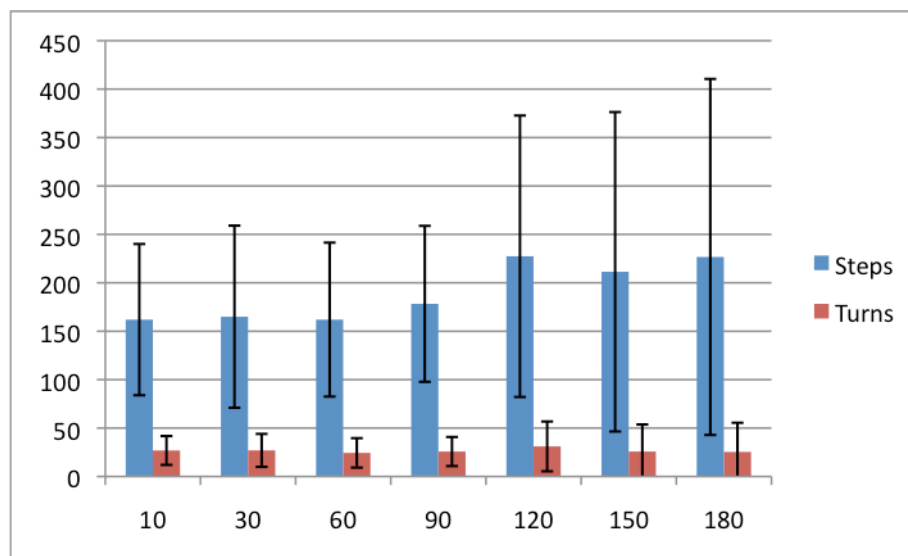


Figure 24 Number of steps and turns for a goal radius of 1m (given the described GPS jump effect).

Figure 24 and Figure 25 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 Figure 11 implies that for a small goal radius a disturbance where the GPS location jumps really influences navigation times.

Figure 25 on the other hand (10 m goal radius) is much closer to the undisturbed condition shown in Figure 4. 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 Figure 3 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.

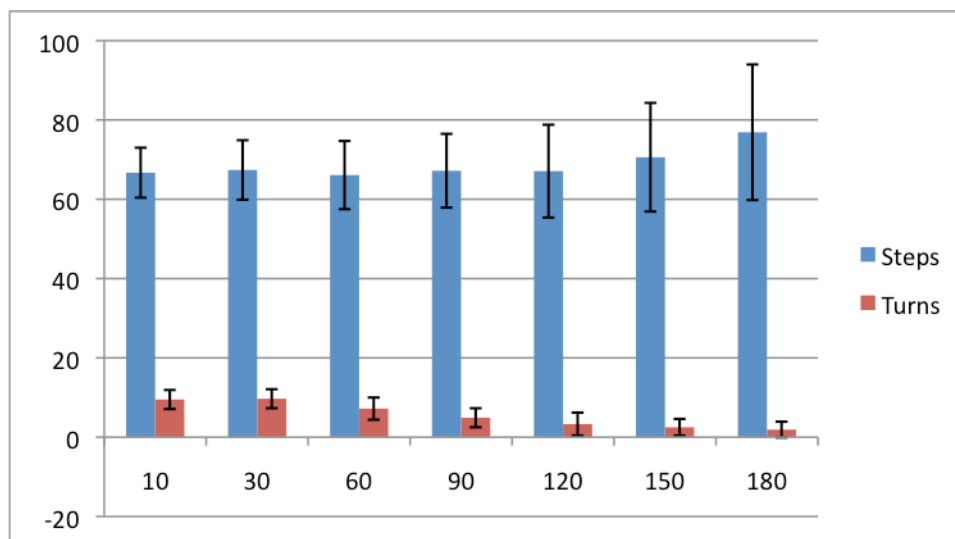


Figure 25 Same as Figure 11 but with a goal radius of 10 m.

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. The results of the outdoor tests are reported in (Magnusson, Rassmus-Gröhn, Szymczak, 2010) and in D2.1. We summarize the results in Figure 26 and Figure 27.

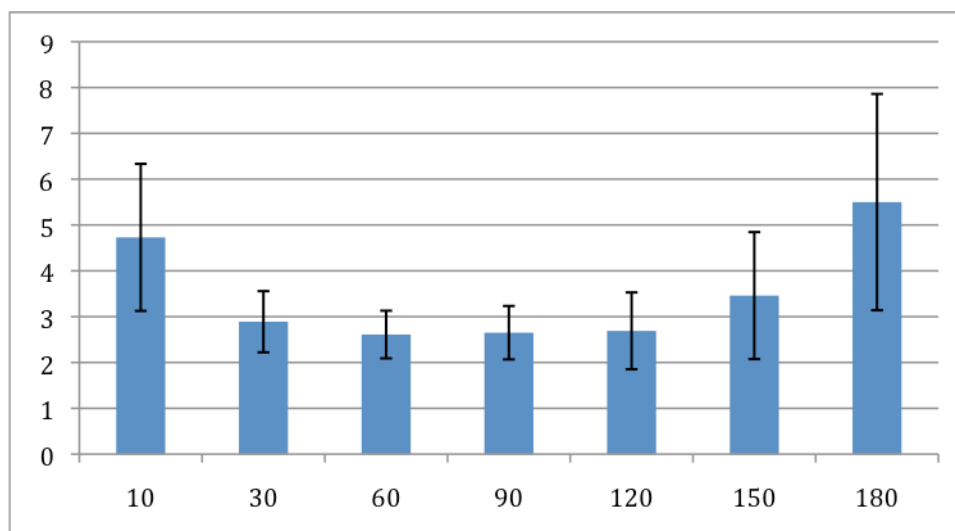


Figure 26 Time to complete for the different angles. Error bars indicate the standard deviation.

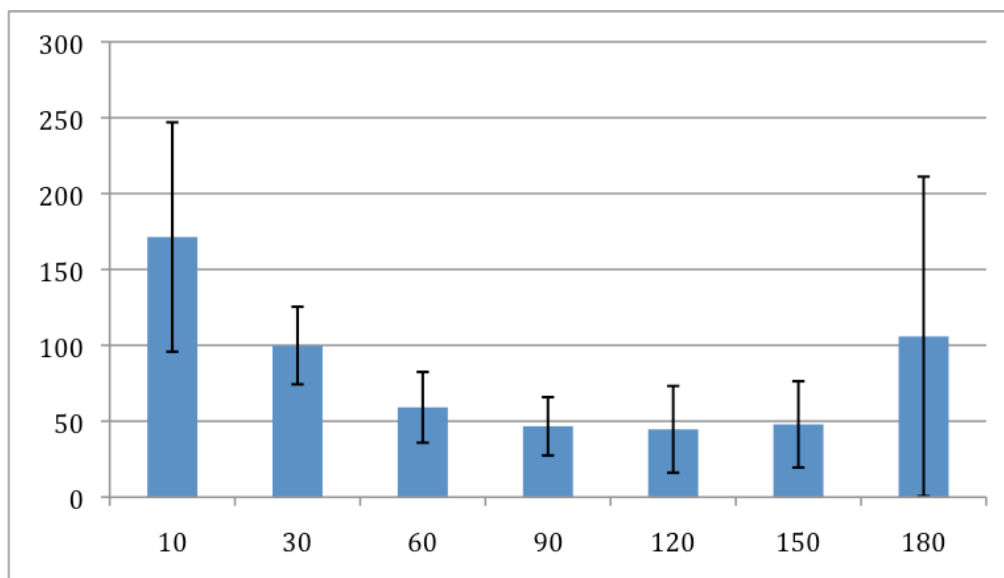


Figure 27 Number of times the user lost the signal for different angles (error bars give the standard deviation).

We also complemented these by investigating the effect of the circle radius.

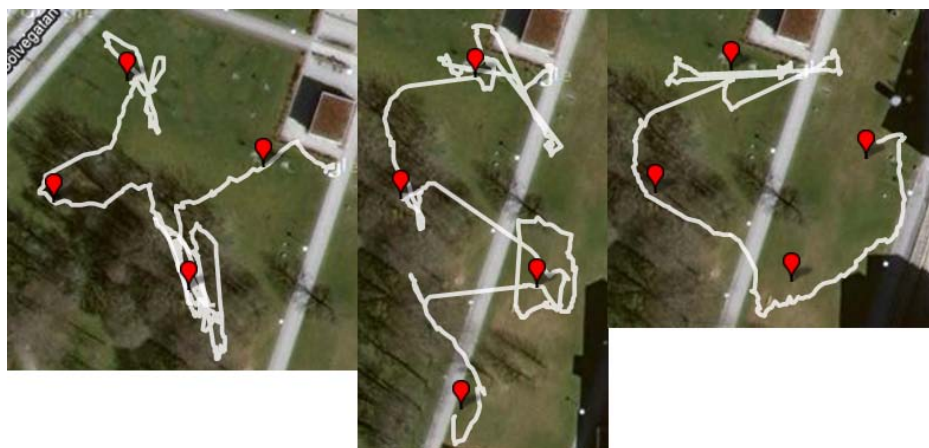


Figure 28 Trails for 1, 2 and 5 m circle radius.

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. For the small circles (Figure 28) we had a lot of problems with jumps in the GPS signal while the cases with larger circle radii (Figure 29) were less affected (just as the simulation results predicted).



Figure 29 Trails for 10 and 20 m circle radius

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.

5.6.4 Discussion

Comparing the behaviour observed in the previous outdoor study ((Magnusson, Rassmus-Gröhn, Szymczak, 2010) and D2.1) to the simulation results we see both the kind of turns appearing in the random simulation as well as curved path indicating a more continuous update of the direction (cf the worst case simulation). This is in agreement with the observation made in (Magnusson, Rassmus-Gröhn, Szymczak, 2010) that some users kept scanning as they were walking, while others tended to walk as soon as they got a steady signal.

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 (Magnusson, Rassmus-Gröhn, Szymczak, 2010):

- 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° to 60°.
- If you want a design that puts small cognitive load on the user it is better to use wider angles. We recommend 60° to 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 maybe even run (e.g. jogging applications) wider angles are preferable.

The 60° used in (Williamson, Robinson et al, 2010) 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 (Ahmaniemi, T., Lantz, V., 2009)). 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 10m.

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.

5.6.5 Guidelines for D1.4

- 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° to 60°.
- If you want a design that puts small cognitive load on the user it is better to use wider angles. We recommend 60° to 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 maybe even run (e.g. jogging applications) wider angles are preferable.
- Be careful to make the circle around the goal point large enough to accommodate signal fluctuations. We recommend a radius of at least 10 m.

5.6.6 Proposed Toolkit HCI Modules

This work does not directly lead to toolkit modules, however the results/recommendations are applicable to bearing modules that are being included in the toolkit, and the guidelines we have derived should be incorporated whenever such a module is implemented.

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5.7 Intuitive Vibration Pattern Coding of Distances

The first part of this study is a small investigation done to check up how distance can be coded intuitively by vibration patterns on a mobile phone. The studies in D1.1 (The Mobile Oracle) indicated distance to be an interesting parameter, but looking at the literature it seems it is not clear how distance should be coded “intuitively” into vibration patterns.

We used the results from the initial study to design a simple test application which guides a person to an area (instead of a point). One conclusion from the initial user work was that points were not enough, and that areas were also needed for open squares etc. In our WP5 work we also noted that for big buildings it can be difficult to know where to put the point – should it be in the middle of the building or at the door?

5.7.1 State of The Art

For guiding a person to an area the present work is to our knowledge the first of its kind. There has been a lot of work on showing points of interest - eg (McGookin, Brewster, Preigo, 2009), (Magnusson, Breidegard, Rassmus-Gröhn, 2009), (Robinson, Eslambolchilar, Jones, 2009), (Robinson, Jones et al, 2010), (Magnusson, Rassmus-Gröhn, Szymczak, 2010), but we have not been able to find anything dealing with areas. The haptic torch (<http://www.reading.ac.uk/isrg/isrg-haptic-torch.aspx>) which allows users to find the location and distance of an object makes use of ultrasound and is designed to help with obstacle avoidance, and does not deal with map or POI information.

Looking at how vibration can be used to code the distance to an object we see that with a vibration motor one basically has two parameters that can be manipulated: pulse length and off time. In (Troy, McDaniel et al, 2009) a constant pulse length of 50ms is used, and the distance coding used is to have shorter off times with closer distance. The work in (Troy, McDaniel et al, 2009) is focused on discrimination – the assumption that shorter off time maps to short distance is not tested. The same assumption is made in (Troy, McDaniel et al, 2009), (VanErp, Hendrik, VanVeen, 2005) where it is assumed shorter pulses should be given nearer the goal (although it is also recognized that when one is far away and needs to select a new direction it is important to get pulses often enough).

Furthermore, these studies test walking speed, and not intuitiveness. In (Pielot, Krull, Boll, 2010) rhythm based, duration based and intensity based encodings are explored. For the rhythm based coding the number of pulses indicate distance – more pulses means further away. In the duration based coding stimulus duration is coded to that longer stimuli map to longer distances, while in the intensity based coding stronger stimuli are given with closer distances. This study reports on perceived simplicity of judging the distance for the different mappings, but participants were able to learn the patterns so first impressions on intuitiveness were not recorded. In (Asif, Heuten, Boll 2010) rhythm, intensity and duration is again investigated. In (Asif, Heuten, Boll 2010) the study designs were based on a pilot study with one participant who indicated that she got stronger sensations with fewer pulses (opposite to the designs in eg (Troy, McDaniel et al, 2009)). Thus all designs in (Asif, Heuten, Boll 2010) have few pulses at close distance. Since we wanted to include the distance to the area in the feedback given to the user and there seems to be no clear

recommendation for what is intuitive, we decided to do a simple test where we included both the mapping we thought intuitive as well as the opposite.

5.7.2 Study Description

For the first test we implemented an application which allowed users to scan the area around them to locate two objects. These objects were put at different distances, and the task was simply to tell the test leader which of the objects they thought was the closest one.

The first prototype treated on time and off time as independent variables, and one could test constant off time with a distance coding for the on time as well as the opposite (constant on time with a distance coding on the off time). The first pilot of the version with varying on time gave very different results – some test persons thought long pulses were closer, while others thought the shorter pulses were closer (the results were roughly distributed 50-50). The reason given for shorter pulses being closer was that they came more often, a comment which serves as a reminder that on time and off time are really not the correct variables – a constant off time is not perceived as pulses come equally often if the on time varies – the parameter one should make use of is the *period* (on time + off time).

Thus the test application was updated to make use of period and pulse length (on time) as variables. In one application we kept the period constant and varied the pulse length, and in the other we kept the pulse length constant and varied the period.

For the second test we implemented an application where we used the design versions that were considered most intuitive in the first test to lead users to two different objects (one object had sides that was three times longer than the sides of the other object making it 9 times bigger). This application also provided audio information to tell the user once he or she was inside a building. This application was pilot tested qualitatively.

5.7.2.1 Interaction design

To be able to experience an area of interest from a distance we suggest one uses an interaction where the user scans the environment with the device. If the device points towards the object, feedback (audio or tactile) is provided. When the device does not point towards the object no feedback is given. The basic principle for the interaction is indicated in Figure 30.

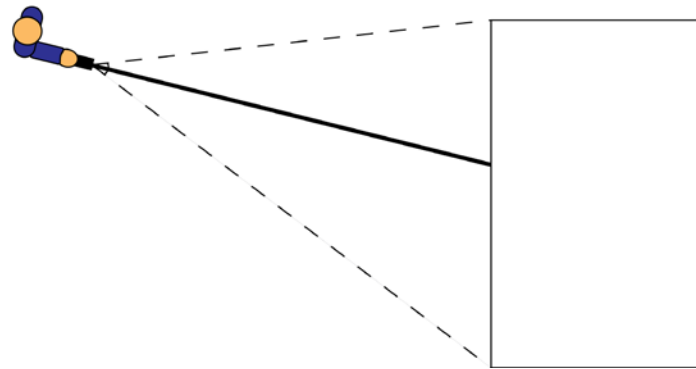


Figure 30 Scanning and area of interest.

The thick line indicates where the device is pointing. If this line intersects any of the sides of the object non-visual feedback is generated. The distance used to generate the feedback is the distance to the intersection point that is closest to the user. In our current prototype we use different vibration patterns (with a pulse length or period that changes depending on the distance to the area) as the non-visual feedback when the user is outside the area. Feedback to indicate that the user is inside an area is also needed. In our current prototype the vibration is turned off, and a sound file is played using different sounds for different objects. The volume of the sound is kept constant inside the object and is turned off immediately the device moves outside.

5.7.3 Research Questions

The research questions we try to address are: How do people intuitively map vibration pulse length and period to distance? How do people perceive non visual AOI information coded as we suggest when using it to explore and locate geo referenced areas?

5.7.4 Study Outline

In order to test different ways of coding the distance using vibration patterns we implemented a prototype which allowed users to scan the area around them to locate two different areas. These areas were put at different distances, and the task was simply to tell the test leader which of the objects they thought was the closest one.

Our first prototype used pulse length and off time as variables, and one could test constant off time with a distance coding for the pulse length as well as the opposite (constant pulse length with a distance coding on the off time). The first pilot of the version with varying pulse length gave very different results – some test persons thought long pulses were closer, while others thought the shorter pulses were closer (the results were roughly distributed 50-50). The reason given for shorter pulses being closer was that they came more often, a comment which serves as a reminder that pulse length and off time are really not the correct variables – a constant off time is not perceived as pulses coming equally often if the pulse length varies – the parameter one should make use of is the period (pulse length + off time). Thus the test application was updated to make use of period and pulse length as variables. In one version we kept the period constant and varied the pulse length, and in the other we kept the pulse length constant and varied the period.

5.7.5 Tests and Results

The user was given the device and told that it was a scanner that allowed him or her to locate two buildings in the vicinity. The user was told to locate the two buildings (while standing still) by pointing the device in different directions. Once the buildings were located the user was asked to tell the test leader which one he/she thought was closest.

In the first part of this study we tested the design where the period was kept constant and the pulse length varied (the short pulse was at 40ms and the long pulse at 800ms). 13 users did this test (7 women and 6 men, ages: 14, 16, 27, 37, 42, 42, 43, 48, 50, 53, 54, 60, 65). 12 of the 13 users thought the longer pulse corresponded to a closer object. The argument given spontaneously by many of these test persons was that the longer pulses felt more intense and thus they were felt to correspond to a closer object. One user disagreed, and said the opposite with the motivation that the shorter pulses felt “blocked out” and thus the object had to be close to block out the pulses. In the second part of this study the on time was kept constant (40ms) and the period varied (short period 100ms and long period 900ms). 12 users did this test (8 women and 4 men, ages 14, 20, 21, 38, 42, 43, 48, 50, 53, 53, 62, 78). All 12 users agreed that a shorter period corresponded to closer distances (the person who had disagreed with the majority in the first test did also the second test). These results are significant (t-test, $p < 0.001$).

5.7.6 Area Exploration

In the area exploration test we asked the test person to walk around the area and explore while thinking aloud. The user was given the information that the device was a scanner that provided vibration in the direction of objects and that this vibration depended on the distance. The user was told that there were two objects, and the general area which contained the objects was indicated. The user was also asked to try to say something about the sizes of the objects. The objects used in the test are shown in Figure 31.

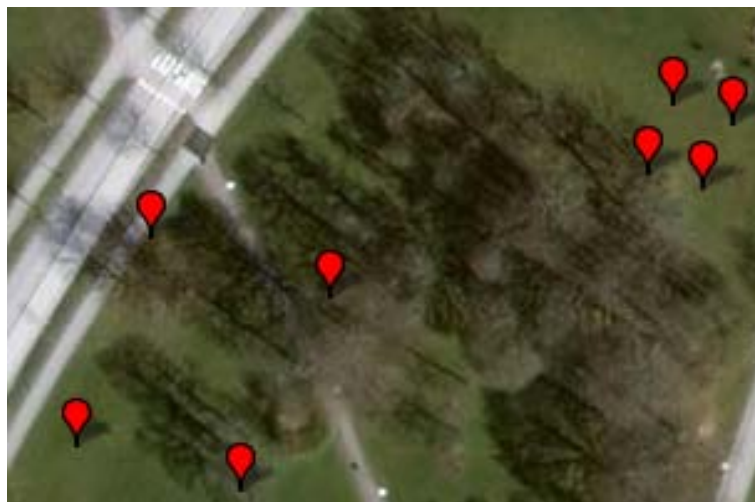


Figure 31 Test areas (GPSVisualizer, www.gpsvisualizer.com/).

Both period and pulse length coding was tested making use of the versions the previous test had indicated as more intuitive. For each we tried two different distance sensitivities: either the pulse length/period started to change at 50m from the object or at 500m from the object. The pattern then changed linearly depending on the distance towards the target object. For the period coding the pulse length was kept constant at 40ms (period from 100ms to 1s), while for the pulse length the period was constant at 1s (pulse length from 40ms to 940ms). This test was done by three persons (two women and one man, ages 24, 42 and 50).

5.7.7 Results

All users were able to find the areas, and both period coding and pulse length coding were said to work, although there were some comments that it was easier to notice the gradual changes towards the object when it was the period that changed. One test person commented that the pulse length coding made it easier to discriminate between different objects if one object was far away (short pulse versus long pulse). Looking at which distance sensitivity that was preferred for the two designs, the period design was said to work better when the change rate was less steep (start at 500m). The pulse length coding on the other hand was said to work better for the 50m starting point which is in agreement with the observation that changes in pulse length are more difficult to feel (this design leads to a steeper increase). It was commented that sweeping the device close to a wall using the period design created an illusion of being close to a wall. Problems with GPS updating and accuracy made it quite hard to judge the size of the objects, even though one object had a side that was three times longer than the side of the other object.

5.7.8 Discussion

The initial study provides what we feel is a good indication for the mappings:

- Longer pulses (with a constant period) should be mapped to closer distances
- Shorter periods (with constant pulse length) should be mapped to closer distances

Our results agree with the designs used in (Troy, McDaniel et al, 2009), (VanVeen, Spapé, Erp, 2004), (VanErp, Hendrik, VanVeen, 2005), while they disagree with some of the mappings in (Pielot, Krull, Boll, 2010), (Asif, Heuten, Boll 2010). In (Pielot, Krull, Boll, 2010) shorter tactile stimuli are used at closer distances (opposite to our recommendation), while the recommendation for longer pulses agrees with two of the designs in (Asif, Heuten, Boll 2010). In contrast the recommendation for shorter periods closer to the object does not agree with the designs used in (Asif, Heuten, Boll 2010). There is obviously room for more advanced designs with pulse trains etc, but if one wants intuitive designs these mappings should preferably not be mixed - as they would be if one has long pulses and periods at close distances and short pulses and periods at long distances (Asif, Heuten, Boll 2010).

The results of the qualitative test showed that users can deal with both pulse length and period based coding. On the whole there was some preference for the period based coding since it was felt to be easier to feel a gradual change towards the object, but one possible advantage of the pulse length

coding was said to be that it could make it easier to discriminate between different objects at different distances. It is still clear that the number of large objects that can be dealt with simultaneously is quite low – if this type of design is used it should be used for few, prominent features in the environment such as a town square or some big building like a church/cathedral. If the comment on being able to “feel” a wall holds for a larger sample of users, the period based coding appears promising for historical/archaeological themes – this type of design could be used to indicate walls that are no longer visible in the environment.

On the other hand this effect is very dependent on signal quality unless one designs transitions/walls with signal quality problems in mind – in our case we had a sharp transition between inside and outside the rectangle. Given the poor signal quality during the tests this was not a good design and a less sharp feedback around the border is likely to work better.

A built in feature of this type of design where one scans for an area (and not a point) is that objects get smaller as they get more distant. This could potentially lead to “automatic filtering” – when objects are too far away they become “invisible” since they are too small to “see” (i.e feel). Just as is the case with vision, small objects disappear more quickly – in fact the results from the study on angles (Magnusson, Rassmus-Gröhn, Szymczak , 2010) indicate that this design is not suitable for too small objects.

Alternatively one could use this feature to filter POI information with distance – if all POIs are assigned rectangles of equal size, points too far away will be filtered out (although care needs to be taken that the angle covered is big enough at reasonable distances without being too large/confusing at close range).

This design will be further tested and elaborated within the development of the Lund Time Machine demonstrator.

5.7.9 Guidelines for D1.4

From the work undertaken, we can derive important guidelines on the polarity of tactile patterns and how these should be mapped to distance. From the results obtained the following general approach should be taken:

- Longer pulses (with a constant period) should be mapped to closer distances
- Shorter periods (with constant pulse length) should be mapped to closer distances

Overlapping areas can be hard to discriminate and we recommend this interaction is used only for a few (prominent) landmarks. If the location signal quality is expected to be poor, we also recommend one avoids interaction designs that have sharp transitions in specific locations.

5.7.10 Proposed Toolkit HCI Modules

The results of this study will be incorporated into the bearing and scanning modules. The bearing module is the module which provides the user with an indication of a direction (and a distance) in

order to be guided to a target. The scanning module allows the user to scan for objects in the vicinity (multiple objects at the same time).

We also suggest to incorporate our algorithms for areas into an area of interest module that should be possible to use together with or alternative to scanning/guiding using points of interests.

Finally, we suggest that one should investigate using this design for the filtering of points of interest within the WP5 work.

5.7.11 References

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5.8 Evaluations of the Tactile Compass

This section describes the continued work and the on the Tactile Compass, first presented in D2.1 (p.96). In the previous work it has been applied to display the direction of landmarks (2nd important requirement according to D1.1 (p.61). In this work we apply it to the most important requirement according to D1.1 (p.61): providing walking directions.

To apply the Tactile Compass to provide directions instead of landmark locations we employ it as waypoint navigation system. Privately residing in the pocket, a handheld device creates vibration patterns indicating the direction of the next waypoint. Like a sixth sense it constantly gives the user an idea of how the route continues. Compared to turn-by-turn instructions, the user continuously receives directional information, not only when reaching a turn.



Figure 32 Vibration patterns indicate the direction of the next waypoint of a route.

As illustrated in the above Figure these tactile icons are used to indicate the direction of the next waypoint, so the user remains aware of the waypoint's location. By walking into the direction of the waypoint the user is guided along the route until reaching the destination.

The aim of using the tactile compass instead of a visual system is to provide an efficient hands-free navigation aid while reducing the users' distraction, which are both important assets of a navigation system according to D1.1.

This section reports from the first evaluation where such a concept is experimentally evaluated in comparison and in combination with a visual navigation system. 21 participants navigated 63 routes

in a busy city center. We found evidence that the concept of a tactile compass does not only form an efficient navigation aid but can also reduce the users' distraction significantly.

5.8.1 State of The Art

Providing multimodal feedback for communicating information about the environment, such as the course of a route, has been studied for many years now. Recently, Frohlich et al. (2011) introduced the term *sixth sense* for such interaction paradigms. The idea is that by cueing spatial information digitally the user.

Early examples using auditory interfaces are AudioGPS (Holland et al. 2002) and GPS tune (Strachan et al. 2005). Both systems use the stereo panning of an auditory signal delivered by headphone to convey the general direction of a geo location, such as the travel destination.

To avoid impairing the sense of hearing and the loss of situational awareness as a consequence, the sense of touch has been investigated for conveying spatial and navigational information. More than a decade ago Tan and Pentland (1997) proposed an 3x3 array of tactile actuators worn on the back for conveying navigation information. By e.g. having a series of pulses moving from the left to the right of the display could be used to indicate "turn right" or "right-hand side".

Bosman et al. (2003) investigated a tactile display for turn-by-turn navigation, where two actuators were worn at the wrist. In a user study taking place in an office building they could show that the tactile navigation cues performed better compared to following the building's signposts in terms of effective walking speed. A similar layout with two actuators attached to the fingers was proposed by Ghiani et al. (2008) for guiding blind people in a museum. This tactile display was compared to a speech-based navigation system. Measuring completion time and preference, no significant differences could be found.

A more complex tactile display for navigation (and more) was proposed by Tsukada et al. (2004). Their so called ActiveBelt is a belt equipped with eight vibro-tactile actuators. It allows creating tactile stimuli around the wearer's torso to "point" into a horizontal direction. By pointing into the direction the user has to go, such tactile belts can effectively guide pedestrians along a route (Elliott et al. 2010). Tactile belts have also been proposed to support map-based navigation. By constantly indicating the direction of the destination the navigation efficiency and the level of distraction develop positively (D2.1, p.55). Tactile belts have even been used to indicate the presence of several objects in the vicinity of the wearer (Lindeman et al. 2005) / (Ferscha et al. 2008) / (D2.1, p.111). Altogether, cueing directional information through body locations by tactile belts has found to be effective and very intuitive.

Disadvantages of tactile belts are that they are custom-made hardware devices, which might not always be available when the user is traveling. User might also just not want to carry such a device if navigation support is not required too often. A solution to this problem is another emerging interaction paradigm, which Frohlich et al. (2011) refer to as the *magic wand*. Users do pointing gestures with common handheld devices to access information about a distant object. Recent implementations provide tactile or auditory feedback when the user roughly points into the correct

direction of the cued geo location (Magnusson et al. 2010), (Robinson et al. 2010), (Williamson et al. 2010). Thus, by actively scanning the environment the user can stay aware of the general direction of her or his travel destination. It has been shown that this technique is very intuitive and allows users to effectively reach a given. However, the intuitiveness is traded with the drawback that the device has to be held in the hand, which has been found undesirable by some users (Robinson et al. 2010).

The tactile compass fills this gap by providing an information presentation method that conveys directional information, such as tactile waist belts, but at the same time can be realized with common handheld devices, such as the magic wand techniques.

5.8.2 Study Description

To investigate the effectiveness and the efficiency of the tactile compass being employed as a waypoint navigation system we conducted a field experiment. 21 participants were asked to navigate through a crowded urban environment. In three conditions, they were equipped with the tactile compass, a state-of-the-art pedestrian navigation system, and the combination of both. We wanted to investigate how users perform with the tactile compass, which navigation strategies the users develop, and if the distraction can be reduced by the tactile feedback.

5.8.2.1 Material

As baseline for the experiment we used a state-of-the-art turn-by-turn navigation system. The user's position and orientation is indicated by an icon drawn onto the map. The map can be set to automatically rotate and align itself with the environment, so the "up" direction on the screen corresponds to the device's orientation. The route is highlighted on the map. Additionally an arrow icon in the bottom left corner of the screen visually indicates into which direction to go. In pilot studies we learned that many users feel embarrassed and distracted by speech output, especially in lively areas. Therefore, only visual feedback was provided.

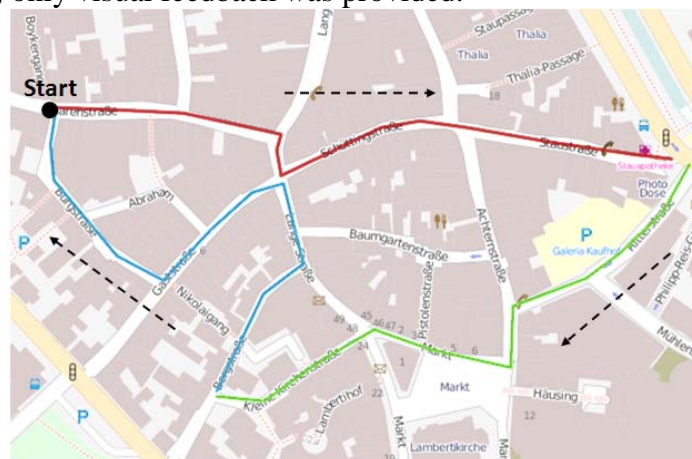


Figure 33 The three evaluation routes covering the city centre of Oldenburg

The study was conducted in the summer of 2010. It took place in the pedestrian zone of *Oldenburg*, a city in Northern Germany with about 150,000 inhabitants. The winding layout of the streets makes it difficult to stay oriented, even for locals. During shopping hours the city center becomes very

crowded, so not bumping into another person requires a lot of attention. We defined two training routes and three evaluation routes. Each route covered about 450 meters. All routes started and ended in calm, less frequented areas and led through the central, most crowded area.

5.8.2.2 Participants

21 participants (10 female, 11 male) took part in the study. Their age ranged from 18 to 41 with an average of 26.6 (SD 6.68). Prior to the study we assessed the participants' familiarity with (pedestrian) navigation systems and their sense of direction. The sense of direction was assessed by the Santa Barbara Sense of Direction Scale (SBSOD) (Hegarty et al. 2002). In a possible range from 1 (low) to 100 (high) the participants scored 54.72 (SD 15.37) in average. The participants judged their familiarity to be average with car navigation systems (3.05, SD 1.02 on a five-point Likert scale) and below average with pedestrian navigation systems (1.95, SD 1.16 on a five-point Likert scale). Although no personally identifiable information was collected all participants signed an informed consent. As appreciation, all participants received a little gift.

5.8.2.3 Design

The navigation system configuration served as independent variable with three levels: *visual*, *tactile*, and *combined*. In the *visual* condition the participants only used the visual feedback of the navigation system. In the *tactile* condition the screen was blinded so only the tactile compass could be used. In the *combined* condition, both, the tactile feedback and the visual feedback were available.

The experiment followed a within-subjects design, so every participant contributed to all three conditions. The order was counter-balanced to cancel out sequence effects. The following dependent measures were taken to assess the navigation performance, the cognitive workload, and the level of distraction:

- **Navigation Performance**

Inspired by previous field studies (e.g. Rukzio et al. 2009 or Pielot and Boll(2010)) navigation performance was measured in terms of completion time, number of navigation errors, number of orientation phases, and number of orientation losses. *Completion time* was defined as the time the participants travelled from start to end of each route. A *navigation error* was counted when a pedestrian took a wrong turn and entered the wrong street for more than 5 meters. *Disorientation events* were defined as situations where the participants stopped for more than 10 seconds or stopped and expressed the disorientation verbally. An *orientation phase* was counted when the participant stopped shortly (less than 10 s) to re-orient themselves.

- **Cognitive & Mental Workload**

The cognitive workload was measured by subjective and objective measures. As subjective measures we issued the widely accepted Nasa TLX (Hart and Staveland 1988) questionnaire. As objective workload measure we monitored the participants' walking speed, as Brewster et al. (2003) suggested that people walk slower when the cognitive workload increases while interacting with a handheld device. The walking speed was extracted from the GPS signal.

- **Distraction**

The distraction was quantified by measuring how much participants interacted with the mobile device and how well they could pay attention to the environment. To assess how well the participants paid attention to the environment we asked the participants to count the number of cafes, hair dressers, and pharmacies and name the sum of all of these shops at the end of the route. The score reflected the percentage of how many existing shops were noticed by the participants. Interacting with the device was divided into two groups: looking at the map and using the scanning feature of the tactile compass. The participants were considered *looking at the map* when the device was held in an angle that allowed that participant to look at the display. The participant was considered *scanning* when the device was held nearly parallel to the ground so the *scanning mode* got active. Since in the *combined* condition the user could also be looking at the map when scanning, the *scanning mode* contributed to both dependent measures at the same time. How the device was held was logged automatically by the device, so these measures could be taken without having to use a video camera.

5.8.3 Procedure

Informed consents, demographic questionnaires, and additional information were sent out to the potential participants prior to the study. Only those participants who signed the consent forms were invited to the study.

Training sessions allowed the participants to get used to the navigation system and the tactile compass. A dedicated application was developed to train the vibration patterns. It allowed the participants to explore and learn the different patterns. To complete the learning phase, 16 random tactile compass patterns had to be recognized. Response time and recognition errors were logged for later analysis.

Afterwards the participants could train the use of the application on two test routes. The first route was done with visual and tactile feedback, the second with tactile feedback only. During both routes we trained the participants to use the scanning mode or to look at the device' screen only when needed and otherwise keep the device in the pocket mode.

When the actual evaluation started we explained the participants that they had to count cafes, hair dressers, and pharmacies they pass by on their route. The navigation time started to be recorded when the route was selected on the mobile device. The experimenter followed the participant in some distance and took notes about navigation errors, orientation losses, and orientation phases. The experimenter also watched out for the number of shops to be counted when participants left the correct route due to a navigation error. When arriving at the last waypoint of the route the completion time was automatically taken. The participants filled out the Nasa TLX for the past condition and then switched to the next condition.

After having completed all three routes we conducted an open post-hoc interview with the participants. The goal was to learn about any of the participants' impressions and suggestions. Our strategy was to not ask any question unless the interview went stuck but encourage the participants to express their thoughts freely. The whole procedure took about 90 minutes for each participant.

5.8.4 Quantitative Results

All participants succeeded reaching the destination in all three conditions. In the following we present the quantitative results, comments and observations, and the identified potentials for improving the design of the tactile compass.

This section presents the quantitative results of the dependent variables. The diagrams show mean value and standard deviation per condition. Statistical significance was analyzed using ANOVA and Tukey post-hoc tests.

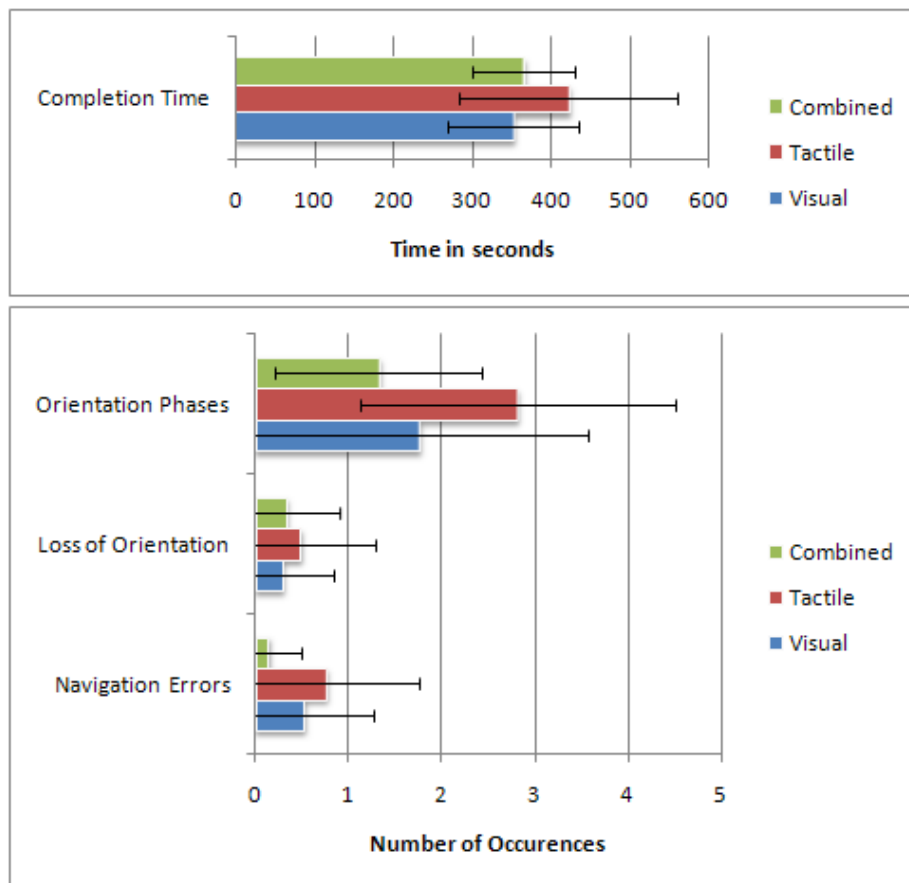


Figure 34 Navigation performance measures

Figure 34 shows the results related to the navigation performance. No significant effects could be found on the *completion time* ($F(2)=2.93, p=.06$) and the number of *orientation losses* ($F(2)=0.47, p=.63$). There was a significant effect on the number of *navigation errors* ($F(2)=3.65, p<.05$). In the *combined* condition participants took less wrong turns than in the *visual* or the *tactile* condition (both $p<.05$). Further, there was a significant effect on the number of *orientation phases* ($F(2)=4.93, p<.01$). In the *tactile* condition the participants made more short stops than in the *visual* condition ($p<.01$). In summary, participants stopped more often to reorient when using the tactile compass only. The combination of the visual navigation system and the tactile compass led to less navigation errors.

Figure 35 shows the results related to the cognitive workload. There was a significant effect on the participants' walking speed ($F(2)=5.01, p<.01$). Participants walked faster in the *visual* condition than in the *tactile* condition ($p<.01$) or in the *combined* condition ($p<.05$). Thus, the objective cognitive workload was higher when the tactile compass was present. However, the subjective judgment of the cognitive workload via the NasaTLX showed no significant differences between the conditions ($F(2)=1.04, p=.36$).

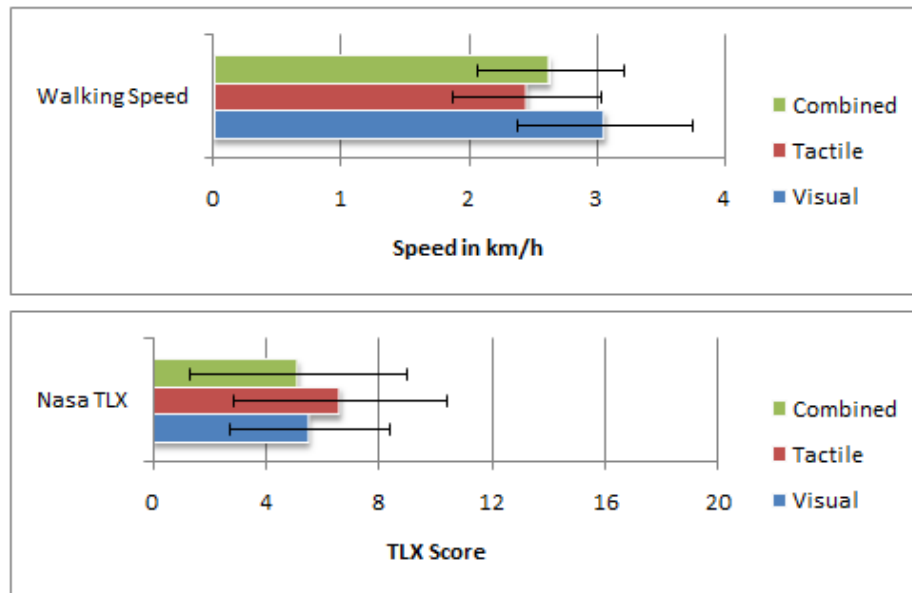


Figure 35 Cognitive Workload Measures

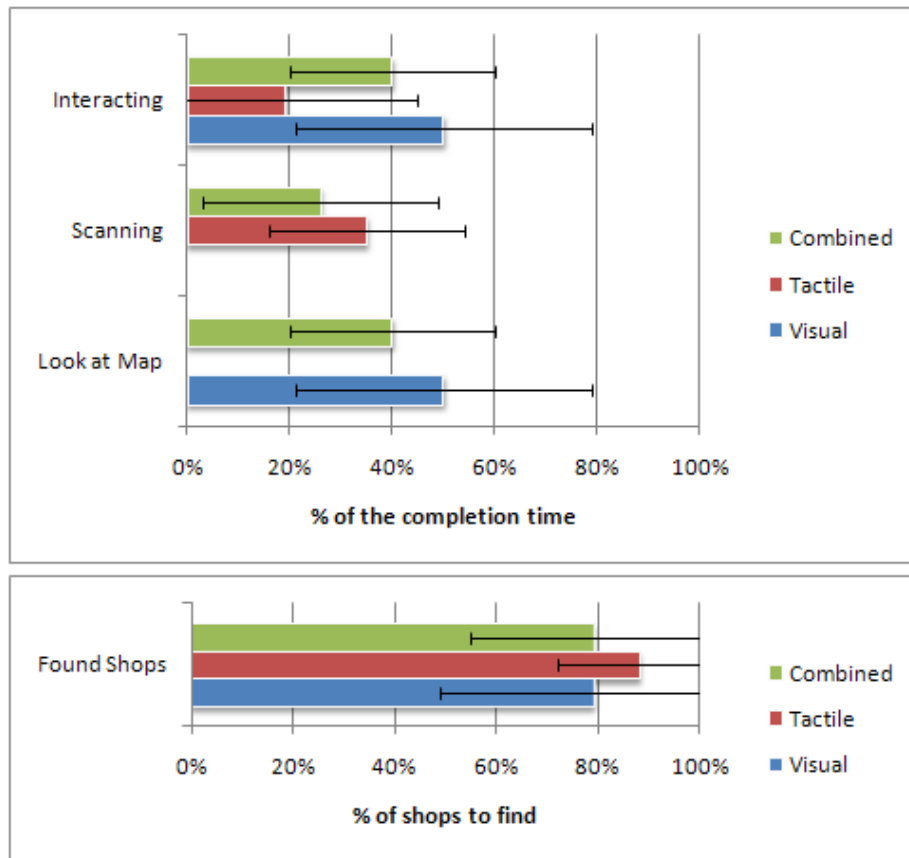


Figure 36 Distraction-related measures

Figure 36 shows the results related to the distraction. There was no significant effect on the number of shops found ($F(2)=.94, p<.40$). But, there was a significant effect on the amount of interaction ($F(2)=3.41, p<.05$). The interaction was significantly lower in the *tactile* and in the *combined* condition than in the *visual* condition (both $p<.05$). Considering only the time spent *looking at the map* in the conditions where the map was available, the participants in the *visual* condition looked significantly less often at the map compared to the *combined* condition ($p<.05$). In the two conditions where the tactile compass was present, the participants used the *scanning mode* significantly less often in the *combined* condition than in the *tactile* condition ($p<.01$). In summary, the visual feedback reduced the amount of *scanning* and the tactile compass had a positive effect on the amount of distractive interaction.

5.8.5 Comments and Observations

In the beginning of the experiment, many participants were questioning if the tactile compass was sufficiently easy to use. During the study, however, none of the participants failed interpreting the tactile patterns. One participant nicely summarized this by stating: *when reading the information sheets I never thought these vibration patterns would work. But in retrospect, it was much more intuitive than I expected.*

5.8.5.1 Navigation Strategies



Figure 37 Left: user concentrating while interpreting tactile compass patterns, right: user struggling to read the display due to sunlight reflections.

5.8.5.1.1 Visual Condition

In the *visual* condition the predominant strategy was "read 'n' run": the participants studied the map, memorized the upcoming route segment, and then passed the memorized part as quickly as possible without looking at the map. Participants using this strategy were walking faster than in any other situations we observed. Since the study took place in summer, sunlight reflections were one of the major issues in reading the map. Three participants reported to have major trouble with reading the display (see Figure 37).

5.8.5.1.2 Tactile Condition

As suggested, the tactile compass was mostly used in the pocket mode. The scanning mode was mostly used when the GPS signal strength declined, when the participants wanted to reorient themselves at a crossing, or when they desired more accurate feedback. Usually the participants pointed the device forward into their walking direction. They tried to learn the direction of the next waypoint from the pattern rather than actively pointing the device in different directions to find the "ahead" pattern by pointing into different direction. Thus, the pointing interaction studied in e.g. Magnusson et al. (2010) has rarely been observed. Although there was no technical need, there was a tendency that the participants stopped when using the scanning mode.

In the post-hoc interview many participants stated that they found the tactile compass surprisingly more easy to use than they had expected. The lack of an overview was named five times as notable drawback. Four participants stated that they were missing the map to understand how the route proceeded beyond the next waypoint. However, six participants expressed to not have missed the map in the tactile condition at all.

5.8.5.1.3 Combined Condition

The combination of visual navigation system and tactile compass was named most often as the preferred condition. The participants enjoyed to have the map to get an overview and at the same time receive constant confirmation by the tactile cues. Many participants focused on one source of information primarily and used the other as support. Eight participants reported to have relied on the map and used the tactile compass to be reminded of an upcoming turn. Seven participants reported to have primarily used the tactile compass and used the map only when being uncertain. Unlike the *visual* condition, the "read 'n' run" strategy was hardly observed in this condition.

5.8.5.2 Cognitive Workload and Distraction

Many participants stated that they were constantly monitoring the vibration patterns. Three participants explicitly mentioned that processing the constant feedback was mentally demanding. On the other hand, four participants appreciated the continuous feedback. They felt that people having bad sense of direction would greatly benefit from the constant confirmation.

With respect to the distraction, participants appreciated that the tactile compass made it unnecessary to look at a display. Nine participants positively mentioned the private and eyes-free usage, in particular when the display is hard to read due to sunlight reflections.

5.8.5.3 Tactile Compass Design

In order to identify areas of improvement we also collected feedback on the design of the tactile compass. In the post-hoc interviews we identified two reoccurring issues:

The first issue was the number of directions to present. Seven participants stated that they mentally ignored the intermediate directions and therefore navigated by ahead, behind, left-hand side and right-hand side only. Additionally, five participants reported to have difficulties to discriminate the ahead and the two adjacent directions (ahead/right - ahead/left). Three participants explicitly suggested reducing the number of directions to four.

The second issue was the continuous repetition of the vibration patterns. It was explicitly appreciated by four participants. These were participants who felt to have a bad sense of direction. However, the bigger share of the participants pointed out that their attention was drawn too much by the constantly repeated vibration patterns. Some said that they could not stop listening for changes in the vibration signals. During the study we observed many cases, where the participants appeared to concentrate a lot on the tactile patterns (see Figure 37). Suggestions for improvement were to play the tactile patterns only on the user's request or only in situations where it is necessary, e.g. when hitting a turn or when leaving the route.

5.8.6 Discussion

All participants were able to reach the given destinations with the tactile compass. It presented itself as an effective navigation aid and reduced the amount of distractive interaction. In combination with the visual navigation system the tactile compass also improved the navigation performance by reducing the number of navigation errors. The presence of the tactile compass slowed users down, which we believe may be a sign for an increased cognitive workload.

The results support previous work showing that cueing directions is possible with a single actuator [Rassmus-Groehn, K. Szymczak] and can form effective navigation aids. The main advancement of the presented work here is that unlike this previous the tactile compass does not resemble the *magic wand* paradigm. Instead, it resembles the *sixth sense* paradigm (Froehlich et al. 2011), which does not require the *magic wand*'s pointing gesture. The tactile compass is a proof-of-concept that the *sixth sense* paradigm can be implemented with a common handheld device.

5.8.6.1 Navigation Performance

Although no statistically significant differences could be observed, there was a tendency towards a decreased navigation performance in the *tactile* condition. We did not find this surprising given the fact that abstract tactile icons were compared to a head-up map enriched with navigation instructions. Most participants had previous experience with navigation systems while the tactile system was completely new to them. The time needed to get to the destination increased by 15%, which may still be acceptable if privacy and unobtrusiveness is preferred over efficiency. Although we included two training routes, the question remains whether the performance would converge over time as the user gains more experience in using the tactile compass.

On the other hand, in the *combined* condition the tactile compass could improve the navigation performance in terms of navigation errors. Similar findings have been made with body centric cues provided by tactile waist belts. In two studies (Smets et al. 2008 and Pielot et al. 2009) it was shown that cueing the location of the destination can improve the navigation performance. However, there are two notable advancements: (1) the work presented here is based on abstract patterns, not body centric cues, which are presumably more difficult to interpret, and (2) in the reported studies the tactile displays were used in combination with maps that did not provide navigation instructions. Thus, in our case, the tactile cues are less intuitive on the one hand, and on the other hand the visual cues are far more powerful compared to the previous work. The fact that we still can observe a positive effect of the added tactile cues is therefore a novel finding.

5.8.6.2 Cognitive Workload

The results indicate that the tactile compass induced cognitive workload. The walking speed was significantly higher in the *visual* condition which according to Brewster et al. (2003) is a sign of less cognitive workload. It also was confirmed by many participants who reported to be constantly "listening" to the vibration patterns. Notably, this happened independent from the visual system being available or not. Even in the *combined* condition the participants did not behave as in the *visual* condition. We are surprised that we did not observe an equivalent of the cocktail party effect, where people selectively listen to a single speaker while ignoring all other conversations and background noise. Our results indicate that even in the *combined* condition, where interpreting the tactile patterns was not necessary at all, the participants tried to interpret them. One explanation might be found in the work by Ho et al. (2005) who found that the sense of touch can be used to attract and direct the human's attention. The tactile cues could have attracted the users' attention even in situations where it was unnecessary. Future design iterations could address this issue by simplifying the tactile icons further (e.g. by reducing the number of directions) and providing information only when necessary. On the good side, these findings indicate that tactile cues are well

perceived on the move and do not suffer from external interferences. So, tactile cues would be particularly effective in drawing the user's attention if required.

5.8.6.3 Distraction

The tactile compass had a positive effect on the distraction. Complementing the tactile compass and the visual system helped reducing the time spent interacting with the device significantly. Compared to the *visual* condition the participants looked less often at the map. Compared to the *tactile* condition the participants used the *scanning mode* less often. Taking the overall time spent scanning & looking on the map into account the participants were interacting most when having visual feedback only. These findings support existing evidence that tactile feedback can reduce the distraction, where people are not paying attention to the environment (Elliott et al. 2010, Pielot and Boll 2010).

However, although the participants found most shops in the *tactile* condition, no significant effect was found on the detection rate. This can be explained by the fact that the detection rates were generally high (between 77 % and 88 %). We therefore cannot confirm the findings by Elliott et al. (2010) where soldiers could spot most "targets" with a tactile navigation system. However, Elliott et al. compared their tactile navigation system with a head-mounted display and an alphanumeric handheld GPS coordinate representation. Both baseline systems presumably require more effort to interpret the navigation information compared to the navigation system used in our study. Thus, the findings by Elliott et al. might be confirmed when the tactile compass is employed with improvements with respect to the cognitive workload and more training.

5.8.6.4 Limitations of the study

Some participants were not completely unfamiliar with the city center. This could account for the "read'n'run" strategy we observed in the *visual* condition, where people recognized familiar areas and navigated by previous knowledge. However, navigating to an unknown place in a somewhat familiar environment is not uncommon. Thus, the setting used in this study render the results applicable to such common scenarios. Also, being familiar with an environment favors map-type systems, as the user can see the course of the route in advance and recognize familiar places on the way. Still, the tactile compass presented itself as an effective navigation aid.

5.8.7 Guidelines for D1.4

The field study showed that the tactile patterns we designed for that purpose can effectively be interpreted and successfully guide pedestrians to a destination without additional auditory or visual navigation information. The positive effects on navigation performance and distraction suggest that including tactile cues into pedestrian navigation and other location-based applications can reduce the user's distraction.

These findings open up new possibilities beyond navigation systems, as cueing directional information is a core feature of many location-based services. Since location-based services are often designed to be used on the move, these applications may benefit from adopting the concept of the tactile compass. The findings presented in this paper can be used to inform the design of such tactile information presentation techniques for location-based applications.

5.8.8 Proposed Toolkit HCI Modules

This study provides additional evidence that the tactile compass is a suitable candidate for an HCI module. In fact, the tactile compass can already be found in the module and is currently planned to be included in several demonstrators. This study helped a lot in refining the details of applying the tactile compass as a navigation aid. For example, several pilot studies helped to test and evolve the algorithms that decided when to switch to the next waypoint.

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5.9 Friend Sense

From the studies in WP1 we took away that people want an accessible and adequate communication of the navigation (D1.1 p.92). Particular desires are hands-free and not disturbing ways of presenting the necessary information (D1.1, p.58). In HaptiMap WP2 we experimentally proved that this is not just a desire but also a necessity. In a study comparing a visual with a tactile navigation system (D2.1, p.71) the users were significantly distracted by the visual system, causing them to bump into other people's way more often. One of the solutions we proposed to convey geospatial locations in an accessible way is the Tactile Compass (see D2.1, p.96). In a field test where users had to reach a location cued by the Tactile Compass we could already prove its effectiveness and a positive effect on the users' distraction.

In another line of work we could show that it is possible to cue the location of people in tactile cues (see D2.1, p.111) and that these cues can be processed despite high perceptual load. The results were, however, obtained in a lab study by using a virtual environment.

Here, we bring together these two developments by investigating whether the Tactile Compass can adequately convey the location of friends in environments that are particularly challenging with respect to the perceptual load. We therefore created an application called FriendSense that similarly to e.g. Google Latitude allows exchanging the location of group members between each other. We deployed FriendSense at a nightly festival, which due its environment (crowded, loud music, darkness) poses particular challenges on the information presentation. In a field study we could show that the Tactile Compass can not only effectively cue friends' locations in a suitable way, but also improves the festival experience by turning its users more relaxed and more confident.

5.9.1 State of The Art

When visiting festivals with a large number of friends, one of the challenges is keeping the group together. Having to look out for the others is challenging given the crowded and noisy nature of such events. The bigger the group is the more stress is induced in meeting up (Colbert 2001). In our previous work (Pielot et al 2008) studying groups visiting festivals, we even encountered the events that people get lost for the rest of the evening. We found that the common approach to locate the group or lost individuals is to use the mobile phone. However, as found in our previous studies, the noise at typical festivals makes it difficult to talk on the phone.

Commercial services, such as Google Latitude or Yahoo Fireeagle, address this challenge by allowing users to publish their own location through their mobile phone so others can see it on a map. However, many leisure events take place at night and often the venue is quite crowded. Thus, interacting with tiny screens will force the user to shift attention between the screen and the environment to avoid walking into obstacles (Axup et al 2005).

The sense of touch is largely unaffected by such environmental interferences. It has been shown that tactile feedback is sufficient to support rendezvousing of groups (Williamson et al. 2010) and can act as a sixth sense (Nagel et al. 2005). We therefore investigated the feasibility of using tactile feedback as a sense of a friend's location to support groups in staying together during at a festival.

Extending our previous work (Pielot et al. 2008) we designed and implemented a vibro-tactile user interface that cues the geospatial locations in vibration patterns. We integrated it into FriendSense, a mobile application that allows sharing one's location. The application was tested with groups visiting one of the biggest festivals in Germany with about 1.5 Million visitors each year.



Figure 38 The Kramermarkt festival where the evaluation has been conducted

We aim at creating a connection between friends, but at the same time do not spoil the experience of the nightly event. Thus, we had to address the questions of how to describe the location of a friend and which sensory modalities should transport that description so that the result is suited for a nightly companion?

5.9.1.1 Describing Locations

A common approach for describing one's location is relating it to a landmark, e.g. "I am next to the ferris wheel". Such information can be described easily on the phone. The disadvantage is that both sides must have a shared knowledge about the landmarks. This can be difficult, since people visit festivals infrequently and their layout probably change over time.

Another approach is conveying locations geocentrically by a map. The advantage is that it is not necessary to have shared knowledge about the landmarks. However, reading a map is not trivial for everyone, as it requires mapping its 2D content to the real world. This becomes even more difficult if the map does not show the layout of the festival environment.

Another option is describing locations from an egocentric perspective, e.g. by using its relative direction and distance (e.g. 2 o'clock in 200m). The advantage with such descriptions is that they neither require mapping them to existing geographic features nor require shared knowledge about the environment. In the ever-changing environment of a festival such descriptions are the most robust form of communicated geospatial locations.

5.9.1.2 Suitable Sensory Modalities

The nature of a festival (noisy, crowded, and nighttime) also raises the question of the actual sensory modalities used for the information presentation. The information presentation should be robust against noise. The need to look at a display should be reduced as much as possible, since looking at a display while navigating through a crowd is highly demanding and it may increase the likeliness to bump into another person (Axup et al. 2005). Finally, as nightly events are often used to maintain social contacts, the information presentation should be unobtrusive and not hamper the user's visual appearance (e.g. by requiring to wear head-mounted displays).

These requirements exclude most modalities and traditional interaction techniques. Auditory feedback is impracticable due to the expected noise level. The use of visual feedback is possible, but only if it is sufficient to consume it in short and infrequent glances. There must be no need to look at the display when e.g. moving through the crowd or chatting with another person. This leaves us with the sense of touch, as it is hardly affected by darkness and noise. It can be used to convey information in an unobtrusive way that remains invisible to others and may interfere less with social interactions.

5.9.2 FriendSense

In our previous work we therefore proposed an application called FriendSense (Pielot et al. 2008). However, the previous design was based on tactile waist belts, which are difficult to provide in sufficient numbers to actually deploy the system. Thus, we created a version of the application that only requires common smart phones. Via 3G networks the user's GPS location is regularly shared with a server. Once retrieved, the location is relayed to the other connected FriendSense clients. Thus, every FriendSense client is aware of each friend's location all the time. Each FriendSense user is able to consume a friend's shared location through visual or vibro-tactile feedback.

5.9.2.1 Vibro-tactile Feedback

To present the location of the selected friend via the sense of touch we encoded her/his location in vibro-tactile patterns generated by the mobile device's vibration motor. We re-used a technique that has been designed in our previous work (Pielot et al. 2011) and proved its effectiveness as navigation aid. The patterns are used to encode the general direction and the distance of a person. Figure 3 shows the patterns used to encode the general direction. For example, two short pulses indicate that the friend is straight ahead. A long pulse followed by a shorter pulse, as shown in the Figure below, indicates that the friend is to the left-hand side. In a lab study with 21 participants the recognition rate was 78%. That result is sufficient for the intended use. First, more errors were off by one sector to the left or right, so the general tendency was mostly recognized correctly. Second, the patterns are played repeatedly as long as a friend is selected, so it is not fatal if the user is temporarily a bit off the mark. The distance is encoded in the pause between the patterns. The closer the friend is the faster the patterns are repeated.

To avoid annoying the user we muted the tactile feedback when not moving. First, groups often stay in one place for a while. In these situations, constant vibration feedback would be only disturbing. Second, users who are searching for the group or lost individuals are either on the move or they can stop to take a glance at the visual radar interface.

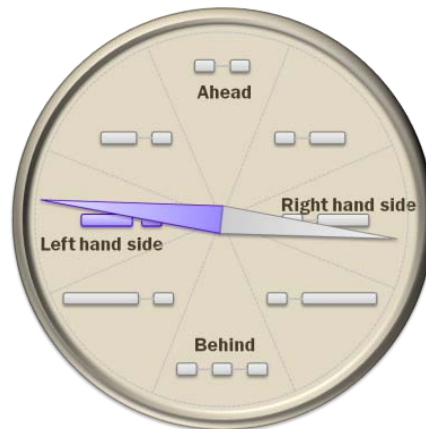


Figure 39 The vibro-tactile friend sense: the grey bars visualize the vibration pattern that would be played to indicate the respective directions. In this picture, the violet pattern (long-short) is played indicating that the friend is to the left-hand side

5.9.2.2 Visual Feedback

The visual component of the FriendSense consists of a radar-like user interface (see Figure below). It shows the direction and the distance of all online friends via small dots. The UI is kept as simple as possible to reduce the time needed to read its state. It aligns itself with the user's heading, so the directions can be read directly from the screen without rotating them mentally. The user can use this UI to select the friend that shall be presented through the sense of touch.



Figure 40 Screenshot of the visual component of FriendSense: direction and distance of all friends are shown in a radar-like UI. In the illustrated situation, two friends have strayed away from the group, which is to the left-hand side.

5.9.3 Study Description

To get first feedback on FriendSense we deployed the application in groups of friends visiting a nightly festival. We wanted to investigate whether the tactile location cueing technique is suitable to

be used in a nightly festival and if the system as a whole has positive effects on the nightly experience.

5.9.3.1 Research Questions

1. Is the information presentation suitable to the context of use?
2. Does the ability to sense one's friends have a positive effect on the festival experience?

5.9.3.2 Participants

On two different nights a total of 12 participants took part in the study. The two groups consisted of friends that were visiting the festival as a leisure activity. The participation in the study was secondary to them.

5.9.3.3 Design

To study the effect of the location cueing techniques we used a between groups design with two conditions: participants in the experimental group were equipped with the fully functional FriendSense. The participants in the control group received stripped down version which only shared its location but did not display the others' locations in any form. The location was shared to ensure that the participants from the experimental group could sense all members of the group.

As means of data-collection we used the experience sampling method (ESM) (Consolvo and Walker 2003) and post-hoc interviews. In our ESM implementation the application triggered an alarm every 20 minutes. Then, a short questionnaire consisting of five-point Likert scales appeared on the device's screen. The participants had to rate how relaxed they felt [Relaxation], how much attention they spent to keep the group together [Attention], and how difficult they perceived it to keep the group together [Difficulty]. Further, we asked whether the participant was with the main group. If the answer was "no" we also asked if the participant had left the group on purpose or not. The results were stored on the device together with a timestamp.

Procedure

All participants were introduced to the application some days before the actual study, so they already knew how to operate and use it. On the night of the study, the experimenter met the group of friends at the beginning of their visit outside the festival area. The group then visited the festival as they normally would. The post-hoc interview was conducted the day after. We asked open questions on how FriendSense had been used, how possible separations from the group were experienced, and how FriendSense affected the general experience of the event.

5.9.4 Results & Discussion

On the first evening, one person came late. Later on, two people split up from the group for about an hour. On the beginning of the second evening some people split up from the group in the beginning to join it again 20 minutes later. Later that evening, a single person left the group two times. Thus, most of the time the group stayed together, or was split into two parts.

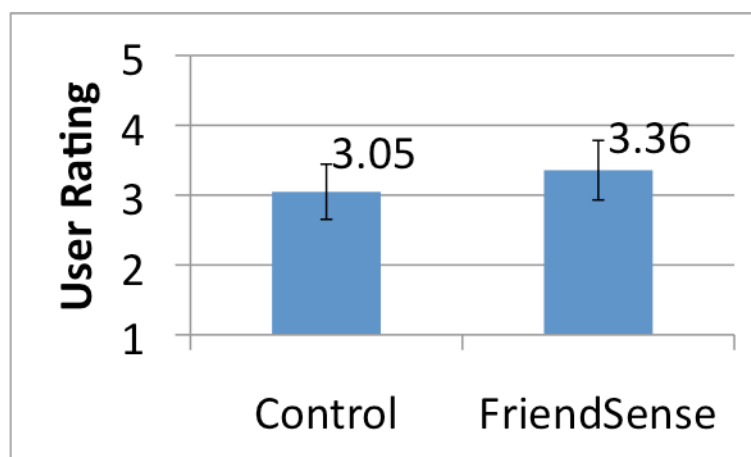


Figure 41 Average rating score of "How relaxed are you at the moment?" The participants felt significantly more relaxed in the FriendSense condition ($p < .05$).

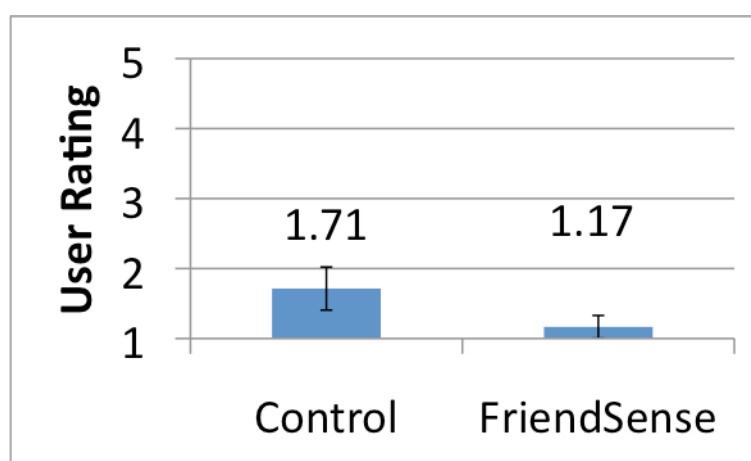


Figure 42 Average rating score of "How much attention did you recently pay to where the others are?" The participants subjectively devoted significantly less attention in the FriendSense condition ($p < .05$).

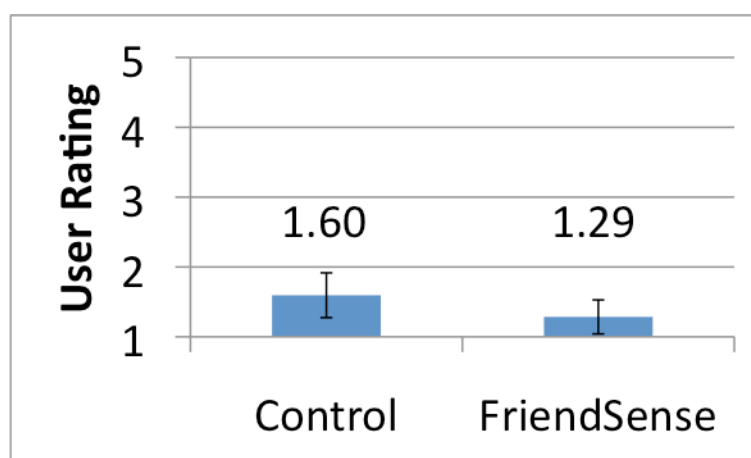


Figure 43 Average rating score of "How difficult is it currently to keep the group together?" The participants found it significantly easier to keep the group together in the FriendSense condition ($p < .05$).

The diagrams above show the results of the Experience Sampling. FriendSense had significant positive effects on all three aspects. The participants felt more relaxed, subjectively devoted less attention to where the other group members are, and found it less difficult to keep the group together (all $p < .05$, independent t-test).

The participants from the experimental group reported six occasions of not being with the group, but always intentionally. The participants from the control group reported ten occasions of not being with the group. In three cases this was intentional, in seven it was by accident. The difference was not statistically significant.

5.9.4.1 Interview Results

From the post-hoc interview we learned that the participants subjectively did not “use” the system much. The most important feature of FriendSense was considered the ability to be located by the group if necessary. Thus, being separated from the group was not considered as fatal as it would have been without the system. This was even true for the participants in the control group. Since they shared their location as well the participants from the experimental group could still locate them. Some participants even felt encouraged to leave the group, knowing that the others could find them.

The tactile feedback was appreciated when moving through the very crowded areas of the festival area. The participants acknowledged that in contrast to the visual display it was suited well for being used on the move and in the crowd.

5.9.4.2 Limitations

One of the study’s limitations is that the participants from the experimental group could track those from the control group. This had the effect that the control group participants were more confident as they could be found if they got lost. Thus, the difference between using FriendSense and using no technical device at all might be even more significant.

5.9.5 Guidelines for D1.4

In conclusion, the study showed evidence that FriendSense can improve the experience of the night out. In particular it made the participants more confident not to get lost and thus had a positive effect on the user experience. The work shows that continuous tactile cueing of coarse information accompanied by a visual overview that can easily be read is suited to such chaotic environments. In particular the tactile feedback – although comprising a rather non-intuitive set of patterns – could effectively be put to use in this casual scenario. The future work needs to focus more closely on the information presentation itself. Remaining questions are how the tactile feedback can be extended to communicate a wider range of information, e.g. several friends’ location at the same time.

5.9.6 Proposed Toolkit HCI Modules

The study provides additional evidence that the Tactile Compass is a suitable HCI module and can, for example, be integrated into the Juicy Beats demonstrator, that also addresses the scenario of being used at a crowded and noisy festival.

5.9.7 References

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5.10 Natch – Reducing Navigation Information to the Necessary

When using predominant map-based navigation systems for pedestrians, distraction is an important factor to consider. It has been shown, that interacting with mobile devices on the move results in fragmented attention (Oulasvirta et al. 2005). Further, our previous work from WP2 (D2.1, p.71, reported in Pielot & Boll 2010), has shown that running into other people is an issue when using vision-based navigation systems in crowded environments, such as city centres. One of the core problems is that navigation information is often presented via maps, which is a complex way of presenting information (see e.g. D2.1, p.55).

We therefore investigated the approach of radically reducing the displayed navigation information to the absolutely necessary minimum and presenting it by a wrist worn display to provide hands-free interaction (see D1.1, p.92). In a user-centred design process we designed Natch (short for Navigation Watch), which only displays the turning directions and the distance to the next decision point. Realised as a Wizard-of-Oz prototype, we evaluated the underlying concept in a field study. We experimentally compared Natch against TomTom[®], a commercial pedestrian navigation application. Nine people had to navigate to two destinations with one of the devices each. We provide evidence that strictly reducing the navigation information decreases distraction while not affecting the navigation performance.

5.10.1 State of The Art

The interaction with pedestrian navigation systems has been subject to research for several years. According to Tscheligi and Sefelin (2006) one of the most important aspects that have to be considered is the context of use. For drivers, driving and navigating are usually the primary tasks. For pedestrians, in contrast, navigation is often only a secondary task. Still, most state-of-the-art navigation systems for pedestrians use the same maps and turning instructions we know from car navigation systems. Oulasvirta et al. (2005) showed that pedestrians interact in short bursts only with mobile devices, which leads to a significant fragmentation of the users' attention. As a potential solution, Tscheligi and Sefelin name the use of wearable computers. In particular, the use of tactile information presentation is discussed as an alternative means. In our WP2 study (D2.1, p.71, reported in Pielot & Boll 2010) we could show that tactile belts, as an instance of wearable computers, benefit the distraction. However, the tested design could not yet keep up with the commercial pedestrian navigation system in terms of navigation performance.

5.10.2 System Design

We therefore tried another approach which is still based on visual feedback, but reduces it to the necessary minimum. To also take hand-free usage into account the display should be wrist-mounted, such as a watch. As watches are still widely worn and interactive, programmable devices are nowadays emerging, this may be a promising approach for the future. As essential navigation information, we identified the distance and direction to the next decision point, the direction to turn

to at a decision point and as additional information, providing confirmation to the user, and the name of the street to enter.

Turns are represented by bend arrows, applying the turn's angle directly on the arrow. Right-angled turns will result in an arrow bend by 90°, while larger or smaller angles will result in a less or more bend arrow.

Navigation systems like TomTom® have the ability to notify a user via audio messages about e.g. approaching a decision point. However, since privacy may also be a desire (see D2.1, p.96) Natch notifies users of upcoming decision points 10-15m in advance by a short vibration pulse.

To be able to evaluate the concept we build a lo-fi, Wizard-of-Oz prototype. The prototype can be seen in Figure 44.

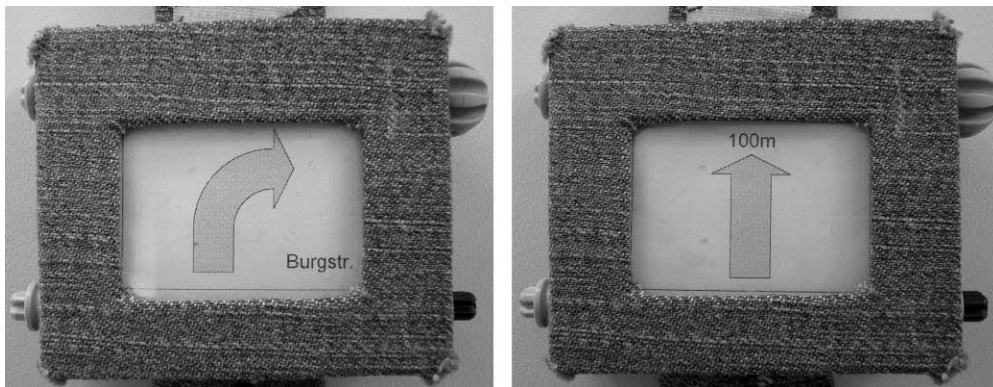


Figure 44 Screen layout of Natch, showing information presentation 5-10m in front of a decision point (left) and after encountering a decision point (right).

The frame of Natch consists of LEGO® and contains the route-information as a paper printout on a reel. The display dimensions are 33mm width and 24mm height, while Natch itself is 57mm x 48mm. The user utilises a small wheel to change the display content manually by sliding the paper printout in the display area to the next screen. Natch is worn around the wrist by a cloth band and is adjustable by a hook-and-loop fastener. Sewn into the wristband is the vibration motor of a mobile phone. The battery and switch for the vibration motor are external and connected by a cable of two meter length, giving a remote control method to trigger events without distracting the user. In front of a decision point the screen shows an arrow bend in the direction to turn to and the name of the street to enter. After a turn an arrow will point in the walking direction and the distance to the next decision point is given in meter.

We used the Wizard-of-Oz method to simulate the GPS and way-finding algorithms. The user is followed by the *Wizard*, who knows the route, and is informed about new information 10-15 meters in front of and after each decision point via a short vibration impulse of about one second, triggered by the *Wizard's* remote control. To read the new information, the user has to use the wheel to slide to the next instruction screen.

5.10.3 Study Overview

In order to investigate our concept of displaying reduced navigation information via a wrist-worn display, we compared our Natch prototype to the commercial navigation system TomTom®. Our hypotheses were:

- (H1) Natch needs less attention and is not as distracting as TomTom© because of its plain and simple presentation of information.
- (H2) The navigation performance with Natch is as good as with TomTom©.
- (H3) The wrist-based concept of Natch is natural and attracts less attention of other people compared to TomTom©.

We conducted a field study to test our hypotheses. During the experiment the participants had to navigate through a city centre with Natch and TomTom©.

5.10.3.1 Material

For the evaluation we used two routes with similar length and difficulty. Each route is about one kilometre long. The first route has seven turns, while the second route includes six turns. To simulate a natural situation, the first route leads through the pedestrian zone of Oldenburg and ends at a church as a point of interest for tourists. The second route starts at this point and leads to the railroad station of Oldenburg, Germany. Both routes lead to their destinations on an indirect way, to prolong the route and add turns.

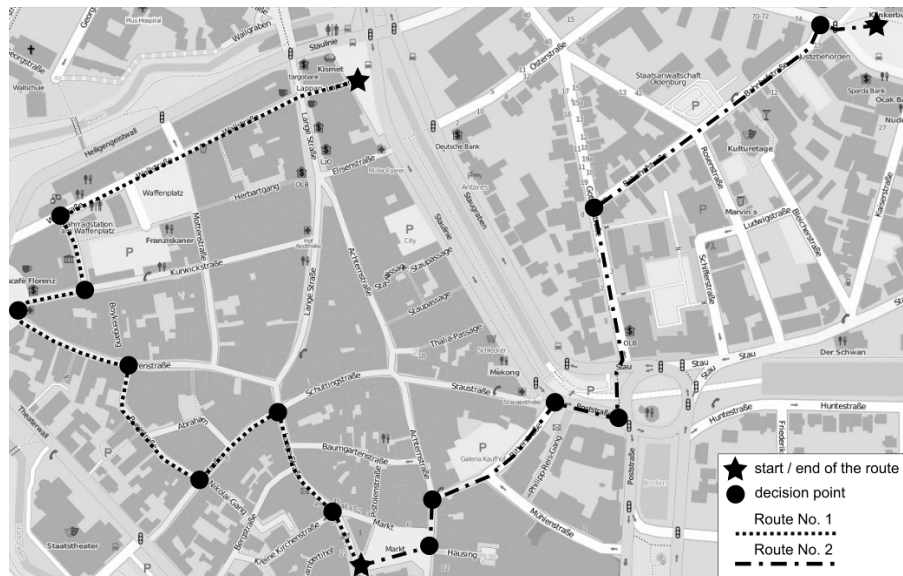


Figure 45 Map of the used routes in Oldenburg

The systems used were on the one hand Natch, described in Section 3, and on the other hand a HTC P3600 Smartphone device with internal GPS and the navigation software TomTom© v6.030. The routes were programmed and set to pedestrian mode by the experimenter, so that the participant did not have to know the input mechanism.

5.10.3.2 Design

The navigation system served as independent variable. Natch is the experimental condition while TomTom© is used as control condition. The study used a within-subjects design. Thus, all participants contributed to both conditions. The order of conditions was counter-balanced to avoid sequence effects. The following dependent variables were measured.

- **Distraction:** We measured distraction by self-report, asking the participants how much of their attention the navigation system drew. The subjective distraction was rated on a Likert-Scale from one (low distraction) to five (high distraction).
- **Visual usage:** In order to collect information on the distraction of the participant from his or her environment, we observed the participant and noted each of his or her eye contacts with the device's display.
- **Navigation errors:** Evaluating the navigation performance of Natch and TomTom©, every wrong turn or leaving the planned route was registered as a navigation error.
- **Visibility:** We measured the participant's feeling of visibility by self-report, asking how standing out or visible they felt while using the navigation system. The visibility was measured on a Likert-Scale from one (not visible) to five (very visible).
- **Manual usage time:** In order to evaluate the participant's visibility for his or her environment, we measured the duration of holding the device in front of the body. The device had to be clearly visible by the observing experimenter and the time was measured whether or not the participant was currently looking at the device. The time for sliding Natch to its next screen was included.

5.10.3.3 Participants

Nine participants (five women and four men) took part in the field study. The mean age of the participants was 29 ranging from 21 to 50 years. 66% of the participants were students. All participants rated their experience with navigation systems as average. Almost all participants came from Oldenburg and were familiar with the city. All volunteered and received no payment.

5.10.3.4 Procedure

The experiment consisted of three phases and took place in January 2010 in the city centre of Oldenburg. All nine participants were able to conduct the experiment on two consecutive weekends, using both types of navigation systems, and were exposed to similar weather and light conditions.

At first we demonstrated systems and let the participants test them. During the actual navigation task, two experimenters followed the participants and noted the duration of eye contact with the devices and the duration of carrying it in front of the body with the help of stopwatches. They also noted navigation errors and either the reaction of a participant on the environment or the reaction of other pedestrians on the participant. If the participant was about to leave the predestined route, an experimenter approached him or her and pointed out the right direction to keep consistency with the planned route.

5.10.4 Results

Table 2 summarizes the descriptive results. To test for significant differences we used a dependent, two-tailed t-test.

Table 2 Results given as mean, standard deviation and p-value of the t-test.

Dependant Variable	Natch		TomTom [®]		p-value
	Mean	S.D.	Mean	S.D.	
Distraction	1.67	0.87	3.56	1.13	0.00
Visual usage count	17.11	1.58	30.33	13.56	0.01
Navigation errors	0.33	0.5	1.22	0.67	0.01
Visibility	1.33	0.5	3.11	0.78	0.00
Manual usage time	6.4s	2.6s	292.0s	368.4s	0.05

As Table 1 shows the experimental manipulation had a significant effect on all dependent measures. The participants felt subjectively less distracted and less visible. They looked less at the display and interacted less with the device. Also, less navigation errors occurred with Natch.

During the experiment TomTom[®] repeatedly showed a routing issue at one position of the second route. Approaching a traffic circle, TomTom[®] tried to guide the participant straight through the traffic circle instead of the planned way around it across pedestrian lights. This contributed to most of the navigation errors with TomTom[®]. However, the distance announcement of TomTom[®] also caused irritation. For instance, being 10m in front of a turn. TomTom[®]'s audio message announced a turn in 30m, followed by a 'Turn left/right' message after five more meters.

Seven participants used the display as primary interface, while two relied on audio output, only using the display when the audio message was not clear or the environment too loud. We observed that the audio output of TomTom[®] interrupted some participants while talking. The participants stopped talking until the audio message ended. Some participants were irritated by the audio messages with wrong distance information.

Three participants encountered problems using the wheel of Natch, caused by thick gloves, and three others had to familiarise with wearing Natch for some minutes. They said they were afraid of damaging the prototype.

5.10.5 Discussion

In summary, Natch could successfully guide our participants to the given destinations. Natch users made significantly less navigation errors, looked less often at the device and spent less time holding it visibly in hand. The participants reported to be less distracted and standing out with Natch. Taking our hypotheses into consideration, we come to the following results:

H1 (Natch is less distracting in comparison to TomTom[®]) is supported. The subjective distraction as well as the time spent looking at the device was significantly reduced with Natch. We believe that the reduced amount of information enabled the participant to comprehend the displayed navigation information at a glance. Since only short glances were needed we conclude that the interaction is more suited for the short interaction bursts described by Oulasvirta et al. (2005).

H2 (Natch has equal navigation performance) is supported. Natch users even made significantly less navigation errors. However, we assume the cause was not the information presentation but in TomTom[®]'s way-finding algorithm. Most of the observed navigation errors occurred at the traffic circle where TomTom[®] gave false routing information. Our observation tried to distinguish a system's navigation error from a participant's error. Taking this into consideration, Natch performed at least equal to TomTom[®], but may not have superior navigation performance.

H3 (Natch attracts less attention) is supported, since our participants interacted less often visibly with the device and subjectively felt attracting less attention. However, the difficulty of measuring environmental attention has to be taken into account. We tried to accommodate this by the personal impression of our participants and an objective measuring of the manual usage time. Our results show that the participants felt less standing out and that using Natch is less visible, but it can be questioned if holding a navigation system attracts the attention of the environment.

The Wizard of Oz low-budget prototype lead to certain disadvantages: the rather short cable connection may have increased the test person's impression of standing out and the need to manually obtain the next instruction added to the overall interaction time. Despite these circumstances, our tests yielded significant findings and Natch still achieved better results.

5.10.6 Guidelines for D1.4

Altogether the study showed that presenting reduced navigation information through a wrist-worn display leads to an improved navigation experience. At the same time, the navigation performance is on a par with systems like TomTom[®], as in most situations complex information is not needed. Thus, we advocate for thinking about how the complexity of the presented navigation information can be reduced to the essentials instead of providing more and more information crammed into a tiny display.

In order to be used in everyday navigation systems the idea has to be advanced further. Since many survey participants mentioned that they felt less safe without a map, but also did not want too much information on the display. Natch could be used together with a Smartphone-based device, providing computing power, input interfaces and a larger display for detail information. Natch itself could therefore be designed slim and lightweight, discretely providing necessary information, while the main device could stay in a pocket.

5.10.7 Proposed Toolkit HCI Modules

The lesson to be learned from this study for the toolkit is to not only provide non-visual versions of navigation information, but also provide full-screen but highly reduced visual information, such as arrows. Figure 46 shows an example of such a reduced visual representation that can be found in the PocketNavigator demonstrator.

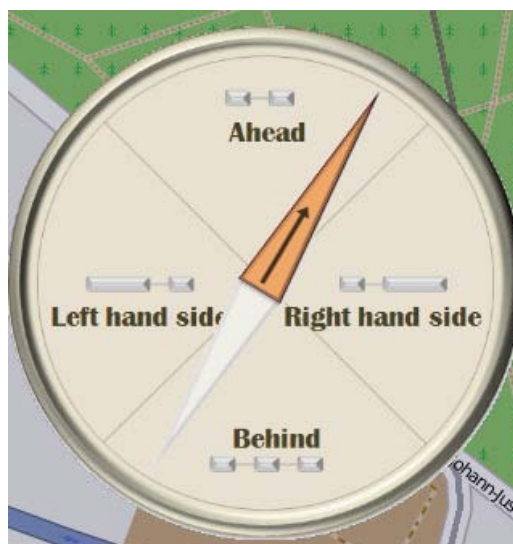


Figure 46 Example for reduced navigation information: the visual representation of the Tactile Compass

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5.11 Pocket Menu

A clear trend of mobile devices is the shift towards less buttons in favour of a large touch screens. The best example is the iPhone, which offers a single "home" key on its front while all the other interaction is done via the screen only.



Figure 47 User struggling to read the handheld device's display on the move.

A well-known problem illustrated by Figure 47 is that touch screens require the user to look at them while interacting. While it is for example easy to control a classic MP3 player that has haptic knobs non-visually in the pocket it is virtually impossible to do the same with the iPod music player. Even if the user learned the layout of the menu it still would be difficult to hit the correct item without looking at them.

With the PocketMenu presented in this paper we aim at re-creating the possibility to use touch screen-based applications in the pocket. While many approaches existing to make touch screens accessible for non-visual use they might not cope well with the limited interaction space and the not-so-well-known orientation of the device when having the device in the pocket (see Figure 48).



Figure 48 The basic concepts of the PocketMenu: the screens border and vibro-tactile feedback make the buttons "feelable".

The PocketMenu exploits the fact that most handheld's screen borders can be perceived haptically. Therefore, all menu items are laid out along the border of the device's touch screen. The transition between two items is indicated through vibro-tactile feedback, so users are enabled to recognise the presence of a button only by the sense of touch.

Here, we report from the PocketMenu's design and its evaluation where we compared experimentally with an iPhone-like VoiceOver menu. PocketMenu users were significantly, faster made fewer errors, experienced less breakdowns, and showed less signs of cognitive workload. The results provide evidence that haptic and vibro-tactile feedback is a powerful design tool to enable non-visual touch screen interaction.

5.11.1 State of The Art

Gestures are a prominent approach to allow eyes-free interaction. In 1988, Callahan et al. (1988) proposed the "pie menu", in which items are arranged in a circle around a given centre. In touch screen implementations (Ecker et al. 2009), users hit the screen with a finger or pen, making the menu items appear around the point of contact. To select an item they drag the finger towards the item. One advantage of pie menus is that the interaction is independent from its screen location, because the menu can be launched directly at the point of contact. Recent work by Bonner et al. (2010) shows that pie menus combined with audio feedback can even allow blind people to enter text with a touch screen. Beyond pie menus, SlideRule (Kane et al. 2006) combines gestures with audio feedback to enable blind users to interact with touch screens. Compared to a button-based system it was faster but more error prone.

Another approach to improve the accessibility of touch screens is the use of haptic feedback. McGookin et al. (2008) proposed using a raised paper overlay to make touch screens palpable. From user studies they inferred guidelines, such as avoiding using simple taps as gestures or providing a "home" position that is easy to identify. The iPhone's VoiceOver approach violates both guidelines, which suggests that there is still potential to improve the interaction. EdgeWrite (Wobbrock et al. 2008) uses a plastic template with a small hole to limit the movement of a stylus used for gesture-based character input. It was shown that EdgeWrite allowed a faster text input than free letter

recognition. Barrier Pointing (Froelich et al. 2007) aims at making stylus-based touch screen interaction more accessible for motor impaired users by utilizing the raised borders of the screen that can be found in some devices. The menu is arranged directly at the border of the screen. To interact with the menu the user slides the stylus into one menu and the drag-movement gets stopped by the raised border.

A related approach to the use of haptic features is providing vibro-tactile feedback to make touch screen elements "visible" during eyes-free use. T-Bars (Hall et al. 2008) introduce stroke-formed menu items which trigger vibration when being touched. To select an item the user slides along the stroke until its end. Pilot evaluations showed that this feedback helps users to keep their fingers on the line more accurately. Rich tactile feedback is used by SemFeel (Yatani and Truong 2009) to not only indicate the presence of an item on the touch screen but also to convey the item's type. Five vibration motors are attached to the back of the device (up, down, left, right, and centre) to create ten well discriminable vibration patterns. In a study where a virtual num pad was enhanced by SemFeel it could significantly reduce the error rate when interacting non-visually.

5.11.2 The PocketMenu

With the PocketMenu we aimed at providing a touch screen menu that re-creates the experience of interacting with haptic knobs, so it can be used to interact with the device non-visually and in spatially constraint environments, e.g. when it is stored in the pocket while listening to music on the move. These constraints make it difficult to directly apply the previous approaches. In particular the unclear orientation of the device and the restricted space make it difficult to perform gestures or to find even haptically enhanced buttons.

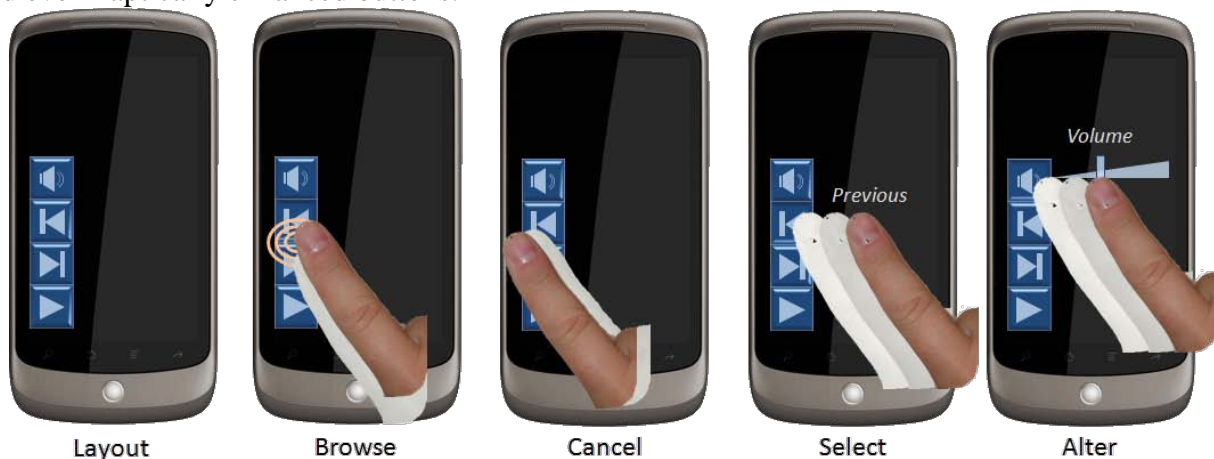


Figure 49 The layout and the four main actions: browse, cancel, select, and alter

5.11.2.1 Layout

The PocketMenu illustrated in Figure 49 provides a solution by combining previously successful approaches into a new concept. The menu items are laid out along the screen's border. Similar to EdgeWrite (Wobbrock et al. 2003), the screen border serves as haptic reference, guiding the user's finger when browsing the menu's items. Tactile feedback, as in T-Bars (Hall et al. 2008), is used to separate the menu items from each other. So, the items are made palpable by one haptic and three vibro-tactile borders. The menu layout depends on what hand is the user's dominant one. For right-

handed users the items origin in the bottom-left corner of the screen and evolve towards the screens top-left corner. The corner serves as reference point to help the user to understand the menu's layout.

5.11.2.2 Browse Items

To browse the items the user slides her/his finger along the screen's border. A short tactile pulse of 100 ms is given if the finger crosses the border between two items. Menu items can be identified in two ways. First, when the finger enters a menu item the associated action is announced via text-to-speech. Second, when the users start building a mental model of the menu, they can just remember the items' position and count the number of vibro-tactile pulses when sliding along the screen border. Expert users might become able to use the menu without speech feedback, being less distracted and annoyed.

5.11.2.3 Cancel Browsing

Browsing the menu can be aborted by simply releasing the finger. In the related work, e.g. SemFeel (Yatani and Truong 2009), releasing the finger has been used to trigger the last selected item. However, due to the constraints we were afraid that users might accidentally lift the finger from time to time. Our design aims at avoiding these kinds of accidents.

5.11.2.4 Select and Alter

The PocketMenu offers two kinds of items: button-like items triggering associated actions (e.g. Play, Pause, ...) and slider-like items that allow to continuously adjusting a value (e.g. Volume). The selection of button items is inspired by the classic PieMenu (Callahan et al. 1988): by swiping the finger towards the middle of the screen the associated action is executed. A short tactile pulse (100ms) confirms that the button item has been 'pressed'. Slider items are selected in a similar way. The associated value can be adjusted by swiping more or less far away from the menu border before lifting the finger. A series of very short tactile pulses (<10ms) issued when moving the finger indicate that the associated value is altered.

5.11.2.5 Design Alternatives

The design went through a number of iterations worth mentioning. First versions placed the menu on the right side of the screen for right-handed users. However, since most users used the right thumb the interaction required non-ergonomic finger positions. Moving the menu to the opposite screen side proved for more ergonomic.

Earlier versions of the menu also needed to be activated by moving the finger into the bottom corner. Otherwise the menu was not visible to avoid accidental activation. However, this resulted into notable performance issues as the finger always had to travel long distances.

In earlier versions the speech output was not immediate. Instead it was triggered when the user rested the finger for about 1 sec. in a menu item. We assumed that users becoming experienced with a specific layout would be able to find items just by counting the number of tactile bumps from the corner item. However, our test users who were novices preferred immediate speech feedback.

5.11.3 Study Description

In order to test the effect of the combined haptic/tactile we conducted a user study. We compared the PocketMenu with an enhanced replica of the VoiceOver menu available on iPhone 3GS and later models.

5.11.3.1 Material

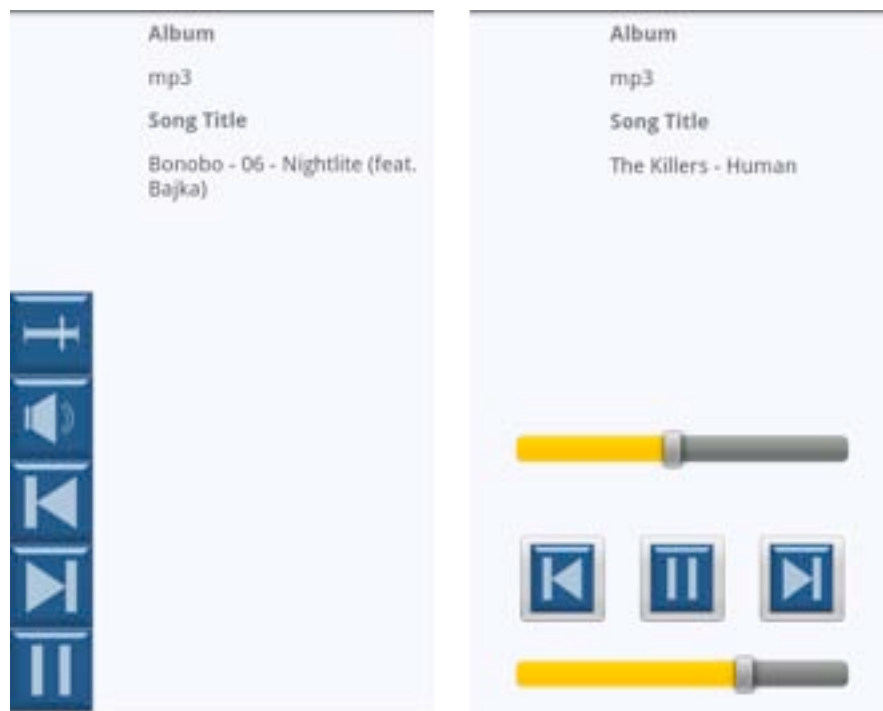


Figure 50 Screenshots of the PocketMenu (left) and the VoiceOver menu (right) as used in the evaluation.

We implemented a simple MP3 player as test application (see Figure 50). It had five different functions: start/pause, next, prev, volume up, volume down. As baseline for the study we replicated the relevant aspects of the iPhone's VoiceOver functionality and implemented menu that resembled a typical MP3 player control. Screenshots of both menus are shown in above Figure. Using the VoiceOver clone users can explore the screen elements by moving the finger over the screen elements. When hitting an element a short click sound is played the associated action function is announced via speech, e.g. "play". To execute the action of the recently touched element the user has to perform a double-tap anywhere on the screen. To alter adjustable elements, such as the volume slider, the finger needs to remain on the screen after the second tap hit the screen. Then the element can be continuously be altered by swiping left or right. Alternatives, the user can double-tap onto the slide to jump the cursor to the tapped position. The core differences of our VoiceOver implementation and the PocketMenu are that the menu items are not arranged along the screen's border, the lack of vibration feedback, and the executing of actions by a double-tap instead of a swipe.

5.11.3.2 Participants

10 participants (4 female) with took part in the study. Their age averaged 25.4 (SD 2.95). The average experience with touch screens was rated above average with a considerable spread (3.40, SD 1.58, on a five-point Likert-scale, 1=low, 3=average, 5=high).

5.11.3.3 Design

The menu type served as independent variable with two levels: (VoiceOver, PocketMenu). We used a within-subject design with a counter-balanced order of the conditions. As performance measures the software automatically recorded the *completion time* (the time it takes the participants to execute a given command) and the *selection errors* (number of times the participants execute the wrong action). Furthermore, we noted the number of *breakdowns* (participant has to take device out of the pocket to execute command) and we approximated the cognitive workload by measuring the *effective walking speed*. The standardized SUS questionnaire was used to query the menus' *subjective usability*.

5.11.3.4 Procedure

To not influence the participant's opinion subconsciously the study was conducted by an external experimenter who had no knowledge about the study's goals. At the beginning of a session the participants could familiarize themselves with the menus. This typically took 10 to 15 minutes. When the participants felt fit with both menus the evaluation was continued outside. During the evaluation the participants had to keep the device in the pocket of the jacket while walking down a pedestrian path. The software announced with action had to be executed (e.g. "press play" or "change the volume"). The participants repeated the announcement, so the experimenter had the chance to correct any misunderstanding. Then, the participants tried to execute the action as fast as possible while avoiding mistakes. 13 items had to be selected with each menu. The interaction with the menu (*completion time & selection errors*) was logged automatically by the application. The *breakdowns* and the walked distance, which was used to infer the *effective walking speed*, were noted by the experimenter. Afterwards, the participants were asked to fill out two SUS questionnaires, one for each menu. Finally, a short open interview was conducted to learn about the participants' impressions and thoughts on both designs.

5.11.4 Results

The quantitative results are summarised in the table below shows the quantitative results. Means and standard deviations are reported in Table 3. T-tests were used to test for significant differences.

Table 3 Quantitative results of the evaluation. The parentheses show the standard deviation.

	VoiceOver Clone (baseline)	PocketMenu (experimental)	Significance Level (p- value)
Completion Time (s)	18.13 (22.33)	11.12 (12.28)	0.001
Selection Errors (#)	1.68 (5.84)	0.51 (1.67)	0.01
Breakdowns (#)	1.80 (1.81)	1.00 (1.70)	0.10
Effective Walking Speed (km/h)	3.21 (2.06)	3.44 (1.47)	0.27
SUS Score (higher = better subjective usability)	50 (28.6)	78.5 (19.7)	0.001

The use of the PocketMenu resulted into a significantly faster *completion time* ($p < .001$) and significantly *fewer selection errors* ($p < .01$). Also, the SUS score indicating the *subjective usability* was significantly higher for the PocketMenu condition ($p < .001$). No significant difference could be found in the number of *breakdowns* between the conditions ($p = .10$). The effective walking speed also did not significantly differ between the conditions.

The participants appreciated that the PocketMenu provides orientation by the border of the screen. It was also proposed to rotate the VoiceOver menu's content by 90° so the two sliders would be next to the screen's border to simplify the interaction with them. For the PocketMenu it was suggested to centre the menu vertically, since reaching the lower left part of the screen was found to be more difficult.

The PocketMenu's swipe technique was preferred over the VoiceOver's double click to activate screen elements. The main point of criticism about the VoiceOver menu was that it was found difficult to perform double-clicks in the pocket. However, it was also appreciated that the double-click selection made it easier to perform repeated selection of the same item.

When browsing the PocketMenu, many participants appreciated the haptic feedback. The speech output, in contrast, was often considered annoying after repeated usage. The VoiceOver also added an auditory click whenever a button was touched, which was found to be adding to the cacophony of sounds. Some participants reported to have browsed the PocketMenu based on the haptic feedback only and ignored the speech announcements altogether. Suggestions were to allow the user to turn off the speech output or replace it by more meaningful non-speech audio or tactile feedback.

5.11.5 Discussion

In summary, the PocketMenu allowed the participants to execute the given actions in less time and with fewer errors. The participants appreciated the haptic feedback and the layout arranging the buttons along the border and rated its usability higher.

There are three design differences between the PocketMenu and the VoiceOver menu, which are potential causes for these observed effects: in the PocketMenu the screen border guides the interaction by providing haptic feedback, buttons provide speech + vibro-tactile instead of speech + auditory feedback, and elements are executed by a swipe gesture instead of a double-click.

The combination of these allowed the participant to faster execute a given action and not accidentally execute a wrong one. From the participants' feedback we learned that the haptic feedback provided by the border, as suggested by Wobbrock et al. (2003) for stylus-based touch screen interaction can successfully be transferred to finger-based interaction. One of the core advancements here is that in Wobbrock's approach the border served to "stop" the stylus being pushed towards it, while here the finger is guided along the border.

Our results support the guideline established by McGookin et al. (2008) to avoid double clicks in non-visual touch screen interaction. Further, the results support the findings by Ecker et al. (2009) and Bonner et al. (2010) that swiping is an effective and efficient gesture for interacting non-visual with touch screens.

The vibro-tactile feedback, as proposed by Hall et al. (2008) or by Yatani and Truong (2009) provide to be highly efficient (although Yatani's and Truong's design is far more complex and powerful). For both menus the participants felt nearing an auditory overload. The vibro-tactile feedback in the PocketMenu allowed foregoing the VoiceOver's click noise when hitting a button, which helped to reduce the amount of auditory feedback. In pilot studies, where we tested the VoiceOver menu with added tactile feedback, we believed to observe a notable performance boost. Further, the PocketMenu's stable layout allows to even do without immediate speech feedback, as user can identify elements by counting the number of vibration buzzes when browsing the menu starting in the lower left corner.

5.11.6 Guidelines for D1.4

With the PocketMenu, we introduced a menu design which is optimized for eyes-free, in-pocket usage on mobile devices. With the presented study, we could show that the concept of laying out buttons along the border of the screen enables non-visual interaction in constraint spaces and can improve the subjective usability. The results indicate that even simple tactile cues can have a strong impact on the ability to interact non-visually with a touch screen. Guidelines we derive are:

- **Include vibration feedback into UI elements on the touch screen**

In our first trials of the evaluation we enhanced the VoiceOver menu with vibro-tactile feedback, since we were afraid the comparison would be unfair otherwise. During the pilot tests we got the strong impression that the vibro-tactile feedback was extremely helpful in interacting with UI elements on the touch screen.

- **Arrange items along the border and provide fault tolerant interaction**

The study showed that the border of a handheld device provides important and helpful haptic feedback, which can positively guide the interaction with UI elements on touch screens. Further, our method of selecting on sliding into the screen helped preventing errors by selecting an item unintentionally. We believe that these design elements help to improve menus for touch screens to be used by blind people.

Allowing to leave the device in the pocket enables a range of new applications: for one, users can operate the mobile device without dedicating visual attention to it. This is particularly convenient to control location-based services when being on the move, e.g. commuting or jogging. Furthermore, the device can be used in situations where privacy is desired, as users cannot be observed when operating the menu in the pocket. For example, when walking through a dangerous neighbourhood, people might prefer to leave the device in their pockets.

5.11.7 Proposed Toolkit HCI Modules

The study has provided evidence that the PocketMenu as described above may be a suitable menu.

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5.12 A Non-Visual Orientation and Guiding Application Based on Pointing Gestures

People who have visual impairments may have difficulties navigating freely and without personal assistance. Current navigation devices designed for the target user group are quite expensive, few, and are in general focused on routing and target finding.

This section deals with a prototype navigation application running on the Android platform in which a user may scan for map information using the mobile phone as a pointing device, and be guided to them non-visually. This application aims to solve some of the requirements elicited in D 1.1, namely:

- Direction and orientation – while guiding, the user can, at any time, switch to scanning mode, in which it is possible to locate landmarks and thus help the user to get an understanding of his/her bearings and orientation.
- Overview and landmarks – through scanning the environment the user can get an overview of the surroundings. Non-visual landmark display is obtained through pointing gestures, speech synthesis and distance information.
- Pedestrian use – the application is primarily aimed at open areas (such as parks) where routing as yet does not work well.
- Eyes-free use – the touch screen has eyes-free access by a tactile button design with vibration and speech feedback.
- Confirmation – tactile patterns and/or speech feedback is repeated continually to ensure that the user feels confident that he/she is going the right way.

5.12.1 State of The Art

Nowadays (April 2011) 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 Laya is one example (layar.com). However, there is also recent research showing how to make use of non-visual feedback, using sounds (Jones et al. 2008, Magnusson et al. 2009 & 2010, McGookin et al. 2009) or vibration (Robinson et al. 2009, Williamson et al. 2010).

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 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.

5.12.2 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). 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.

Guide	Far	Scan
More info	Middle	Mute
Add	Near	Start

Figure 51 The touchscreen Interaction Design.

The touch screen contains nine buttons as shown in Figure 51. 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. This design allows the user to slide her finger over the screen to find the right button without accidentally selecting something unwanted.

5.12.2.1 Scanning mode

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 is currently 30°, and if several POIs fall into a sector, the one closest to the 0° 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).

5.12.2.2 Guiding mode

In the guiding mode the user is guided to the previously selected point. The behaviour is such that the application provides the user with information about how the device is pointing towards the target point. When pointing +23 degrees from the target, the feedback will be to “keep straight”. If pointing in the opposite direction of the target (+30 degrees) it will signal “turn around”. If pointing beside the target, the user will receive information about whether to “keep left” or “keep right”. For the design of the angle intervals we have been guided by the recommendations in Magnusson et al. (2010). The speech feedback says the name of the goal, the distance to it and the text referred to above. The vibration feedback uses combinations of long and short pulses (long-short: keep right, short-long: keep left, forward: three short and turn back: five 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. For the vibration patterns described above a short vibration is 50 ms and a long vibration is 150 ms.

5.12.3 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 52).

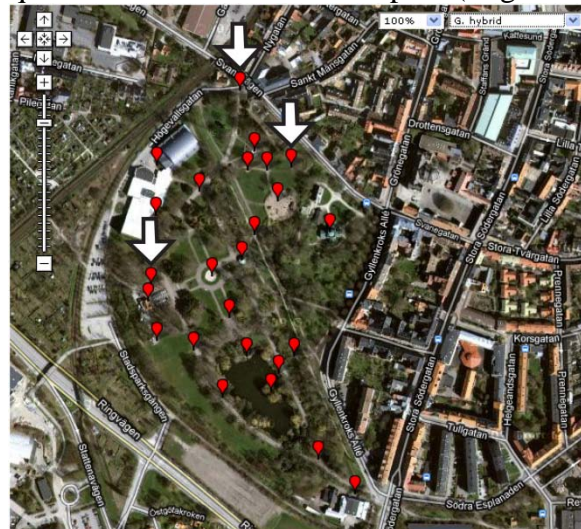


Figure 52 POIs in the test area. The POIs used in the test are indication by arrows.

Of our visually impaired users three were completely blind while two had some residual vision. We tested with 3 men and 3 women, aged 14, 16, 44, 44, 52 and 80 years. To allow the users to familiarize themselves with the application the test started with a tutorial on finding the test starting point (top arrow in Figure 52). Once at the test starting point the user was asked to locate the fictional place “Beechstock” (rightmost of the arrows in Figure 52) and go there using the guiding functionality. Once at “Beechstock” the user was asked to locate “Neverhood” (leftmost in Figure 52) and then to go there. The user was not told in which distance interval the points could be found, but needed to search for it. 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 52) 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.

5.12.4 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 because of GPS imprecision. The user commented: “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 to remember and understand the names of the buttons. 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 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 user and included a sighted teenager among our test users. Teenagers can be considered mobile phone expert users, and much marketing is targeted towards this group. We can make no general statements, but at least this user reacted very positively to the application and thought something like this could be 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.

5.12.5 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 (McGookin et al. 2009, Robinson et al. 2009) or guiding (Jones et al. 2008, Magnusson et al. 2009 & 2010, Williamson et al. 2010, Pielot et al. 2010). In contrast to Jones et al. (2008), McGookin et al. (2009), Robinson et al. (2009) and Williamson et al. (2010) we have also tested with visually impaired users. The test reported in Magnusson et al. (2009) 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. At the point of the test, no standard well-working screen reader solution was available for the Android platform, and there still (April 2011) is no solution that enables direct access to the touch screen.

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 pointing interaction described in this article 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 (routing and straight-line guiding) can be combined in a good way.

5.12.6 Guidelines for D1.4

This investigation made use of certain design solutions that can be formulated as guidelines, but each application needs to be considered in context and design solutions that worked in this context may not work in others. The guidelines are of different importance and generality, which we have tried to highlight in the headings below.

Always:

- Design with the GPS inaccuracy in mind i.e.
 - Display distance ranges rather than exact distances in meters.

- When arriving at a POI that is tied to a physical object, use a language that tells the user that “you are close to X”, “you are soon arriving at X” rather than “you are at X”.
- Display (also non-visually) the measured GPS inaccuracy.
- Test your application with standard screen readers.
- Provide the user with a variety of guiding behaviours to choose between. Different sounds / speech / vibration patterns.

Consider:

- Designing a non-visual touch screen interface solution if standard screen readers have poor usability in your application.
- Select-on-release design (although there may be a consensus on double-tap to select, so keep up with current design standards).
- Using pointing for orientation instead of (standard) ways of getting information on “what’s around me”. The standard way makes it necessary for the user to know his/her orientation relative to north, and therefore is more cognitively demanding.
- While guiding – use feedback for all directions, this confirms to the user that the application is alive and running.
- Repeat guiding instructions regularly for the same reason as above.
- How to handle filtering of POI’s. It is possible and quite simple to filter on distance, however, e.g. “prominence” or “size” could possibly also be used, provided that this information is present and accessible in the map data.

5.12.7 Proposed Toolkit HCI Modules

The functions in the PointNav application have been written before the toolkit became available, so the proposed modules will need discussing and rewriting, also for an Android platform-specific set of toolkit functions.

5.12.7.1 Guiding module 1 - speech

This module may be incorporated in other guiding modules, or they might also be totally separate, to enable the developers to choose a selection of guiding behaviours. The guiding module takes a heading (a compass direction in which the user is pointing with the device), and a bearing (in which compass direction the goal is). It outputs speech telling the user to keep left, keep right, turn around or keep straight.

5.12.7.2 Guiding module 2 – vibration patterns

This module may be incorporated in other guiding modules, or they might also be totally separate, to enable the developers to choose a selection of guiding behaviours. It is similar to the OFFIS tactile compass, but “morse code” and “Geiger” patterns were also tried in pilot tests. By creating a module that can change its vibration pattern depending on a definition file, a vibration pattern guiding module could be written.

5.12.7.3 Scanning module

The scanning module is a module that allows the user to scan the environment by pointing the mobile phone in different directions to get an overview of POIs in the vicinity. This module should

allow haptic and/or audio feedback and should also include functions for selection (to allow the user to select a point to be guided to).

5.12.7.4 Non-visual touch screen access

Possibly, the touch screen access technique with vibratory feedback on buttons, speech and select-on-release could be incorporated.

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5.13 NiviNav - A Location-Based Game for Mobility Training and Fun

5.13.1 Introduction

This investigation deals with the idea that location based pervasive games can be used to make mobility training for visually impaired children more fun. The user centred development process which has been carried out in collaboration with both visually impaired children and rehabilitation staff is described and we present a novel game concept which combines locative play, sound traces and a physical catch movement. We report and discuss results of user tests and summarize our experience in a set of tentative development and design guidelines for this type of game. The design solution addresses the recommendations in D 1.1 in the following ways:

- Direction and orientation – Pointing interaction helps the user understand the direction to target.
- Eyes-free use – the touch screen has eyes-free access by using the entire screen as a single button which activates the Geiger.
- Confirmation – sound Geiger feedback can be requested at any time to ensure that the user feels confident that he/she is walking towards the target.

5.13.2 State of The Art

For most people, learning to navigate a neighborhood comes naturally. Kids learn it through walking with their parents to and from the playground or kindergarten, and later start to explore it on their own. If you are visually impaired, learning to navigate your neighborhood is a slow process and involves the learning of a number of skills, including walking with a stick and interpreting the surroundings based only hearing, touch and smell (Blasch et al. 1997). This can be considered as a tedious and slow process, and it is also hard to let children train on their own due to safety concerns, making them less independent. The result is that sight-impaired children remain largely inside or confined to restricted areas that they know well. Encouraging and supporting navigation training would thus empower these kids to live a more independent life.

Computer games are already a well established solution for encouraging training activities in other contexts, utilizing e.g. Nintendo Wii or the Sony EyeToy (Deutsch et al. 2008, Brooks & Petersson 2005). In addition, computer games are an integrated part of children's culture, and many people spend hours every day online playing on games consoles, computers and mobile devices with people across the world. The anonymization of players in these games reduces differences such as age, gender and disabilities (Linderöth & Olsson 2010). Thus games hold great potential for both learning and training as well as for increased inclusion. Platforms such as Apple's iPhone and other smart phones equipped with GPS form the basis for location-based and mobile games, a small but growing segment of the games industry. Being games that can be present in almost every aspect of our lives, they have particular potential both for inclusion, learning and training. This potential remains to be explored systematically.

We have designed a location based intended to make mobility training more fun for visually impaired children. An important perspective underlying the presented work is to strive for “games for all” – the gameplay should allow both disabled users and non-disabled users to play the game. This is important for inclusion, but also increases the potential training opportunities available.

Non-visual interaction design for mobile devices is a very hot topic in interaction research. Although current high end phones such as the iPhone puts focus on visual designs, it is clear that future mobile applications require the other senses if users are to use them when moving around the real world which demands much visual attention (Oulasvirta et al. 2006).

A great deal of research has been done on systems for people with severe visual impairments that use non-visual feedback. One example is the Swan Project (Wilson et al. 2007) which uses sound to provide information about routes and contexts. In “Audio Bubbles”, the authors use a sound-design that is similar to that used in a Geiger counter (McGookin et al. 2009), while “Soundcrumbs” (Magnusson et al. 2009) use different types of music and natural sounds (e.g. waves against the shore). The “Soundcrumbs” application also introduced a direction-finding interaction model where the user points the mobile device in a direction and the sound feedback depends on if the device is pointing towards the goal or not. A similar design although making use of vibration feedback instead of sounds and assuming a stationary user was introduced in the Sweep-Shake (Robinson et al. 2009). The use of vibrations from a belt around the torso that depend on which way the user is heading is explored by Pielot et al. (2010) while Robinson et al (2010) extend the Sweep-Shake design to a situation where the user is also guided towards the target. Another similar example is the PointNav navigation prototype in (Magnusson et al. 2010b) which enables users to select points of interest by pointing at them, to get more information about different points or to be guided to the selected location.

Other examples of augmented reality applications are the kind of applications where you can point in one direction and see different types of environmental information superimposed on the image (Layar, <http://layar.com>, is an example). If we look at more experience-oriented applications there are different types of soundscapes created by artists or communities. An example of the latter is the Tactical Sound Garden (<http://www.tacticalsoundgarden.net/>) and the Urban Sound Garden (Vazquez-Alvarez et al. 2010). Malmo Living lab for new media have explored different ways to make your music mobile – an example is the “Barcode beats” (<http://barcodebeats.hobye.dk/>) which allows the user to design music loops by scanning bar codes on different food packages in a shop. An audio design which involves listening to localized story elements was used in the location based game ‘Backseat Playground’ project, in which children travelling in the backseat of a car would use a location- and direction-sensitive device to scan for virtual sounds sources situated in the environment (Richard et al. 2006).

5.13.2.1 The Game Prototype

The game runs on iPhone iOS 4.2, and uses the GPS position and the compass to get its input. The game has two modes of use. In the setup mode, the game leader places virtual “animals”, creating a trail with them. In the navigation mode, the user uses the mobile phone as a “scanner” to find the animals and to catch them (see Figure 53) using a large virtual butterfly net.



Figure 53 Catching the animal (picture sequence from the final evaluation)

Creating a trail or a game is straightforward. The game leader walks to the desired positions and places an animal at that position by touching the screen (Figure 54). The game play is embedded in a story, where the children are asked to help a farmer recollect his runaway animals before the mad scientist captures them to do experiments on them (Figure 55).



Figure 54. Place mode screen shots. Left: press the corner to start place mode. Right: Press the screen to place animal 1 at your current location.

The children receive an “animal scanner” (the iPhone with the application) to help them find the animals. Scanning for animals is done by pointing the scanner (iPhone) in different directions.



Figure 55 Game screen shots. Left: Welcome screen. Middle: The screen where the farmer gives you the mission (sound file played). Right: Game screen with a small visual representation of the scanner (the main scanner feedback is through sound). The debug printout was included to be able to monitor the application performance.

The scanning sound changes its characteristics depending on if the child is pointing directly at the animal or beside it, or in the opposite direction. When pointing directly at the animal, the sound will have a higher pitch and a clear tone, while it is muffled and lower pitched when pointing in other directions. The clear sound is heard when the user points within $\pm 15^\circ$ towards the target (based on the recommendations made in (Magnusson et al. 2010a)). Outside this the sound gradually loses the high frequency components and sounds more like being played inside a tin. Outside the angle $\pm 45^\circ$ the sound is very dull and tin like. When approaching the animal, and when in a certain distance from the GPS point where it is located (at the moment 12 meters) a rustling sound will be heard. If the child now proceeds in the direction for a few meters (which is calculated by using step counting), the particular sound for the animal (at the moment domestic farm animals) will be played. At that point it is time to do the gesture as if using a large butterfly net to catch the animal. If the animal is caught, the animal screams. If you don't catch the animal within 2 seconds of hearing the sound, it runs away. After catching (or missing) one animal, the player proceeds with the next animal in the trail, until the entire trail has been walked. At the end of the trail, a result message is read to the user, displaying the time to complete the trail and the number of animals caught. To encourage the participation of the children in the design process, the storytelling voice is also asking the children what they think should happen to the animals now when they are caught.

5.13.3 The Development Process

The training game was developed in a user centered and iterative process. The process has involved staff from a rehabilitation center for children with vision impairment, children with visual impairments, game designers and game and technology developers. Key activities have been designer workshops involving rehabilitation staff, designers and developers and user workshops involving visually impaired children/young adults, rehabilitation staff as well as designers and developers. The flow of the project has been built around the following workshop activities:

- Designer workshop
- User workshop 1
- Game design workshop
- User workshop 2
- User workshop 3
- Longterm final evaluation with 2 visually impaired children (8 and 10 years)
- Proof-of-concept test with 2 sighted children (6 and 7 years)

Software development as well as additional informal interviews and tests have been running in parallel with the workshops – but the sequence of workshops has provided the overall structure for the project work.

The initial design workshop served to do a first exploration of the design space, and to generate ideas and material for the first user workshop. At the first user workshop the children present were allowed to test two non-visual interaction designs in order to give them a concrete background for the discussions. The results from this workshop were used as input for a targeted design workshop where two game designs were explored in greater detail. Together with the rehabilitation staff we selected one of these game designs for implementation – and a first prototype was tested and discussed at the second user workshop. At this workshop we also discussed the not yet implemented design. The results of the second workshop were used to improve the prototype into a pre-final game version which was evaluated at user workshop three. This led to final improvements and the final game design was tested by two children under a two week period. The children were interviewed before and after the two week period. A single observed test of the application was also done in connection with the second interview (after the two weeks).

5.13.4 Final Evaluations and Results

The final evaluation of the prototype was done in a long term trial with two children with visual impairment. The two users, 8 and 10 years old, were asked to test the game for a period of two weeks. As the trial was run in January, we purchased mittens so that the device could be used inside the mitten to keep both hand and device warm. This design also reduced the risk of accidental device throwing in the catching gesture. Even if the user loses grip of the phone it will still stay inside the mitten. The test procedure was designed together with the rehabilitation staff, so that the test was performed in a way that fitted well with the way the game could be used for mobility training in the future.

The rehabilitation staff visited the children and played the game with them on the first use occasion. After this one iPhone was left with each participant, so that they could continue to use the application without rehabilitation staff present. The participants asked to keep a short diary and were given a set of questions to answer each time they used the game. On the 8 days later the rehabilitation staff again visited both children and played the game. Finally 15 days later a final video taped game session was run. On this occasion the participants were also interviewed.

5.13.4.1 Test Diary

8 year old user. This person used the game 3 times, once with a sister and twice with the father. It was fun all three times. GPS problems influenced how easy the game was felt to be – the rating

varies between “easy” and “intermediate”. When the GPS jumped one animal got away, and this user got quite upset.

10 year old user. This person used the game 4 times. Both parents followed the exercise. All animals were caught and it was fun to play. The game was easy (maybe too easy) and the trail got easier to follow each time.

5.13.4.2 Observed Play Session

8 year old user. This person held the hand of a mobility trainer during the test. The test user used to game to find out where they should go – and also caught the animals. The day the test was performed was quite cold, and there were some problems with the application stopping (this happened three times), but in the end the trail was completed successfully. Comments from the user: This user would like more levels in the game. Reflections: This user is very engaged in the game and gets upset by the risk of losing animals.

10 year old user. This person walks and handles the iPhone independently. Very distinct catching gestures are made and all the animals are caught. The goal is reached quickly. Comments from the user: The game is easy now that the animal locations have been learned. It is good that the game has a story. As it is now, it is too easy and finishes too early. The users would like to play more. Reflections: This user had learned the trail well. At the initial point there was some GPS problem but the user clearly knew where the animal should be and walked around until it appeared where it was supposed to be.

5.13.4.3 Interview

8 year old user. This person found the game motivating and would not have practiced this route if not for the game, but the user is also scared to lose any animals since they are then lost forever. The fun level of the game was rated as 8 on a scale from 0 to 10. The negative comments were about the game stopping sometimes and that you have to walk. This user would like to play the game once every day, but would also like to play it while sitting still indoors.

10 year old user. This person found the game motivating. It was fun to catch animals along the way. The user would like to try more trails and states that it is a good way of learning a new route. The fun level of the game was rated as 9 on a scale from 0 to 10. The reason given was that it was problematic that the game sometimes stopped. This user would like to play the game every second day.

5.13.4.4 Play Session - Sighted Children

Two sighted children, 6 and 7 years old, also tested the game. On this occasion, the animals were placed randomly in a garden. The game was played in collaboration, allowing the children to take turns catching the animals. After introducing the scanning sound and showing the catch movement, the children listened to the story, and were then able to catch all animals. The scanning sound presented no difficulties, but for the younger child the catching gesture was seen to be somewhat difficult to carry out. After one round, the children wanted to play again.

5.13.5 Discussion

There are several indications that the game is both engaging and fun. The reason that the game is not rated at the top is primarily due to technical issues with GPS positioning. Locations can only be relied on to within 10-20 m, which makes it impossible to guide a user exactly. Unless better

positioning is made available this is something all such applications need to take into account. In the present project the game was designed with this in mind (just as recommended in (Benford et al. 2006)) – the circles within which the animals could be heard were kept large to avoid forcing a user out into a street etc. For mobility training this may actually be beneficial to some extent, as the ultimate objective is to learn to navigate independently in the environment. In the game, the user has to keep track of the environment, while the game is designed to provide an indication of in which direction to go and adds motivation for the exercise. This is not to say that better precision is not something to strive for. With better location precision, the game could present the information at different levels of imprecision depending on what is needed for a particular user or usage context.

The final test was done with one user who cannot navigate alone but needs a person as company, and one more independent user. The latter user was able to learn a route through using the game. The game was seen to work in both settings – it increased the motivation for going out to train also for the less independent user, and the more independent user learned the trail as well as all the animal locations.

These test results show that the game is well suited for integration in the mobility training – it can be used both early in the process (together with a human guide) and later by a person who is able to move independently but who needs to learn a route.

Designing location-based games for sight-impaired involves more than just using sound. The application had to be possible to use without being able to see the screen at all, and it was also necessary to design it to be possible to use with only one hand, since the other hand might hold a cane. At the same time, our design ideal of ‘design for all’ required a design where the game was attractive to sighted people. These considerations led to a design that is based on non-visual interaction, and uses the on-screen information as an enhancement. This is in contrast to how most location based games of today are designed. Even “Backseat playground” (Bichard et al. 2006) which makes use of audio for most of its interaction requires interaction, used on-screen visual elements for feedback. The authors report this as a design flaw, as it drew the eyes of its (sighted) users towards the screen rather than to the surrounding environment where the game was (virtually) staged by sound overlays.

In order to enable non visual usage, much of the design efforts were focused on the design of audio feedback. Previous work, like Audio GPS (Holland et al. 2001) and Audio Bubbles (McGookin et al. 2009) has used a Geiger counter metaphor, where the pulse frequency indicates the direction of the target. Volume has also been used to indicate direction in (Magnusson et al. 2009), for example. Spatialized sound was used in the Roaring navigator (Stahl, 2007). Timbre, which is used in our design in addition to pitch, is a parameter which has not been explored before, but that turned out to work really well and once introduced to it, none of the children appeared to have problems with it.

In addition, the interaction is based on gestures with the whole phone, rather than by e.g. pressing buttons as in most existing location-based games. Gesture-based interaction has been explored in the context of stationary game devices for a while, but the combination of locative play, sound traces and a catch movement makes the game interaction model unique. We arrived at this interaction model solely through the focus on sight-impaired players, but given the success of the Wiimote and

the recent Kinetics device, as well as the feedback from the participating children, we have reason to believe that it is an entertaining mode of interaction also for sighted players.

The result is a mobile game that is fun and simple to use for sighted and sight-impaired children alike. (It is probably also the world's only mobile phone game that can be played with the phone inside a mitten.)

5.13.6 Guidelines for D1.4

To use this type of technology for (re)habilitation is an immature field which is in need of further exploration. From our experience with this location based game, we wish to share the following recommendations:

- Design explicitly for position inaccuracies.
- Start from the non-visual design and make sure all information can be accessed also without vision.
- Design for one-handed or hands free use.
- Think “inclusive design”, also for applications that maybe primarily are designed with a specific user group in mind. This makes it possible to share the experience with others.
- Involve both real users and real contexts in the development process.

5.13.7 Proposed Toolkit HCI Modules

5.13.7.1 Guiding module – Audio Geiger

This module may be incorporated in other guiding modules, or they might also be totally separate, to enable the developers to choose a selection of guiding behaviours. In this example, the sound feedback was based on a sound sample that was played with different characteristics in sound (see also section “The Game Prototype” on page 124). Technically, different sound files will be played depending on if the phone is pointing directly at a goal (+/-15 degrees), beside it (several files with decreasing clarity until +/-75 degrees from the goal), or in the wrong direction (dull sound for the rest of the angles).

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5.14 TouchOver Map

With the success of iPhone and Android, the handheld devices of today are more and more controlled by touch screens. As at the same time the use of GPS and mobile Internet has increased, we nowadays find a large variety of location-based services for these devices. Typically, these services use visual maps to communicate location data.

However, interacting with such maps on touch screen devices require the user to look at the display. This prevents users with visual impairments from accessing map-based information. Visual impairments may occur in various ways, ranging from congenital blindness over age-related impairments, to sighted people with situational impairments, such as moving through a crowd of people.

A solution to this problem is the use of non-visual presentation modalities, namely audio and haptic feedback, to present geospatial information. Thereby, two key challenges need to be addressed: first, the meaning or name of geospatial objects has to be provided and secondly, the spatial relation between the geospatial objects has to be communicated. In this paper we investigate how this information can be conveyed interactively by using a smart phone's vibration motor together with speech output.

5.14.1 State of The Art

An early solution from the last century is the use of raised paper maps. Small rises in the paper indicate the shape of geospatial objects and braille letters communicate names. McGookin et al. (2008) investigated using raised paper as touch screen overlays to enable non-visual interaction. They found that visually impaired users could effectively interact with raised paper-enhanced touch screens. Nevertheless, a disadvantage of raised paper is that it can hardly be created or altered on-the-fly to accommodate a certain desire, such as searching for restaurants in the vicinity.

Another approach that has been investigated independently from touch screens is sonification of geospatial data. Sonification refers to data conveyed by non-speech sound. Jacobson (1998) proposed to associate geospatial objects on the map with natural non-speech sounds. For example, a lake would be represented by the sound of water bubbles. In their design prototype, users explore a map by moving a finger over a digitizer tablet. When the finger enters a geospatial object the associated sound is played. The design was evaluated with 5 blind and 5 sighted people. Exploring a map in its non-visual representation only, they could successfully draw a sketch of the presented map.

Parente and Bishop (2003) proposed not only displaying the touched geospatial object, but also presenting the adjacent geospatial objects while mapping the spatial relation to 3D sound. For example, a lake left of the touched geospatial entity would be heard from the left. Heuten et al. (2006) showed that such information presentation allows visually impaired people to reconstruct the shape of a city with Lego bricks.

Recently, Su et al. (2010) investigated the sonification on handheld touch screens. Their Timbremap prototype investigated how to support people in exploring lines and areas by sound feedback. They showed that people identify shapes with a recognition rate of 81% and can develop an understanding of an indoor floor plan.

All the above solutions are directed specifically at severely visually impaired persons. If one instead starts from existing map formats, we suggest it is potentially useful to extend this by providing the information also through non-visual channels. Although such enhancements are likely to be most useful for persons who have some visual ability (using the non-visual modalities together with the visual presentation), we wanted to start by testing our design in the extreme case where they user is unable to see the screen at all.

Beyond previous design, our work bases on publicly available OpenStreetmap data. Our goal was to find out to what extend the existing work could be applied to a geographic street network from a real world city.

5.14.2 Design and Realisation

The key elements, a sighted person gets from a map are roads and certain points of interest, e.g. the location of a church. However, either for way finding or to get an overview over the map, streets are often more important than points of interests.

Our approach is to use vibration and speech to make the road network accessible to a visually impaired or blind person. We think that the most intuitive approach would be to explore the map with one's finger, like e.g. a blind person reads Braille. Interaction-wise it is questionable, how this touch-over behavior can be integrated into recent interactive map applications. For the moment we are approaching this problem with two different modes a map can provide: the usual interactive mode, and the touch-over mode. A button allows switching between these modes.

Once a finger touches the map and a road is underlying, vibration is issued and the name of the road is read out continuously. If the finger leaves the road, both signals stop. However, the speech continues to read the name until the end. We assume that the continuous feedback allows the user to follow the road on the map to get a decent knowledge on where the road actually is on the screen.

As platform we decided to use Android. We integrated the concept by implementing an overlay for an existing map-based navigation application. In practice, the overlay does both: drawing the raw map data for debug and testing purposes, and handling the user generated touch events to trigger vibration and speech feedback.

As one can't use pre-rendered map tiles, we need raw map vector data. This data is obtained from a geo server, providing data from OpenStreetMap. We use an XML-based format to query and transport the map data. On the smart phone the XML is parsed and stored as line segment in an internal data structure.

These line segments don't come with a width. However, line width for the touch handling is a very important design factor. On the one hand, a line can be easier discovered if it is wider. On the other

hand, we lose spatial precision if the lines are too wide. Through empirical tests on multiple devices we end up with a preliminary ideal line width of approx. 48 pixels.

Most challenging implementation-wise was the mapping of a touch event to a line fragment. A finger movement on mobile phone's touch screen causes multiple touch events and each of these events must be analyzed, if it touches one of the line segments or not. OpenStreetMap aims to be very accurate and, thus, provides lots of line fragments. This ends up with a quite complex calculation task, even for the powerful mobile phones of today. This results in slight delays in the interaction process. For the next iteration we aim at more intelligent algorithms, which maintain the precision, but are less complex.

5.14.3 Study Description

Describe the study (obviously there is some flexibility here depending on the study completed). The test task was to explore the map non-visually and draw a map of it with pen and paper. To avoid making the test into a test of how well the person was able to remember the map, we allowed the person to draw and explore at the same time. To keep the person from seeing the screen the setup in Figure 56 was used.



Figure 56 Test setup.

Eight sighted persons carried out the test (4 women and 4 men). The ages of the participants were 15, 24, 28, 33, 39, 42, 49 and 50. The phone used for the test was a Google Nexus One. Since this phone has software buttons that the user might accidentally trigger during the test, these buttons were covered with paper (see Figure 57). We tested two different levels of complexity by using two different zoom levels of the map. The map was centered on the GPS coordinates 56.667406 N, 12.873412 E (Halmstad, Sweden). This location was selected since it was expected to be unfamiliar to the test persons. We used “My Fake Location” to manually set the location.

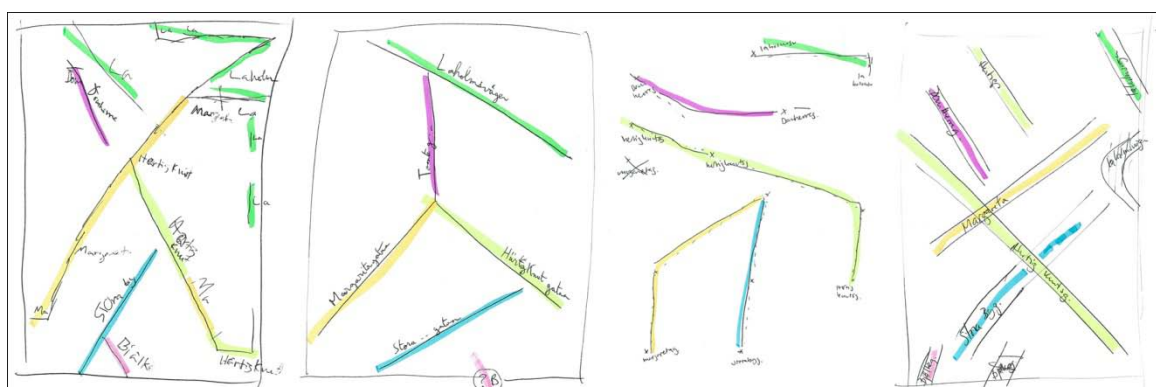


Figure 57 Left: phone with paper covers and the “zoomed out” map. Right: phone with “zoomed in” map.

As was stated earlier our implementation makes use of OpenStreetMap, and the street information used for audio and tactile feedback is indicated by blue lines in Figure 57. The exploration time was limited to 15 minutes although participants were allowed to stop earlier if they wanted. As we expected learning effects both for the interaction and the map area, half of the participants tested the “zoomed out” map first, and half of them started with the “zoomed in” map instead.

5.14.4 Results

The maps generated by the participants for the “zoomed in” map are shown in Figure 58. The maps for the “zoomed out” map are shown in Figure 60. For reference the actual maps are given in Figure 59.



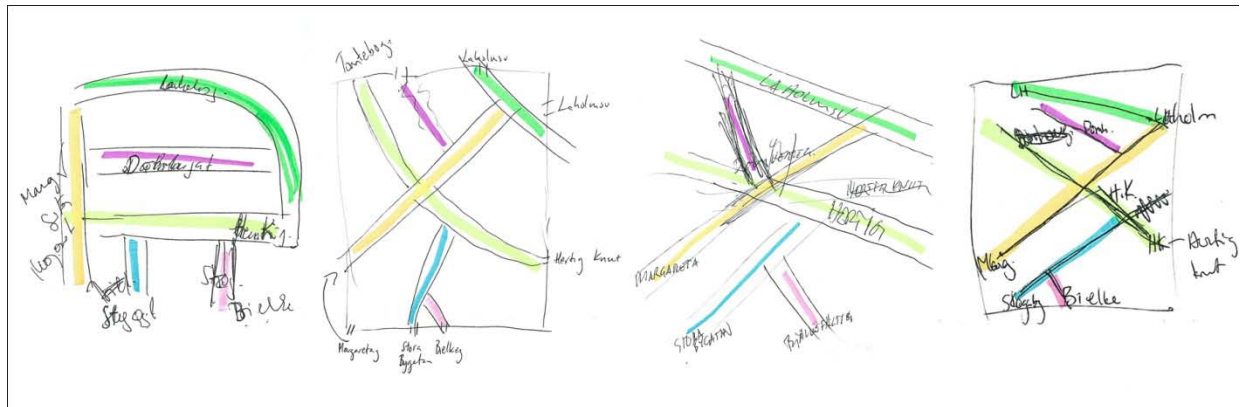


Figure 58 Maps drawn for the “zoomed in” condition.

The maps are colour coded to help identification of the different streets. Although it is obvious that none of the drawn maps replicate the original map perfectly it is clear that all participants got basic objects and relations right. The big green road (Laholmsvägen) is put in the upper right part of the screen, the orange road (Margaretavägen) is somewhere in the left and goes upwards. The yellow-green road (Hertig Knuts gata) goes from the right across the screen, etc. On the whole the “zoomed in” maps appear more accurate – all streets are present and some of the maps (e.g. Figure 58, lower rightmost) are quite accurate. The fact that participants needed up to 15 minutes to get a map together shows that without visual support this is quite a cognitively demanding task. Comments during the test showed that participants felt the “zoomed out” condition was too difficult (and also confusing) while they handled the “zoomed in” condition better.



Figure 59 Left: Actual “zoomed in” map. Right: Actual “zoomed out” map.

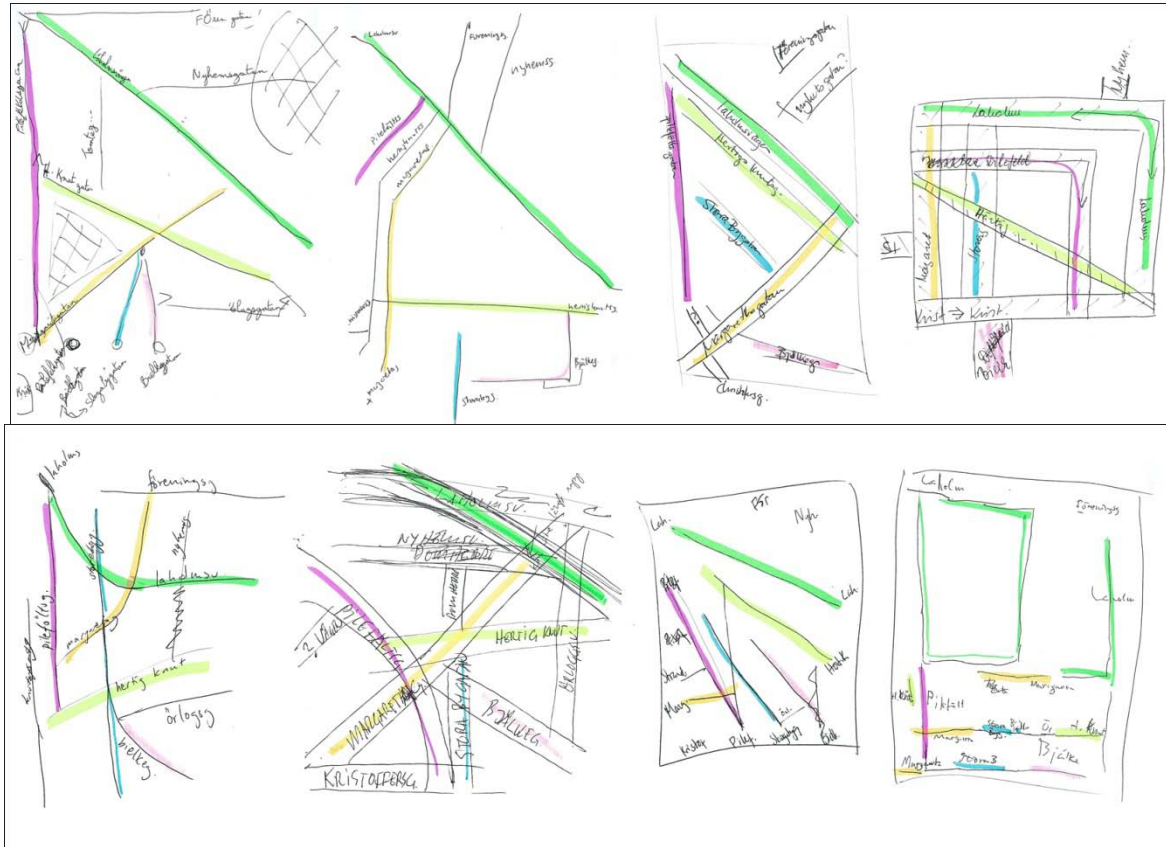


Figure 60 Maps drawn for the “zoomed out” condition.

The high cognitive load in the “zoomed out” condition is also reflected by the fact that all participants had to be stopped from continuing in this condition, while in the “zoomed in” condition they were mostly doing checks/small fixes by the time was up (two users even finished before the time was up). Finally, some identified problems with the current implementation were:

1. The speech would keep talking also after the finger no longer touched the street. This confused some users into thinking roads were more extended or at different locations from where they really were.
2. That the speech kept talking also led to it being possible to move to a new street before the speech had finished (leading users to think this was the wrong street).
3. It is impossible to know if roads are close or if they cross.
4. It is hard to tell the direction of short roads.

5.14.5 Discussion

This reported results show that it is indeed possible to use vibration and speech feedback as the finger moves over relevant map objects works as a means of perceptualizing the map content. Compared to earlier work (Heuten et al. 2006, Jacobson 1998, McGooking et al. 2008, Parente and Bishop 2003, and Su et al. 2010), which has been directed at severely visually impaired or blind persons, we start from the “design for all” perspective and enhance an existing real visual map. We

still chose to do a first test in the extreme case of the user not having access to the visual information in order to check if this kind of solution could also work for this type of setting.

5.14.6 Guidelines for D1.4

Our results show that it is indeed possible to make basic features of a map layout accessible by using our approach, although it is quite a cognitively demanding task. The results in combination with user comments indicate that the level of detail in the “zoomed in” condition appears manageable while the “zoomed out” condition is perceived as more demanding/confusing. Thus we get a preliminary recommendation that the amount of content one can deal with non-visually should be kept at the level of complexity used in the “zoomed in” condition. We also note some problems in the current interaction design. In particular we suggest that the feedback for on/off a road needs to be made clearer and that information about crossings is needed. Small objects are a problem which needs to be considered carefully. Finally, in order to test this design in real situations and with both sighted and visually impaired users, future designs need to include feedback for the user's own position in the map.

5.14.7 Proposed Toolkit HCI Modules

For the toolkit we propose to integrate the *TouchOver Map* design as an HCI module. In its current implementation it uses OpenStreetMap data, which are stored as simple line strings, which goes perfectly well with the toolkit's internal geo data storage philosophy.

5.14.8 References

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5.15 Virtual Navigator

5.15.1 Introduction

Navigation in the environment is a vital skill in allowing an individual to lead an independent life. For blind and visually impaired people however, such trips are challenging and require specialised training to learn routes as short as walking from home to the local shops. In the U.K., this training is usually provided by the local government authority and involves a mobility training officer developing a route between the two locations a user would wish to walk. The routes developed involve the user piloting between multiple landmarks that exist in the built environment (such as post-boxes, drain-covers or lamp-posts). These routes are chosen to be safe and may therefore not be the most efficient or shortest routes available. Over several one-on-one sessions, the mobility officer trains the visually impaired user on the route. As the routes are complex, multiple sessions may be required and there is often a waiting list for training. Additionally, each individual will learn only a few routes. Therefore in cases where a primary route may be blocked (e.g. due to road works), the visually impaired person will not have an alternate route to navigate. In this work we wanted to look at how we could develop techniques to simulate this learning experience in a self directed way. These techniques could be in future used to explore routes generated from other haptimap applications, allowing users to explore routes that have been generated from search queries.

5.15.2 Related Work

The problem of navigation by visually impaired people is not a new one and several research attempts have been made to allow independent navigation in the environment. Primarily these have consisted of satellite navigation (GPS) based systems to guide the user dynamically in the environment. GPS based systems offer the possibility of navigation without a visually impaired person needing to pre-learn a route (in a similar way that car GPS systems negate the need to read the map) (Loomis et al. 2001) However, as noted by Strothotte *et al.* (Strothotte et al. 1995) such navigation requires piloting between close together, small landmarks. Such landmarks are often much smaller than even high quality GPS accuracy, so might be missed. Walker and Lindsay's SWAN system (Walker and Lindsay 2006) which uses audio beacons to navigate a route, recommends a position accuracy of less than 1m. Something that is not currently available.

5.15.3 Design of Virtual Navigator

To overcome many of the problems identified, we have begun to develop an application called Virtual Navigator. Virtual Navigator is designed to augment the training supplied by mobility trainers and allow blind and visually impaired cane users to develop basic navigation skills and learn routes in safety. We do not argue that the use of Virtual Navigator will replace mobility trainers, but rather allow more opportunities for a learner to experience a route and thus make better use of limited training sessions that are available. We are developing Virtual Navigator in a participatory design manner, with feedback from users being incorporated into future versions. The version discussed here is based on initial interviews with, and observations of, mobility trainers and discussions with visually impaired users.

Virtual Navigator allows a user to interact with a virtual 3D model of a test route (see Figure 61) via the use of a haptic force-feedback device and spatialised auditory feedback. This allows many of the physical aspects of the environment that are used as landmarks to be simulated. The user explores the environment in a first person perspective (similar to a 3D "shooter" computer game). Figure 62 presents a screenshot of the visual interface of Virtual Navigator. The model is generated at a prototypical size as this most closely matches the world. I.e. a meter in the built environment is a meter in the real world. Our current models represent a fairly small environment so doesn't take very long to move through. In larger environments, such as prototypical routes, it remains an open question if the model scale could be reduced so that the route could be covered in less time without comprising learning. The model used in the simulator is currently produced via the Milkshape 3D (<http://www.milkshape3d.com>) modelling package. Future work will investigate automatically creating the model from both online map data and a toolkit of pre-built objects (such as post-boxes or lamp-posts) that can be dragged and dropped into the environment by the trainer.

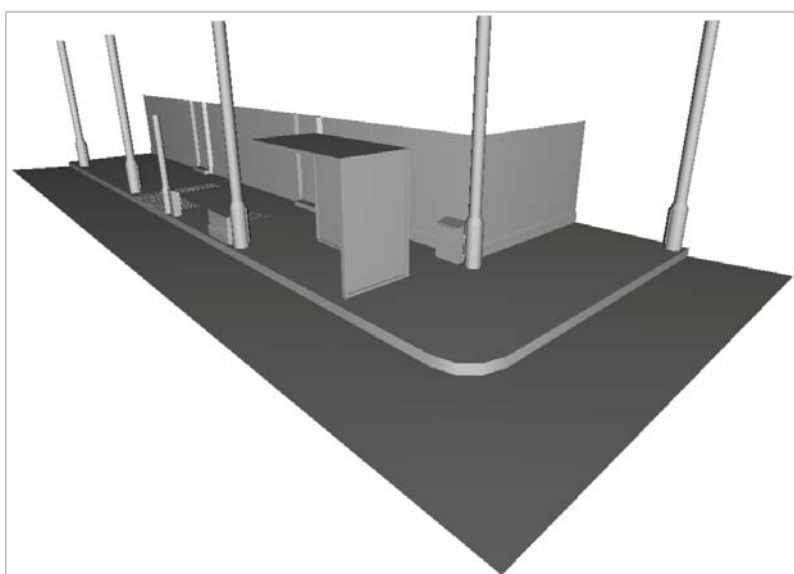


Figure 61 The test environment used in Virtual Navigator.

Movement in the environment is achieved by using the directional cursor keys on the keyboard. Pressing the forward or backward keys cause the user to take a step in the corresponding direction. The sound of footsteps (one step sound per step taken) is used to provide an indication of distance travelled. The left and right arrows cause the user to turn 45° in the appropriate direction. As users are conventionally trained to turn on the spot to change direction and to pilot in straight lines, such a mechanism is more appropriate than stepping left or right.

5.15.3.1 Virtual White Cane Interaction

A NOVINT Falcon (www.novint.com) (see Figure 63) was used to act as a virtual white cane. The Falcon, as with many other force-feedback devices, works like a 3D mouse. As the user moves the end-effector around, a proxy object in the virtual scene moves (see Figure 62). When this proxy is determined to have come into contact with an object, a resistive force is applied providing the impression of a physical object. The Falcon provides a fairly limited workspace and only allows exploration of the scene with a single point of contact. In many applications this has been argued as

a disadvantage of virtual haptic devices. However, in this case, it is very similar to the way in which a white cane acts when exploring the world.

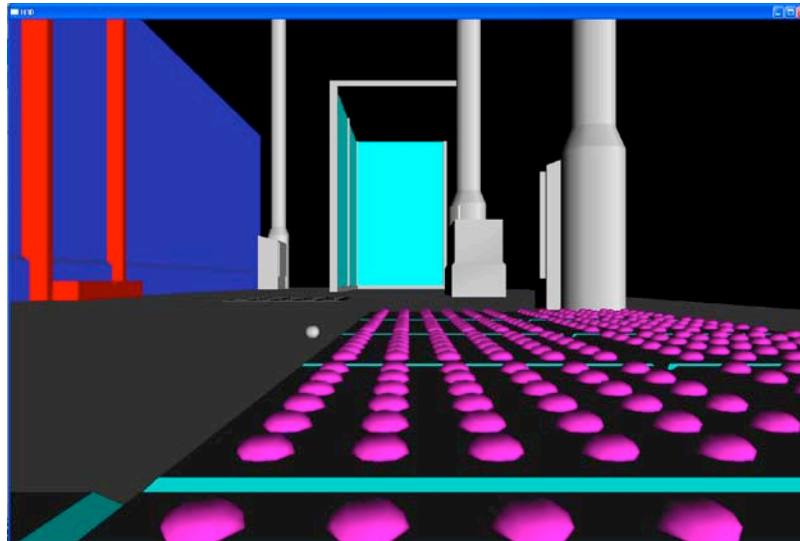


Figure 62 A screenshot of the Virtual Navigator system. Showing the model and the proxy object.

Because of the impoverished nature of the feedback provided by a white cane, identification of landmarks is usually undertaken by sound caused by the interaction of the white cane on a landmark. Virtual Navigator deals with this by providing both contact sounds and movement sounds when the Falcon proxy comes into contact with the landmark. Both are important, as landmarks can take many different forms. Some, such as a post-box, will be identified through both physical forces stopping the cane moving, as well as the contact sound of appropriate pitch and timbre to indicate a hollow metal tube. Other landmarks, such as a manhole cover or tactile paving, will be identified via vibration and the repetitive striking sound as the user moves the cane over the surface. We used FMOD (www.fmod.org) to allow for low latency playback of recorded sounds when the user taps a feature in the virtual environment, or moves the proxy object over the surface.



Figure 63 The NOVINT Falcon. A 3D haptic force feedback device used to allow interaction with the model.

The sounds used were generated by a visually impaired cane user tapping and scrapping surfaces made of different materials in the built environment. The sounds were recorded using an iPod Touch with microphone attachment and were processed in the WavePad software package. The sounds are triggered if the user touches or moves the Falcon along a surface in the virtual environment. We have found that combining these simple categories of sound with realistic physical models of the tactile paving and manhole covers in Virtual Navigator, naturally generate composite sounds in our environment that closely mirror the sounds of interacting with real world objects.

5.15.3.2 Auditory Clues

Whilst piloting between landmarks is the primary means of route navigation, other transitory features of the environment called clues are also useful. These are features of the environment that may or may not be available when navigating. If they are available, they provide useful indication that the correct direction is being taken. Whilst clues may be physical (such as a table outside a cafe), they are more likely to be auditory based. The way that sound changes on a street between rush hour and night time, or when walking under a tree lined avenue rather than an open street, can all be used to provide additional clues to the cane user that the correct direction is being followed. Virtual Navigator supports such clues by incorporating an environmental soundtrack that can be modified through FMOD to reflect the environment the user is passing through. So far we have included a simple reverberation to the environmental and footstep sounds as the user moves through more enclosed features of the environment - such as under a bus shelter.

5.15.4 Discussion

We have carried out qualitative evaluations with three late-blind cane users on a simple street model and employed a mobility training officer to provide comments and guidance for improvement. In all of these evaluations Virtual Navigator was seen as a positive addition to route training and was felt to provide a useful ability to learn a route. From these several recommendations for interaction were discussed that should be incorporated into a real system. Firstly, was the use of the virtual

white cane. In the initial system we modelled the cane as a single point. However as the user is sweeping left and right in the environment and walking at the same time, it is possible to miss small landmarks such as lampposts and simply sweep behind them. As the cane is modelled as a point, no indication that this occurs is currently provided. The white cane should therefore be modelled as a stick, and contact at any point of the stick will cause haptic and auditory feedback. Further to this, one of the late blind users said that he swept from left to right with the cane whilst walking. This is a common interaction strategy, but he said he had no idea of how far he was sweeping and, when he was unable to sweep further, had no idea if the limit of the device workspace had been reached, or he was interacting with an obstacle. He noted that some form of awareness of when the cane reached width of his shoulders would be useful. The mobility trainers also provided important feedback that clues can be formed of multiple different modalities, of which haptic feedback and sound are only two. She noted that smells, such as a florist or chip shop could also be used as clues to allow a participant to orient his or herself in the environment. We intend to incorporate such feedback here using devices such as the Dale Air Vortex (www.daleair.com). In such a way Virtual Navigator will be able to provide a much closer set of landmarks and clues to those of the prototypical environment. We believe that with these enhancements incorporated, Virtual Navigator can provide a useful augmentation for visually impaired and blind users in the important skill of environmental navigation.

5.15.5 Guidelines for D1.4

From this work, the following guidelines can be derived for D1.4

Virtual White cane provides a good approximation of the built environment.

In our evaluations the relatively impoverished feedback from the Falcon was effective in allowing users to gain a sense of the environment in a similar way to a white cane.

Virtual White cane needs to be a cane.

Commonly, when using force feedback haptic devices, the cursor object is modelled as a single point in the virtual scene. From our user feedback this can lead to problems, such as missing landmarks or other environmental features when sweeping in the environment. The proxy object should therefore be modelled as a stick, with haptic feedback generated in response to contact at any point in its length.

Simple audio feedback is effective.

The audio cues we generated were simple, using only contact and scraping sounds. However, as these were played in response to similar physical movements they proved to be very effective. We do not believe that complex sounds are necessary to provide a feeling of the built environment.

Provide body awareness of the cane.

From the discussions with visually impaired users, awareness of the cane and how this related to their bodies was important in understanding the environment. Specifically, when the end of the cane passes beyond the shoulder width of the user. Feedback to indicate this should be provided.

The scale of the model and environment.

An issue raised, that we were not fully able to explore, is the scale between the real world and the virtual model. A 1:1 scale is most realistic, but might take a long time to navigate. A smaller scale makes navigation less realistic but faster. On the other hand, from D1.1 we know that navigation is essentially piloting between different landmarks, so “cartoonification” (1:1 scale at turning/decision points with smaller distances between them) might be a useful way to proceed.

5.15.6 Proposed Toolkit HCI Modules

From this work, we propose that a white cane module could be integrated into the WP4 toolkit. This would allow a user to explore a 3D virtual environment. The module should allow haptic interaction along the length of the cane and provide auditory or vibration feedback when the cane is moved outwith the user’s shoulders.

5.15.7 References

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5.16 Non-Visual Tangible User Interfaces

5.16.1 Introduction

Visually impaired and blind computer users face significant hurdles in accessing computer-based data. Screen-reading software is useful for textual data, but less so for the millions of charts, graphs, maps and other commonly used visualizations produced each year. In order to make this data accessible it must be specially formatted, usually by hand, and printed onto swell paper – special paper that causes the print surface to raise up when subjected to heat – to create a tactile diagram which can be explored through touch. Such diagrams are inflexible and cannot be modified after creation or interactively manipulated (McGookin et al. 2010). This makes the display of map based data difficult and the interactive interrogation and planning tasks that are common when sighted users are planning routes or holiday trips difficult. Such diagrams however, do allow the user to employ both hands and the rich human tactile sense when exploring the diagrams. This allows the user to mark and spatially reference features. Much research has been carried out to present and allow manipulation of visualizations without the need to create these diagrams (Fritz and Barner 1999; Wall and Brewster 2006). Whilst successful, most of this work introduces new problems, such as the loss of two-handed interaction or impoverished tactile feedback (Wall and Brewster 2006). Such as the case when using a PHANTOM haptic device. In D2.1 (p28) we introduced the development of the first system to support non-visual tangible user interaction for visually impaired users. This work is more accessibly reported as (McGookin et al. 2010). Employing tabletop tangible user interfaces (TUIs) can be employed non-visually, allowing the advantages of tactile diagrams to be retained but with the advantages of dynamic data display and modification. This was successful and as discussed in the following sections, other researchers have started to further investigate this area, meaning that Haptimap has caused a new research topic to emerge. However, there were several issues that required further investigation. Notably in the way that the physical markers, or Phicons (Fishkin 2004) could communicate with the user. In this section we discuss our efforts to understand the best way to do this.

5.16.2 State of The Art

Similar to visual tabletop TUIs, non-visual TUIs involve the user placing computer-tracked Phicons (physical icons) on a physical table. Manipulating Phicons (Fishkin 2004) on the table surface controls a computer-based model of some data visualisation. Where non-visual TUIs differ, is that the model, rather than being visually displayed on the tabletop, is presented aurally through a sonification (a direct mapping between data parameters and sound, usually pitch) (Riedenklaus et al. 2010). For example, Figure 64 shows a non-visual TUI to allow the interactive creation of simple line charts, such as might be the case at school (McGookin et al. 2010). Phicons represent control points for two data series and are placed in a physical grid. The system interprets these and infers the graph. This graph can be sonified when the user interacts with a special Phicon at the base of the graph or saved and restored at a future date.

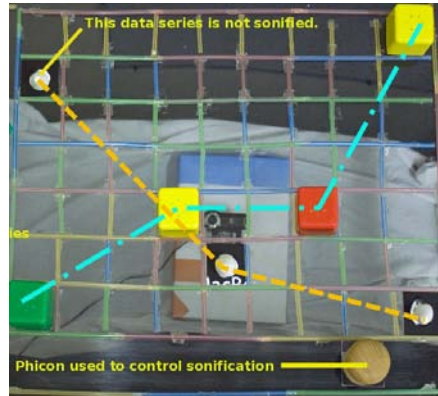


Figure 64 An illustration of a non-visual tabletop tangible user interface. Different Phicons provide control points for a graph containing two data series. Moving the sonification Phicon sonifies the graph so an overview can be obtained.

Several examples of non-visual TUIs exist (Choi and Walker 2010; McGookin et al. 2010; Riedenklaue et al. 2010). Whilst successful, there are not yet clear design guidelines in many areas. One important area is Phicon feedback. In visual TUIs, the sense of embodiment (Fishkin 2004), that information is contained within the Phicon, is important. This means that data is projected, or otherwise visually shown, close to the Phicon. E.g. when placed on a map, a Phicon representing wealth may have the average salary of people living nearby to be displayed next to it. In non-visual scenarios this is not possible. In other examples, Phicons can visually alter their appearance in response to a query from the user (e.g. Ljungblad *et al.*'s tangible/digital film festival planner (Ljungblad et al. 2007)). In non-visual TUIs this information has been shown to be useful (mostly as it has not been provided, yet it is requested by users (Choi and Walker 2010; McGookin et al. 2010)). However, how it should be supplied, and in what way, is not clear. What are the common interactions that users would need to perform with Phicons, and how should the Phicons support being located non-visually?

5.16.3 Study Description

We are trying to develop answers to these questions by creating a set of basic guidelines to drive future research into non-visual TUIs. Development of an entire system and Phicons is both expensive and time consuming, and might limit the general applicability of the guidelines. Therefore, we have adapted a low-cost prototyping approach for this initial stage, allowing us try many things quickly in order to develop candidate guidelines that we will later validate with real applications. We developed two application scenarios (see next section) where a non-visual TUI could be useful, and derived tasks users would need to perform with it. We coupled this with the construction of exemplar Phicons illustrating a range of multimodal feedback and sensing options. Brainstorming with a visually impaired usability expert then identified common user interactions.

5.16.3.1 Application Scenarios

Our application scenarios were derived from two common uses of tactile diagrams: graphs and maps.

Graph Construction

The first application scenario was based on our previous work in developing a non-visual TUI to support the construction and manipulation of simple mathematical charts and graphs (McGookin et al. 2010). In this scenario, users would construct a bar chart or line graph with up to two data series. Each data series was represented by a different set of Phicons. Graphs are constructed by placing Phicons in a physical grid where they acted as control points (either the top of a bar or a turning point in a line series). We assumed that the TUI would have some notion of the correct answer, and could offer support if a Phicon was misplaced. We considered users would want to know the name or value of a data series, find a particular named bar in the bar chart, as well as label a data series or bar. These are all tasks that are common when interactively drawing graphs in school.

Geographic Investigation

We chose this scenario as it involved less structured data. Unlike the rigid grid structure of the graph example, the map was assumed to be virtual, and could be interacted with by the user moving his or her fingers across its surface, causing features such as roads or houses to be read out. This meant that Phicons could be placed anywhere and would be (theoretically) harder to find. This is likely to be the case if an online map that could be panned and zoomed by users was employed. The dynamic nature of the data means that it would not be possible to have enough tactile overlays, or switch those tactile overlays rapidly enough, for them to be useful. When placed on the table, Phicons would calculate statistics in their immediate vicinity (e.g. education level, poverty, wealth, etc.). Each calculated statistic would be represented by a different set of Phicons, similar to the multiple data series in the graph example. Again, we assumed users would be able to query the placed Phicons to find the highest or lowest of a specific statistic, e.g. the area with the highest level of poverty or lowest life expectancy. The example problems we developed were again derived from the kinds of problems users might be asked to solve in school. They required understanding relationships between the Phicons, such as between economic wealth and life expectancy.

5.16.3.2 Technical Development

When exploring design solutions it is common to sketch or to create paper-based prototypes to support discussion and quickly evaluate possibilities. These allow multiple solutions to be quickly and cheaply compared. This is harder when considering non-visual TUIs. Interaction is through other senses and requires a physical object to give a proper sense of how a task might be achieved. To overcome this, we choose a hybrid approach using pre-existing Phicons from a previous study (McGookin et al. 2010). These Phicons (see Figure 65) are inert, but do vary significantly in physical properties such as size, material, shape, texture and weight. In addition, we constructed an exemplar dynamic Phicon. This contained a number of different sensing and output modalities that we could use to quickly prototype ideas that arose in the discussion.

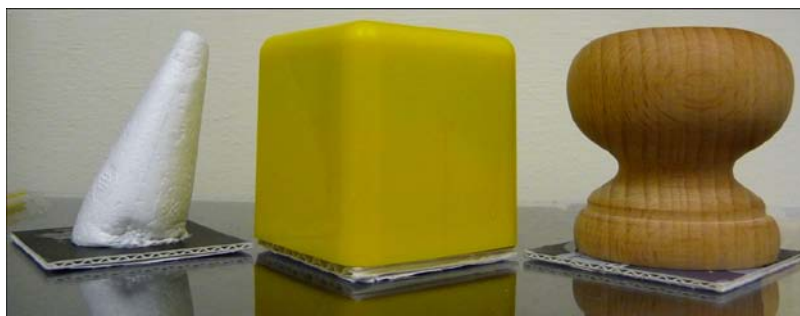


Figure 65 The Phicons used in the previous study reported in D2.1. Phicons vary significantly in weight and other haptic properties.

This exemplar Phicon was constructed from a 4x4x4 cm cube (see Figure 66). Within the cube we embedded a small fan, similar to those used to cool computer chips. A grill was embedded into the top of the cube to allow the fan to blow out. We also inserted a small vibration motor into the cube, and took care that the motor was not powerful enough to move the cube independently. This would be undesirable in a real system. Many visually impaired users are not fully blind and wish to retain as much use of their vision as possible. Therefore, we added three superbright LEDs to the top of the cube. We also added a light sensor that could detect variations in light intensity, such as if covered with a hand (see Figure 4 top). An umbilical cable ran from the base of the Phicon to an Arduino (www.arduino.cc) microcontroller. The Arduino was connected to an Apple Mac that ran software to control the components in the Phicon.

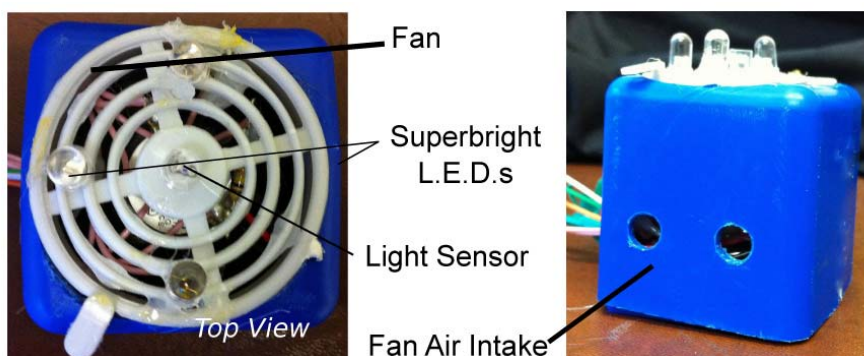


Figure 66 An overview of the exemplar Phicon, illustrating the sensors and actuators present.

5.16.3.3 Prototyping with Blind Usability Expert

To identify the requirements, and how the Phicons could provide these, we carried out a session with a usability expert who is both blind and specialises in non-visual accessibility. We started the session by introducing the problem area and each of the scenarios that were developed. This was followed by exploration of the Phicons, including demonstrations of each of the modalities on the exemplar Phicon. The session then proceeded by working through each of the tasks identified for each scenario. Possible solutions were tried out using a “Wizard of Oz” approach. The blind expert attempted to carry out some of the tasks with the different Phicons, while the experimenter acted as the rest of the system, manually controlling the exemplar Phicon and providing speech feedback. The “Wizard of Oz” approach also allowed us to incorporate a “virtual” accelerometer within the

Phicons. The experimenter determined if a particular gesture had been performed and acted accordingly.

5.16.4 Results

The results of the session yielded three main areas of consideration in non-visual Phicon embodiment: Dynamic vs. static physical properties, types of interaction and, modalities and sensors.

5.16.4.1 Dynamic vs. Static Physical Properties

In the initial demonstration of the Phicons, the expert was immediately drawn to their physical, material variations, and identified that the layout of the LEDs on the exemplar Phicon formed a triangle. Static physical properties such as material and texture offer graspable identification, and the richness of the human haptic system is able to quickly identify different shapes and materials (Wall and Brewster 2006). Dynamic physical properties, such as those in our exemplar Phicon, allow greater flexibility, but these can take longer to identify. They are also subtler, such as a change in the pattern generated by the vibration motor. However, there was a strong preference towards the use of dynamic properties wherever possible, as these were felt to be more flexible. In our geography scenario, for example, we assumed that a Phicon with different material physical properties represented each statistic. This would require a set of Phicons for each possible statistic to be created. A set of Phicons which varied only in their dynamic physical properties, retaining the same form factor, material and other static properties, would require a smaller set and allow each one to represent any statistical quality that the user wished. In practical applications however, there is a limit to the number of dynamic components a Phicon can contain, but static properties should only be relied upon if they represent attributes of the data that are known not to change.

5.16.4.2 Type of Interaction

Whilst carrying out the scenario tasks it became clear that there were three broad categories that Phicon interaction fell into.

Interrogation + response: This occurs where a user wishes to be informed of some attribute of the data represented by the Phicon. In our scenarios, this might be the name of a bar in a bar chart, the current statistical value of the map area around the Phicon, etc. The most straightforward way to accomplish this was through physical contact with the Phicon. In our prototyping we employed the light sensor, but any sensing technique to indicate the user is touching the Phicon would be suitable. This is distinct from gesturing with the Phicon using the “virtual” accelerometer, as this required the Phicon to be moved. Moving the Phicon made it difficult to replace in its original location. The response from the TUI does not need to, though it can, come from the Phicon directly. We tried both the vibration motor as well as speech feedback and both were felt to be equally useful. This allows feedback to be optimized through whatever modalities are available and appropriate given the task.

Attracting attention: This occurs when the system needs to alert the user to attend to a particular Phicon. This might occur due to a query, such as showing the area with the highest level of poverty, or alternately in the graph scenario, if a Phicon had been placed in the wrong location. There are few ways that grabbing attention could be achieved solely by the components within the Phicon. In the cases where we did identify solutions, these were dependent on user capabilities. For users with

limited sight the LEDs are obvious solutions. Other than this, most of the devices within the exemplar Phicon require the user to be in physical contact. This cannot be guaranteed. Practically, this means that an auditory alert would need to be presented to indicate that a Phicon required attention. The user would then need to scan the area to find the correct Phicon (using localisation + homing). Confirmation could be provided by a vibration motor, or using the interrogation + response technique outlined.

Localisation + homing: This is closely related to attention. We separate them, as attention is more concerned with notifying the user about a Phicon rather than helping the user to find it. However, the differences between the two are subtle and may prove to be unimportant in time. A key point in exploring an unstructured data space is to gain an overview of what is around (Wall and Brewster 2006), as well as being able to find the relatively small Phicons. As our expert stated: “You want something that is able to draw attention and receive attention when you are in the vicinity”. The fan in the exemplar Phicon could be felt from a height of 10-15cm. Therefore the user needs only to be in general proximity of the Phicon, rather than in direct physical contact. By moving his or her hand over the Phicons, such an indirect physical contact could provide a quick overview of where the Phicons are without the danger of knocking any over.

5.16.4.3 Modalities and Sensors

To gain the basic requirements outlined here, only the ability to sense that the user is touching a Phicon as well as having some way of interacting with the user when he or she is in proximity is required. We found little requirement for actuators that required the user to be in direct physical contact (e.g. the vibration motor or a hypothesized thermal interface). This means that such components could be used for other purposes, such as providing the rich feedback in response to queries previously outlined. There is a practical limit to the number of components that can be embedded within a Phicon, but we do not have enough information yet to suggest what those limits are.

5.16.5 Discussion

Our aim is to reduce the large design space of non-visual tabletop TUIs by trying to quickly and cheaply identify basic, common requirements for Phicon feedback, and practical ways these can be implemented. The construction of an exemplar Phicon allowed us to show the practical design possibilities. This meant we avoided generating solutions that, whilst optimal, could not be implemented. We were able to play and try out different approaches and ideas in a way that would not be possible with fully constructed systems. In conjunction with the guidelines from D2.1, we can provide comprehensive support to developers choosing to apply a tabletop TUI solution to a navigation and planning problem, and we have shown that such approaches provide clear advantages over existing interaction approaches.

5.16.6 Guidelines for D1.4

In this section we revise and add to the guidelines from D2.1 for the use of TUIs in

From existing work in D2.1:

Phicons Should be Physically Stable: Phicons should be haptically different to aid in their easy discrimination. This can be done in many ways, but should be done in such a way as to make the Phicons physically stable. Phicons which are poorly designed or too light, are likely to be dislodged more easily. In our studies, weights of around 110g are a good starting point.

Phicons Should have Irregular Forms: Although the use of dynamic attributes offer advantages, physical properties are also important. An easy way to ensure that Phicons can be quickly discriminated is to provide them with irregular forms, using different materials, shapes and textures. This provides “at a glance” discrimination, which may not always be possible with dynamic properties such as a vibration motor.

Divide Functionality Appropriately: In any non-visual tangible user interface, there are three types of data. Data which are fixed (or very infrequently changed) through the use of the system (e.g. the grid the user constructs the graph on), data which are frequently and directly changed by the user (e.g. the position of data points on the grid) and data which are frequently and indirectly changed by the user (the relationship between consecutive phicons in the grid).

New Guidelines that augment and extend those previously discovered are discussed in Section 5.16.4.

5.16.7 Proposed Toolkit HCI Modules

There are not toolkit modules as such that can be supported from this. The phicons are largely designed by physical tangible properties. However any support for phicons should support the following functions.

- Detecting and reporting to system that the user is in contact with a Phicon
- Instructing the system to attract user’s attention.
- Being able to instruct the Phicon to begin supporting the user’s attempts at homing onto it.
- Detecting and reporting the orientation and position of the Phicon on the table.

5.16.8 References

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6 Task 2.2 - Perceptualization and Reasoning in a 3D Landscape

6.1 Introduction

This survey is a part of HaptiMap's WP2 work on 'Interface design research' and includes the work carried out by the FGI and ULUND/GIS-group in Task 2.2, 'Perceptualization and reasoning in a 3D landscape'. The goal is to describe the most important spatial concepts regarding hiking in such a formal way that they can be utilised in implementing the Terrain Navigator demonstrator application in WP5.

From Deliverable D1.1, we have found that landmarks are extremely important for pedestrian navigation. Additionally, the hiker studies in D1.1 point out the importance of direction/orientation and environment information for a user. Although many research findings confirm the important role of landmarks, the use of landmark information has not yet been realised in such applications as hiking. When implementing a demonstrator application for hiking the question is in which way the information needed about the landmarks, the spatial concepts used, and the environment is different for hiking compared to, e.g., the pedestrian case in the city. It is also of interest based on D1.1 to provide users with additional voice-based navigation instructions on top of a visual map in order to increase their safety and to ensure that they are on the right trail.

6.1.1 Motivation of the Study

Let us call a device that supports us in hiking to be 'a terrain navigator'. The terrain navigator provides a digital map of the surroundings; it also supports us in several ways when hiking, cycling or skiing in a national park. In many aspects it can be compared to a car navigator. It provides route-planning functionality along the hiking trails and supports personal navigation while we are moving. It is also able to inform us about the accessibility of trails or warn us of any obstacles on the trail. We have learned from car navigators that they can provide turn-by-turn directions in text form, which can also be given to the user as voice-based instructions, and similar functionality can be expected to be useful in a terrain navigator.

To be able to provide sensible route guidance in environments such as national parks, a terrain navigator must make simple reasoning of the hiking trails and their surroundings. The information of the hiking environment is available to a terrain navigator through digital maps, also called 'geographic information' (GI). From the geographic information it is possible to infer deeper information like spatial relationships between one or several geographic features or between the user's current location and one or several geographic features.

6.1.2 Structure of this Section

This part of the report starts with a state-of-the-art section that briefly describes the previous studies in verbal route descriptions and then, some related ontology work. Thereafter the description and results of the completed studies are given. To form a theoretical and methodological basis for the implementation of the functionalities illustrated above, we have carried out studies from two starting points:

1. **An empirical study.** To get a deeper understanding about what kind of concepts people use when moving in a national park and how they describe their surroundings, an empirical study was carried out during both winter and summer conditions. The detailed report of the study carried out during winter conditions was given in D2.1. The study is briefly explained in Section 6.3 and is also submitted for publishing (Sarjakoski et al. 2011).

2. **Ontology studies.** As identified already in the DoW of the HaptiMap -project, ontology approaches could be used in formalizing the concepts describing the 3D landscape and also the concepts people are using when reasoning and moving around in a natural environment. For this purpose, a baseline study based on a literature review of ontology research in geographic information science was carried out and reported in D2.1, of which an overview is provided in this deliverable D2.2, Section 6.2. The baseline study is also partly published in Stigmar (2010). In Section 6.4.2.1 the creation and formalisation of important landmarks for hiking is presented, based on the results from the empirical study. The final formalisation is made with the Web Ontology Language (OWL).

Finally, design recommendations are delivered for the toolkit development in WP4 and the application development in WP5.

6.2 State of the Art

6.2.1 Analysis of Verbal Route Descriptions and Landmarks for Hiking

The empirical study carried out in this Task 2.2 aims to provide additional knowledge on human verbal descriptions of routes regarding the classification of route expressions given by Denis (1997). His classification has been used in several studies (Daniel and Denis 1998; Denis et al. 1999; Daniel and Denis 2004; Brosset et al. 2008; Rehrl et al. 2009) and provides a means to compare verbal route descriptions collected in experiments in different environments and conditions, and with different kinds of test persons. We apply Denis (1997) and Rehrl et al. (2009) in our study but expand their method to cover such a natural environment as a national park. In addition, our study was carried out in the national park during the winter and the summer.

The studies of Denis (1997) and Rehrl et al. (2009) are important to our work because they provide a reference to compare our results. Therefore, a summary of the relevant parts of their studies is given in the following.

6.2.1.1 Denis' Classification of Verbal Route Descriptions

Denis (1997) builds a general framework in order to analyse route descriptions. To understand the human thinking procedure in route description tasks, he proposes a sequence of cognitive operations involved when a person constructs route descriptions in his or her mind:

1. activating a representation of the territory covering the route
2. planning a route in the activated representation
3. formulating a verbal description of the navigation along the route

Denis reports a laboratory test with 20 students who were asked to describe verbally two routes at their campus. They knew the area well and gave their instructions in a closed room. Transcripts of descriptions were reorganised into minimal informational units on which the analyses were made. The core of Denis' analyses is the classification of the propositions in five classes with regard to actions and landmarks:

1. prescribing action (16.9% of all propositions)
2. prescribing action with reference to landmark (33.5%)
3. introducing landmark (36.0%)
4. describing landmark (11.3%)
5. commentary (2.3%)

Class 1 contains the propositions of action without any reference to landmarks. These were mostly of two types in Denis' experiment: proceeding straight ahead (e.g. "Go straight on.") and re-orientating ("Turn left."). Class 2 contains propositions that link an action to a landmark ("Walk past the library.") and has six subclasses with different types of actions. Class 3 contains propositions referring to landmarks without action. A sub-classification was found based on whether the propositions were spatially referenced ("To your right, there is the main building.") or not ("One sees a church."). Class 4 contains propositions describing the non-locating characteristics of landmarks. ("The path is difficult to see.") Finally, Class 5 contains commentaries on general conditions ("Follow the main roads only.")

Denis' main observation in his analysis was that landmarks possess significant cognitive importance in the verbal description of routes. Their importance is even superior to that of actions. It also became clear that topological information overrides metric information in descriptions, which leads to the conclusion that human route descriptions are essentially qualitative in nature.

6.2.1.2 Rehrl's Application of Denis' Classification

Rehrl et al. (2009) motivated their study with the lack of 'in situ' studies on route descriptions. Earlier studies were not carried out in real world decision situations and did not use participants who were unfamiliar with the environment. To collect data on the situational spatial discourse in unfamiliar environments, Rehrl et al. organised experiments in Salzburg and Vienna with ten participants in both cities. The participants were new students who did not know the cities well. They had to walk a route in the inner city and another in a peripheral district. The routes contained 22 and 27 decision points, i.e., locations where one has to decide which way to take. The participants were given a task to identify the decision points and to describe the surrounding environment as well as their possible choices of direction at the decision points.

The propositions of the collected discourse data were classified using Denis' (1997) classification. Rehrl et al. (2009) did not give information on how the propositions were extracted from the transcript, but they ended up with the following distribution:

1. prescribing action: 4.1% of all propositions
2. prescribing action with reference to landmark: 44.3%
3. introducing landmark: 23.6%
4. describing landmark: 24.3%
5. commentary: 3.6%

The distribution of propositions was stable between the routes and the cities. About half of the propositions described an action, and most of these were related to landmarks. The other half described landmarks and were distributed evenly between introducing landmarks and describing landmarks.

Rehrl et al. (2009) paid attention to the extensive use of landmarks in propositions which made up 90% of all propositions. In comparison to former laboratory studies, they found the distribution between the action- and landmark-related propositions to be the same. However, action-landmark propositions were significantly more present in this 'in-situ' study, as well as landmark descriptions. The latter was also the case in Brosset et al.'s (2008) study. Consequently, Rehrl et al. (2009) summarised that, regarding the description propositions on action-landmarks and landmarks, verbal route descriptions given in an 'in situ' set-up differ from those in a laboratory set-up.

6.2.1.3 Ontologies for Reasoning in a 3D Landscape

The notion of space is very important to humans and has gained great attention in research. According to Zlatev (2007), this is because spatial cognition is central to our thinking and functioning in our environment. Thus, it relates to our experiences. Additionally, it is a concrete, directly perceptible domain and can therefore easily be used in metaphorical mappings for more abstract domains.

The major purpose of geographic information science is to get an understanding of our environment. With this understanding, it is possible for us to analyse the environment, draw conclusions, and finally communicate important findings and knowledge. One fundamental issue in the search for an understanding of the environment is how we conceptualize geographic reality and how these conceptualizations lead to knowledge. In this context, the term concept refers to all the knowledge that one has about a category (which is a collection of instances). In the conceptualization of the geographic reality, we use both classical geographic concepts from the real world as well as constructed ones. Often conceptualizations differ, which can create partial, imprecise, or conflicting depictions and can lead to problems in use or communication (Kavouras and Kokla 2008).

The term ontology refers to a branch of philosophy and the science of what is. Ontologies deal with the semantic characteristics of objects, properties, processes and relations, how they are structured in reality, and try to create classifications of this. The classifications should be well-defined and unambiguous (Bittner et al. 2005, Gruber 1993, Guarino 1998).

Ontology work, or similar work, is performed by different communities, for example the ontology research community, software developers, standardization organizations, and the database community. They all work to overcome the problems of differing vocabularies, approaches, representations, and tools. Today, three major uses of ontologies are: to assist in communication between human agents, to achieve interoperability among software systems, and to improve the process and the quality of software systems (Jasper and Uschold 1999).

6.2.1.4 Classifications of Ontologies

There are different classifications of ontologies. Two major classifications are logic-based and non-logic-based. A logic-based ontology is a logical theory that uses axioms and definitions to express relationships. The relationships can be between entities, classes, and other relations. Using these constituents, the semantics of the terminology is specified by admitting or rejecting certain interpretations. A non-logic-based ontology does not use this type of logical axioms. Instead, the meaning of the terminology is specified by a well-defined and fixed domain of interpretation. One type of non-logic-based ontologies is standards (Bittner et al. 2005).

Two other classifications of ontologies are high-level ontologies and low-level ontologies, which are based on the content. High-level ontologies have concepts with rich semantics and define general concepts that have foundational roles in nearly every discipline (e.g., ‘equals’, ‘is part of’). Low-level ontologies have shallow semantics and define concepts for a specific domain or task. Top-level ontologies are the ‘highest’ high-level ontologies. Domain ontologies, on the other hand, are low-level ontologies, specified for a specific domain. Task ontologies are similar to domain ontologies but focus on a specific task or activity instead of a domain. Application ontologies are even more specific and define the concepts for a specific application, depending both on a specific domain and a specific task (Kavouras and Kokla 2008, Bittner et al. 2005, Guarino 1998). The relations between these different types of ontologies are shown in Figure 67.

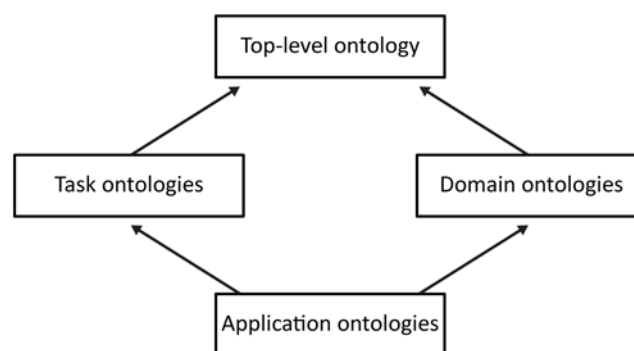


Figure 67 The relations between different types of ontologies (from Guarino 1998).

Concepts are the building blocks of ontologies and linguistic systems. Additionally, ontologies consist of three more components: relations, axioms (rules about values of properties or relations), and instances (the ‘things’) (Kavouras and Kokla 2008).

6.2.1.5 Ontology in Information Science

In recent years, ontologies have become popular in the field of computer and information science. The main purpose is to express how humans conceptualize something in order to represent and manipulate this in machines (mainly computers and robots).

Today, to use ontology to mean a conceptual model is widely accepted in the information science community and has little to do with the original question of ontological realism (searching for the truth). It has become pragmatic (Smith 2003). According to Guarino (1998), the philosophical language-independent perspective of ontologies can be termed conceptualization, while the information-science language-dependent perspective should be the one to use the term ontology.

There are various forms of ontologies in information science. However, the foundations are the vocabulary of terms, a description of their meaning, and a specification of their relations. There are different levels of formalities, and depending on these, ontologies can also include axioms introducing rules and limiting the values of concepts. The concepts themselves can be categorized as primitive concepts, which determine class membership only with necessary conditions, and defined concepts, which determine class membership with necessary and sufficient conditions. The relations between the concepts, on the other hand, can be categorized as taxonomical relations, which describe concepts according to the ontological hierarchies, and associative relations, which do not describe concepts according to the hierarchical structures but instead describe the concepts' properties, functions, and processes (Kavouras and Kokla 2008).

The different types of ontologies are often classified according to the formality, contents, or structure. Regarding the formality, there are informal ontologies and formal ontologies and a wide range in between. Informal ontologies use natural language to express the meaning of the terms, while formal ontologies use an artificial formal language, often with formal semantics, theorems, and proofs. However, it should be noted that ontologies often have both formal and informal parts, where formal parts support automated processing, and informal parts support human understanding (Kavouras and Kokla 2008).

In order to represent the information in the ontologies, ontology languages are used. Examples of ontology languages are RDF (Resource Description Framework) and OWL (Web Ontology Language), which are used in the Semantic Web, GFO (General Formal Ontology), and GOL (General Ontology Language).

6.2.1.6 Creating Geo-ontologies

The conceptual richness, robustness, and ease of management of ontologies depend to a large degree on the methods used to specify them (Mark et al. 2004). For the general construction of ontologies, Uschold (1996) and Stuckenschmidt and van Harmelen (2004) define four phases:

- 1) Identifying purpose, level of formality, and scope.
- 2) Building the ontology:
 - a) ontology capture,
 - b) ontology coding, and
 - c) integrating existing ontologies.
- 3) Evaluation, verification, and validation.

4) Guidelines for each phase.

The creation of geo-ontologies is a priority research theme in the geospatial domain. However, the creation of a domain ontology for the geospatial world would be very complex, as it would have to be enormous in order to contain a sufficient number of taxonomical concepts and be neutral among different communities. This would not be possible without making major compromises. Therefore, the creation of an upper-level and a number of sub-level ontologies is more feasible. The top-level ontology could then deal with highly general categories of: time, space, inherence, instantiation, identity, measure, quantity, functional dependence, process, event, attribute, boundary, etc. The lower-level ontologies could then be domain-specific, for example, for geography, climatology, etc. This approach is also stated on the research agenda of UCGIS (the American University Consortium for Geographic Information Science) (Mark et al. 2004).

The sources cited in this review seem to agree that more work needs to be done in order to fully take advantage of the possibilities that ontologies and the semantic web technology can provide. Mark et al. (2004) list the influence of ontologies in the design of information systems and ontology-based wayfinding systems among some of the issues that need to be addressed. In the present study, the creation and formalisation of important landmarks for hiking is presented with final formalisation in the ontology language OWL.

6.3 Study Description

6.3.1 Research Questions

The research question in the study is how to provide a simple speech as an additional channel on top of visual perceptualization in order to support people hiking in a national park. The goal of the research of this survey is to provide a theoretical basis for a demonstrator application on hiking to be implemented in WP5. One of the final outcomes in WP5 for the hiking use case will be the Terrain Navigator (Figure 68).

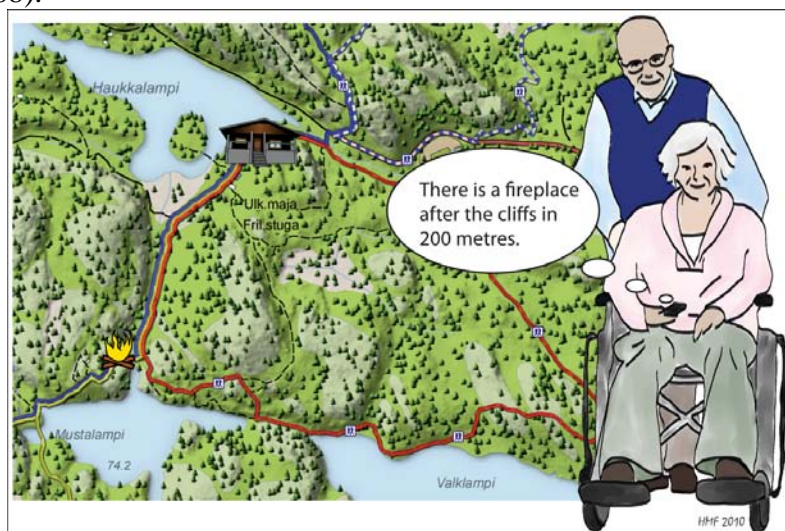


Figure 68 The results of the study are utilised in the demonstrator application, the Terrain Navigator.

The central question regarding a terrain navigator is what kind of spatial concepts and term descriptions people use when hiking. Are the concepts and terms different than when navigating in urban environments? We are also interested in the role seasons have in navigation. Do we need remarkably different navigational instructions during winter than during summer?

We also study in this task how the spatial concepts should be formalized for the implementation of the Terrain Navigator.

6.3.2 Study Outline

Verbal route descriptions were collected in an experiment in which 20 participants were taken into a national park where they each had to follow and describe a route and the landmarks nearby. Altogether ten people participated in the experiment during summer conditions and the other then in snowy winter conditions. In the following, it is described how the experiments were carried out and how the results were analysed in order to study differences in route descriptions between the seasons.

6.3.2.1 Collection of Route Descriptions

The experimental set-up is briefly presented in the following. The set-up is documented in more detail in D2.1 and Sarjakoski et al. (2011). The participants filled in a background questionnaire before they started the test session. Contact information for the participants and some background information, such as the year of birth, profession and previous hiking experience were asked. The participants aged 19 to 54 spoke Finnish as their mother tongue. They reported that they used to hike in the nature a few times a month, in average.

The experiments were carried out in the Nuuksio National Park in southern Finland. The 1.2 km test route was defined prior to the test sessions. Walking through the route took about half an hour. Before the experiments, we identified 24 decision points along the route (Figure 69). Half of the route consisted of marked hiking routes while the other half consisted of small non-marked paths in the forest.

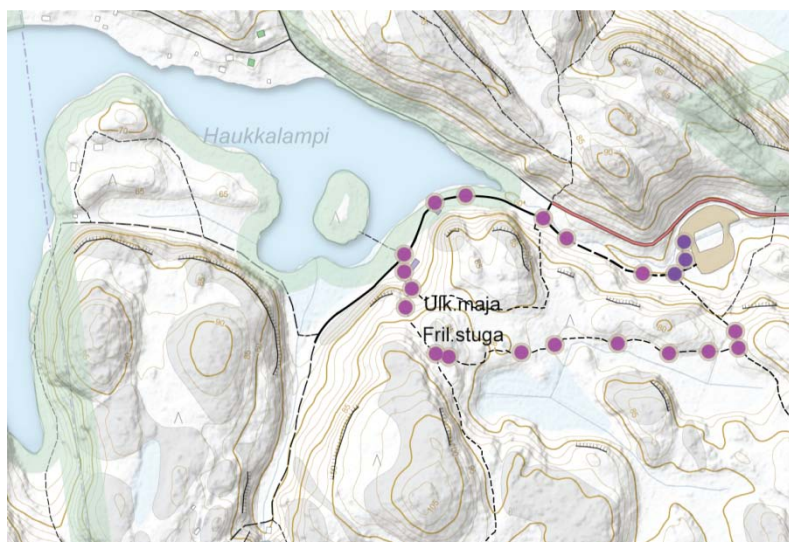


Figure 69 Participants followed a route defined prior to the test sessions. The route contained 24 decision points.

The following assignment was given to the participants while walking on the route:

“Describe everything you find remarkable in the surroundings and explain their locations. Stop when you have to make a decision about which route to take. Describe the options in detail.”

The participants did not use any navigational aids such as maps, compasses, or navigators. The instructor asked the participants to follow the route until they came to a point where they had to decide which way to continue. At this decision point, the participant had to describe the possible options by thinking out loud (Boren and Ramey 2000). After the introduction of the possible alternatives by the participant, the instructor pointed out the direction to continue. When the description was too short, the instructor asked the participant to elaborate and keep talking; otherwise the instructor kept quiet. Each test session was documented by audio and video (Figure 70).



Figure 70 Each test session was documented by audio and video.

After the test sessions, the research group conducted a transcript of each participant's observations with the aid of the audio and video recordings. The transcripts were further analysed, as described in the following.

6.3.2.2 Classification of Propositions

In the first phase of the route description analysis, we split the transcripts in propositions, that is, in basic units of speech in which participants introduced single distinguishable statements. We considered short sentences to be statements as such, while longer sentences were split in parts. In splitting the transcripts, we followed the approach of Denis (1997) to apply his method for the classification of propositions.

The classification of propositions was based on Denis' five classes (1997):

- action propositions without landmarks, such as "I continue forward";
- propositions containing both actions and landmarks, such as "I pass a red sign";
- landmark propositions without actions, such as "I see two huts on the left";
- non-spatial landmark descriptions, such as "The trees are growing very near to the path";
- commentaries, such as "I'm following the tracks of other people in front of me".

Classifying natural language into discrete classes is often ambiguous, and we encountered problems in classifying some of the propositions. In such ambiguous cases, we created classification rules to apply. Some examples for ambiguous classification cases are collected in Table 4.

Table 4 Rules for classifying ambiguous propositions.

Case	Classification	Rationale	Examples
Reading out loud a sign	Landmark description	The participant reads out the sign content	"The sign says that Haukkalampi is to the left."
Introducing an ambiguous entity	Landmark description	the entity is boundless → not a landmark	"The forest is dense here." "The path begins to rise steeply."
Speaking about a temporary entity	Commentary	The entity may vanish → not a landmark	"The snow is deep." "There are people around."
Introducing a route alternative	Action & landmark	The participant describes route alternatives that she/he could take	"There is a small path to the right." "Stairs ascend towards the top of the hill."
A repeated reference to a landmark	Landmark description	The landmark description continues	"The building I noticed earlier seems to be a warehouse."
Introducing a landmark with two or more descriptive modifiers	Landmark + landmark description	Descriptive modifiers form a description	"There is a steep rocky fall ahead." "I see a thick dead tree on my left."

In order to analyse the contents of route descriptions at the decision points and between them, we registered with the help of the audio and video recordings for every proposition whether it was spoken at a decision point or not. Table 5 presents an example of the classification of propositions.

The classification of propositions allowed us to calculate the proportions of route description classes among the total number of propositions. We compared class proportions between the summer and winter experiments and also analysed whether the proportions at decision points were different from the propositions between the decision points.

Table 5 Classification of route description propositions according to Denis (1997). 'V' denotes whether a proposition was introduced at a decision point or between decision points.

Sentence	Between Decision points	Decision point	Action	Action & landmark	Landmark	Landmark description	Commentary
There is also a stretch of road that leads to the island along the bridge.		V		X			
I don't discover any more route alternatives now.		V					X
We walk along the ring routes following the blue, red and yellow signs.	V			X			
There seems to be a school excursion group.	V						X
There is Haukkalampi	V				X		
and I guess this is a well	V				X		
that is covered with some kind of a shelter.	V					X	

6.3.2.3 Counting Landmarks

We continued our analysis by focusing on the landmarks in the thinking aloud route descriptions. We wanted to know which kinds of landmarks the participants used in their descriptions and how the amount of usage was distributed among the landmarks. For accomplishing this task, we applied methods of Natural Language Processing (NLP) (Manning and Schütze 2009) to the thinking aloud transcripts.

The Finnish language abounds with fluctuations making NLP difficult because calculations can only be made on the basic forms of the words. Therefore, our first task was to transform the transcripts into basic form words for which we used Helsinki Finite-State Transducer Technology (HFST 2011). The HFST was able to propose all the possible basic forms for most of the words in our transcripts, but it did not succeed well in guessing the correct basic forms. This led us to create a semi-automatic basic form selector application with which we could rapidly choose the correct basic forms based on the proposals. When the HFST did not find a basic form, we entered the form manually. We preserved the boundaries of sentences during the transformation in order to be able to analyse sentences in later phases.

Next, we counted words for the transcripts in a basic form. We made the calculations using the Python programming language and the Natural Language Toolkit (NLTK 2011) Python library, which provides core functionalities for NLP analysis. We first calculated the total number of every word in its basic form in the summer and winter experiments. We made the calculations for each season in order to make comparisons between the seasons. We then created a list of landmark words by picking up the words from the basic form list that denoted landmarks. For a word to mean a landmark, we required it to represent a physical and clearly identifiable permanent object in the environment. Snow, spoors, flowers, and similar temporary and changing objects were not included in the list of landmark words. The list grew to include groups of synonyms that denoted the same landmarks. In order to calculate the usage amounts of landmark objects, we gathered the synonyms of landmark words in groups that represented the landmark objects.

6.4 Results

6.4.1 Denis' Classification of Propositions

The participants in our experiments were Finnish-speaking adults. Overall, they had an intermediate experience in hiking in nature and almost all had visited the area where the experiments were organised a couple of times (Table 3). The scale of the experience in Table 6 ranges from 'Never' (0) to 'Every day' (4), and the scale of familiarity from 'Never' (0) to 'More than three times' (2).

The number of decision points that the participants recognised during the experiment varied from 7 to 18 (Table 3). On average, the participants recognised about 11 decision points both in the winter and in the summer experiments in contrast to the 24 decision points that we had identified as possible decision points when planning the experiments. Many paths that were connected to the route were so unobtrusive that participants did not report them as route alternatives even if they noticed the path. Often a route alternative failed to be noticed because a participant was explaining something else or looking in another direction.

The analysis of Denis' classifications showed that 'Landmark description' was the most frequently used proposition class in both the winter and summer experiments (Figure 70), followed by 'Commentary' in the winter and 'Landmark' in the summer. The class 'Action & landmark' was fourth in terms of occurrence and the class 'Action' occurred the least. The large number of commentaries in winter arose from many propositions concerning snow. Landmarks were involved in most of the propositions in both seasons but more frequently in the summer, when 79% of the propositions were landmark-related (classes 'Action & landmark', 'Landmark' and 'Landmark description') whereas the portion was 70% in the winter. On the contrary, action-related propositions ('Action', 'Action & landmark') were more frequent in the winter experiment with a portion of 20% against 15% in the summer.

At decision points, the participants most frequently introduced 'Action & landmark' propositions both in the winter and in the summer (Figure 71). The large number of 'Action & landmark' propositions originated mainly from introductions of route alternatives that were given at decision points, such as "I can take the small path to the right." 'Landmark description' propositions were the second most common class at decision points and the third was 'Commentary' in the winter and 'Landmark' in the summer. Again, many winter commentaries concerned snow. 'Action' propositions were very few at decision points in the summer (1%), and they were the least frequent proposition class in the winter as well. Actions were almost every time linked to landmarks at decision points. The predominate portion of landmark-related proposition classes on the whole route was still larger at decision points, with 73% in the winter and 86% in the summer. The significance of action-related classes also increased at decision points, with 36% both in the winter and in the summer, mainly due to introducing the route alternatives.

Table 6 Data on participants in the winter and summer experiments and the numbers of decision points found.

WINTER					
Participant	Gender	Age	Experience (0-4)	Familiarity (0-2)	Decision points
A	female	35	2	2	10
B	male	26	2	1	9
C	male	22	2	1	11
D	female	19	2	0	18
E	male	26	4	1	11
F	male	27	3	1	10
G	male	41	2	0	12
H	male	43	4	2	10
I	female	54	4	2	10
J	female	37	4	0	10
MEAN	4f / 6m	33	2,9	1	11,1
MEDIAN		31	2,5	1	10
SUMMER					
Participant	Gender	Age	Experience (0-4)	Familiarity (0-2)	Decision points
K	female	25	3	2	11
L	male	28	3	1	13
M	male	27	3	0	9
N	male	29	2	0	10
O	male	25	2	0	10
P	male	25	3	0	12
Q	male	28	1	2	9
R	male	34	3	2	11
S	female	40	2	0	18
T	male	51	2	1	7
MEAN	2f / 8m	31,2	2,4	0,8	11
MEDIAN		28	2,5	0,5	10,5

When ranking the proposition classes between decision points, their order of magnitude was similar to that of the whole route both in the winter and in the summer (Figure 71). ‘Landmark description’ propositions were the most common ones, which was due to the verbose descriptions of surroundings that the participants gave while walking. Landmark-related classes decreased slightly in frequency between the decision points compared to the whole route with 68% in the winter and 73% in the summer, and action-related propositions decreased more, with 12% in the winter and 8% in the summer.

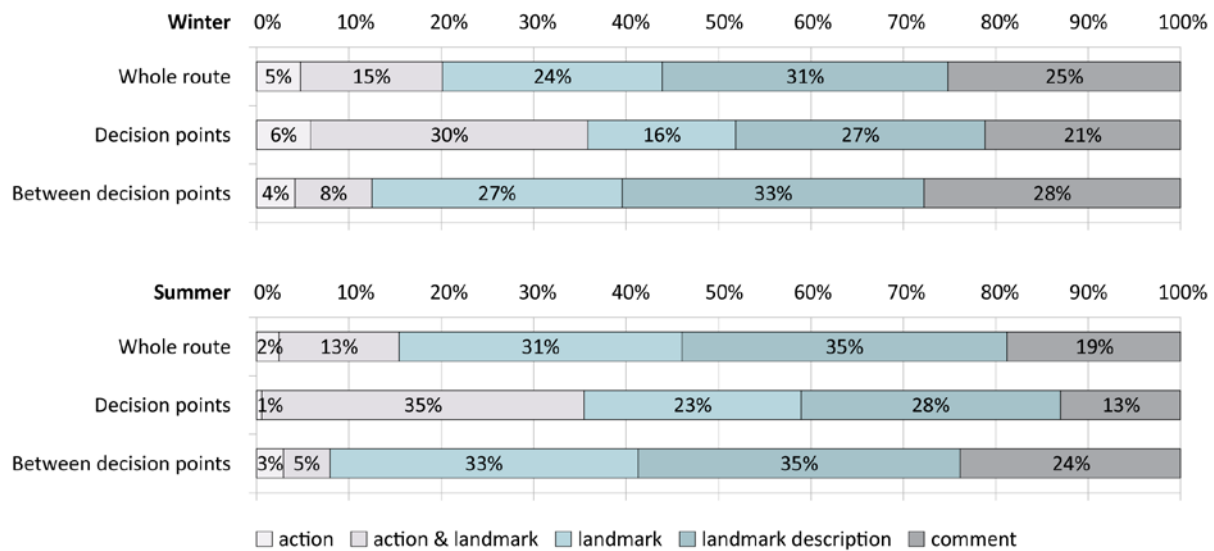


Figure 71 Distributions of propositions in Denis' classes in the winter and summer experiments and in the different parts of the route.

The number of propositions varied considerably between participants, both in the summer and winter and the distribution of propositions into Denis' classes also varied (Figure 72). Especially the frequency of commentaries had a significant variance between participants: participant 'a' had commentaries on only 2% of his speech, whereas participant 'b' had them on half of his spoken propositions. Despite the variance of distributions and excluding the 'Commentary' class, 'Landmark' and 'Landmark description' proposition classes were the most frequent ones for the large majority of participants.

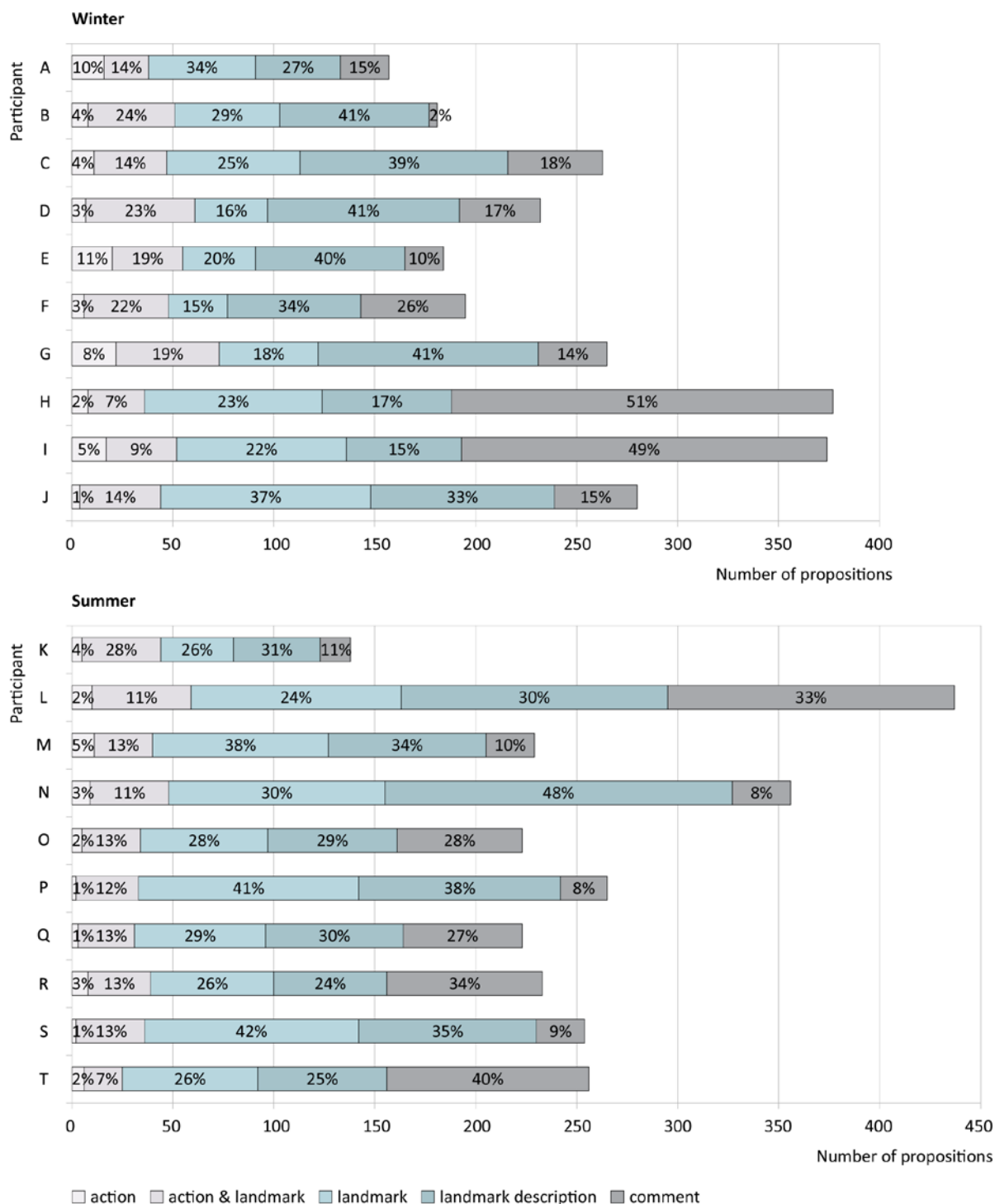


Figure 72 Distributions of propositions per participant on the whole route.

When comparing distributions of single Denis' classes among participants between the summer and winter, we could see differences in class frequencies (Table 7). The largest difference was observed

on the whole route for the ‘Landmark’ class, for which the mean frequency decreased 7.16% units from the summer to winter and the median frequency 5.80% units. The statistical test for equality of locations (two-tailed Wilcoxon rank sum test) between the summer and winter distributions showed the difference to be significant ($W=80$, $p=0.020$). Another large and statistically significant ($W=23$, $p=0.043$) difference was in the ‘Action’ class, the mean of which increased 2.80% units from summer to winter and the median 1.99% units. These significances were also present at decision points where the differences were larger: a decrease by 7.53% units in mean and 8.38% units in median for the ‘Landmark’ class ($W=83$, $p=0.012$) and an increase by 5.88% units in mean and 4.42% units in median for the ‘Action’ class. Between the decision points, the statistical tests did not show significances for class frequency differences, meaning that the decision points were the main source of difference between the seasons.

Table 7 Differences in the occurrence of Denis’ proposition classes from the summer to winter in different parts of the route.
P-values less than 0.05 are emphasised.

WHOLE ROUTE					
Difference from summer to winter	Mean (% unit)	Median (% unit)	Equality of locations (Wilcoxon test p-value)	Standard deviation (% unit)	Equality of variances (F test p-value)
Action	2.80	1.99	0.0433	2.08	0.0084
Action & landmark	3.11	4.04	0.0753	0.18	0.9234
Landmark	-7.16	-5.80	0.0200	0.77	0.7491
Landmark description	0.33	5.68	0.5288	2.99	0.3033
Commentary	0.91	-2.40	0.7959	3.63	0.4499
DECISION POINTS					
Difference from summer to winter	Mean (% unit)	Median (% unit)	Equality of locations (Wilcoxon test p-value)	Standard deviation (% unit)	Equality of variances (F test p-value)
Action	5.88	4.42	0.0034	5.78	<0.0001
Action & landmark	-4.72	-9.19	0.4359	-0.35	0.9320
Landmark	-7.53	-8.38	0.0115	-1.61	0.3820
Landmark description	-1.18	0.09	0.6305	1.73	0.4607
Commentary	7.54	7.43	0.0524	1.39	0.6500
BETWEEN DECISION POINTS					
Difference from summer to winter	Mean (% unit)	Median (% unit)	Equality of locations (Wilcoxon test p-value)	Standard deviation (% unit)	Equality of variances (F test p-value)
Action	1.53	1.02	0.2121	1.45	0.0709
Action & landmark	4.46	5.57	0.0753	1.91	0.2385
Landmark	-6.38	-6.28	0.0630	0.30	0.9212
Landmark description	1.15	5.35	0.5787	3.51	0.3259
Commentary	-0.77	-4.47	0.9118	4.06	0.4700

Comparing variances of single Denis’ classes between seasons resulted in a statistical significance only for the ‘Action’ class ($F(9.9)=0.1457$, $p=0.008$). The significance was present both at the decision points and between the decision points, but the difference was larger at the decision points. This supports the experimenters’ observation that the participants introduced ‘Action’ propositions randomly without any regularity, such as “Here we go forward.”

The distribution of propositions into Denis' classes was similar on the whole route and between the decision points, both when looking at the class frequencies (Figure 72) and their differences between the seasons (Table 7). The similarity reflects the predominating amount of the propositions spoken between the decision points, being approximately two-thirds of all propositions. At the decision points, the distribution was considerably different due to the larger number of landmark-related propositions. The difference between the seasons was also greater, as the frequency of the landmark-related classes decreased considerably from the summer to winter and the frequencies of the 'Action' and 'Commentary' classes considerably increased at the same time.

6.4.2 Use of Landmarks

The total length of the thinking aloud transcripts was 26 505 words, 11 092 in the winter and 15 413 in the summer. The total number of separate words was 2 357, which was calculated from the basic form conversions of the transcripts. Accordingly, the total number of distinct landmark words was 295, and the grouping of synonyms ended up in a total of 62 separate landmark objects used by the participants in their descriptions in the experiments (Figure 73). From these, 59 landmarks were used in the winter and 60 in the summer. These landmarks were used 1 129 times in the winter experiment and 1 560 times in the summer experiment, which represent portions of 10.18% and 10.12% of all words per season, respectively.



Figure 73 The participants described their surroundings and the landmarks at the decision points.

There were four landmarks that every participant used during the experiment:

- a house,
- a lake,
- a parking place, and
- a creek.

These are clearly distinctive landmarks during both winter and summer. All winter participants also used landmarks 'uphill' and 'info board'. The 'uphill' was much used due to slippery slopes on

footpaths. All summer participants used ‘spruce’, ‘path’, ‘fallen tree’, ‘cliff’, ‘bridge’ and ‘anthill’, many of which were distinctive in the summer but not in the winter when they were covered by snow. There were also landmarks that were only used in one of the seasons. In the winter, these were: ‘willow’, ‘bent tree’, and ‘witch’s broom’, and in the summer: ‘pit’, ‘vegetation boundary’, ‘cape’ and ‘marsh’. Of these, only ‘witch’s broom’, ‘pit’, and ‘marsh’ were used by more than one participant. These three landmarks were clearly distinct during only one of the seasons.

The nine most commonly used landmarks were the same in the winter and in the summer except for the path (Table 8):

1. a house,
2. a road,
3. a lake,
4. a spruce,
5. a creek,
6. a parking place,
7. a road,
8. a birch, and
9. a fallen tree.

Table 8 The 20 most used landmarks in the summer and in the winter with the descriptive measures for them. No. of part in the first and last columns denotes 'The number of participants'. Significantly frequently used landmarks are separated by horizontal lines ($p < 0.05$ in one-tail binomial test, in the winter B(11092, 1129/11092), and in the summer B(15413, 1560/15413)).

WINTER LANDMARKS					SUMMER LANDMARKS			
No. of part.	P-value binom. test	Frequency/ landmarks	Landmark	Rank	Landmark	Frequence/ landmarks	P-value binom. test	No. of part.
10	0.000000	8.86%	house	1	road	9.49%	0.000000	10
10	0.000000	7.09%	creek	2	house	7.44%	0.000000	10
10	0.000000	6.47%	lake	3	spruce	6.35%	0.000000	10
9	0.000000	6.02%	spruce	4	lake	6.28%	0.000000	10
10	0.000000	5.49%	parking	5	creek	5.77%	0.000000	10
8	0.000000	4.07%	route mark	6	parking	5.64%	0.000000	10
8	0.000001	3.90%	road	7	path	5.19%	0.000000	10
8	0.000017	3.54%	birch	8	birch	3.40%	0.000002	9
9	0.000037	3.45%	fallen tree	9	fallen tree	3.14%	0.000031	10
8	0.000037	3.45%	spruce woods	10	crossing	3.01%	0.000116	9
10	0.000079	3.37%	uphill	11	cliff	2.88%	0.000399	10
7	0.002271	2.92%	ditch	12	route mark	2.82%	0.000717	8
8	0.012246	2.66%	pine	13	marked passage	2.76%	0.001262	7
6	0.050466	2.39%	path	14	boulder	2.63%	0.003657	9
8	0.050466	2.39%	guidepost	15	ditch	2.50%	0.009686	8
8	0.110946	2.21%	cliff	16	spruce woods	2.44%	0.015229	8
9	0.110946	2.21%	bridge	17	pine	2.44%	0.015229	9
7	0.156765	2.13%	boulder	18	bridge	2.18%	0.073383	10
10	0.214433	2.04%	info board	19	guidepost	2.18%	0.073383	9
8	0.214433	2.04%	thicket	20	anthill	2.12%	0.102321	10

After these nine landmarks, the landmark ranking differed significantly between the seasons. The distribution of the use of landmarks was also different: in the winter 13 landmarks were significantly more frequent than on average and covered 61.29% of the total use of landmarks, whereas in the summer, 17 landmarks were significantly frequent and covered 74.17% of the total use. There were also more users per landmark in the summer, as all the participants used the seven most common landmarks, but only three landmarks were used by all in the winter. The more varied use of significantly frequent landmarks in the summer resulted mainly from the objects in the forest that were covered by snow in the winter: paths, crossings, cliffs, and boulders.

There were six statistically significant differences between the summer and winter among the frequency differences of the twenty largest landmarks: 'path', 'uphill', 'crossing', 'anthill', 'shore', and 'barrier bar' ($p < 0.05$ in two-tail Wilcoxon rank sum test, Table 9). For all these significant differences, there was also a difference of two or more participants between the seasons in the number of users. 'Path', 'crossing', 'anthill', and 'shore' were used more in the summer; all of these objects are covered by snow in the winter. 'Uphill' and 'barrier bar' were used more in the winter. The use of 'uphill' can be explained by the slipperiness of the slopes and the 'barrier bar' by its

distinctiveness in the snowy surroundings. ‘Road’ clearly had the largest difference in usage frequency in summer and winter, but a statistical significance of the difference was not evident ($p=0.0588$). ‘Birch woods’ was another landmark for which the statistical significance of the difference was close but not clear ($p=0.0588$). ‘Road’ and ‘birch woods’ were used more frequently in the summer when they were more visible since the road was not covered by snow and the birches had leaves.

Table 9 The 20 largest differences in the landmark usage in the summer and winter. Significant differences in distributions among participants are emphasised ($p < 0.05$ in two-tail Wilcoxon rank sum test).

Rank	Landmark	Frequency / landmarks (%-unit)	Difference in No. of participants	P-value Wilcoxon
1	road	-5.59	-2	0.058782
2	path	-2.80	-4	0.006502
3	uphill	2.40	3	0.006502
4	crossing	-1.68	-2	0.025748
5	house	1.42	0	0.173617
6	creek	1.32	0	0.650147
7	route mark	1.25	0	0.449692
8	anthill	-1.23	-7	0.006502
9	hill	1.06	0	0.427355
10	spruce woods	1.02	0	0.705457
11	marked passage	-0.90	-2	0.449692
12	clearing	0.83	0	0.449692
13	birch woods	-0.76	-5	0.058782
14	shore	-0.76	-4	0.025748
15	thicket	0.76	-1	0.198765
16	cliff	-0.67	-2	0.427355
17	info board	0.63	1	0.096304
18	barrier bar	0.57	3	0.041250
19	stump	0.56	3	0.226476
20	downhill	0.50	3	0.185877

6.4.2.1 Landmark Groups

In order to reach an overall view of the usage of landmarks in our route description experiments, we gathered the extracted landmarks into homogeneous groups. We ended up with eight landmark groups inside which the landmarks resembled each other more than between the groups:

1. structures (man- and animal-made constructions: house, electricity line, bridge, anthill, bird's nest, etc.)
2. passages (routes or part of routes for moving: road, path, crossing, etc.)
3. trees and related (single trees and their parts: spruce, witch's broom, stump, etc.)

4. waters (parts of water systems: lake, ditch, shore, etc.)
5. landcover (vegetation type: spruce wood, clearing, marsh, etc.)
6. rocks (rocky features: stone, bare rock area, crack, etc.)
7. signs (man-made signs: guidepost, information board, route mark, etc.)
8. landforms (parts of natural topography: upward slope, hill, pit, etc.)

The ‘structures’ was the most used landmark group in the experiments both in the summer and in the winter (Figure 74). Otherwise, the distributions of landmark groups differed between the seasons. In the summer, there were three other large landmark groups with more than 15% usage proportion: ‘passages’, ‘trees and related’ and ‘waters’. In the winter, the usage of ‘passages’ was at the level of the small landmark groups with under 10% usage proportion, other groups being ‘landcover’, ‘rocks’, ‘signs’, and ‘landforms’.

When looking at the usage frequency of the differences at the level of landmark groups, ‘passages’ had the greatest difference between the seasons (Table 10). The ‘passages’ landmarks were used 11.0% units less in the winter than in the summer and statistical testing rated the difference of participant-wise distributions to be clearly significant ($p=0.0009$ in two-tail Wilcoxon rank sum test). The ‘passages’ landmarks, such as roads, paths and crossings were more visible in the summer when they were not covered by snow, which seemed to lead the participants to mention them more often.

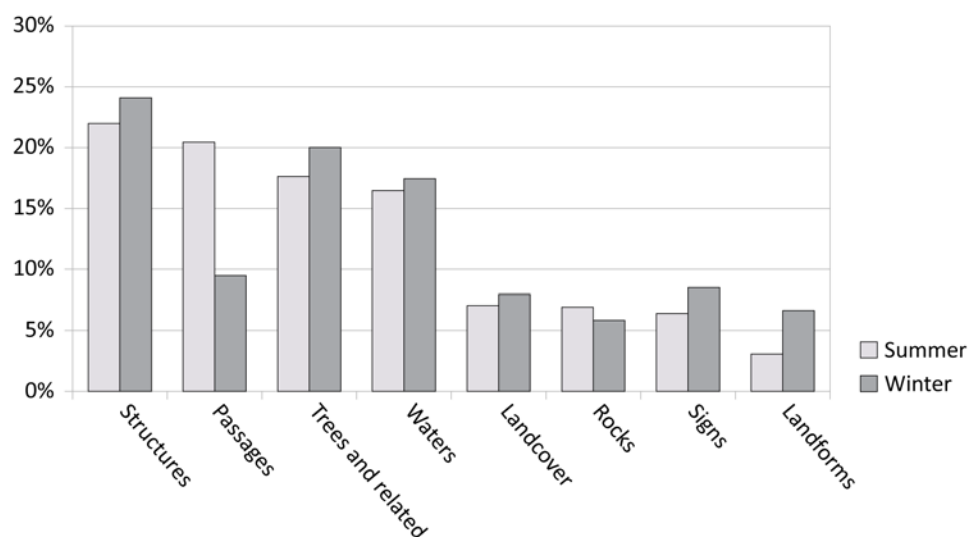


Figure 74 Frequencies of landmark groups in the summer and in the winter.

The ‘landforms’ was another landmark group that showed a statistically significant difference in the usage frequency between the summer and winter ($p=0.0494$, Figure 74). The ‘landforms’ group was used 3.6% units more frequently in the winter experiment. The difference may result from the snow coverage that makes large landforms more visible as the ground details are hidden, but also because slopes were slippery in the winter experiments and the participants recognised the hills due to the

slipperiness. Besides the ‘passages’ and ‘landforms’, the other landmark groups showed no significant differences in the usage frequencies between the summer and winter.

Table 10 Differences in the usage of landmark groups in the summer and winter. The significant differences are highlighted (p < 0.05 in two-tail Wilcoxon rank sum test).

Landmark group	Frequency / landmarks (% units)	Difference in No. of participants	No. of landmarks	P-value Wilcoxon
passages	-10.97	-1	0	0.0009
landforms	3.57	2	-1	0.0494
trees and related	2.39	0	3	0.9397
structures	2.10	0	0	0.1509
signs	2.09	0	0	0.2265
rocks	-1.08	0	0	0.5454
waters	0.97	0	-1	0.7055
landcover	0.92	-1	-2	0.7055

6.4.2.2 Creating a Hiking Landmark Ontology

The landmarks and landmark groups that were extracted from the thinking aloud experiments formed a basic frame for an ontology of hiking landmarks. As described, an ontology is a semantically organised structure of concepts and relationships between the concepts, a structure that can be modelled in many formal and informal ways. As we aim at an automated use of landmark knowledge in the Terrain Navigator, we need a formalised ontological presentation of the landmarks. We used Protégé ontology editor (Protégé 2011; Horridge 2009) for the formalisation of the ontology and chose an open standard ontology language, Web Ontology Language (OWL) (Dean and Schreiber 2004), as a means of formalisation because of its expressiveness and prevalence in the creation of task ontologies. The OWL DL sub-language was used.

The 62 landmarks that were extracted from the transcripts of the thinking aloud test sessions formed the bottom level ontology classes for a landmark taxonomy for which the eight landmark groups formed the top level classes. The preliminary hiking landmark taxonomy was formalised using the Protégé ontology editor and stored in the OWL format (Figure 75). While formalising the taxonomy in Protégé, mid-level ontology classes were added between the landmarks and landmark groups where necessary. For example, landmarks ‘bare rock area’ and ‘cliff’ were placed in a new mid-level class, ‘rockSurface’, in the taxonomy (Figure 75). At the end of the taxonomy formalisation, there were 22 new mid-level classes in the taxonomy.

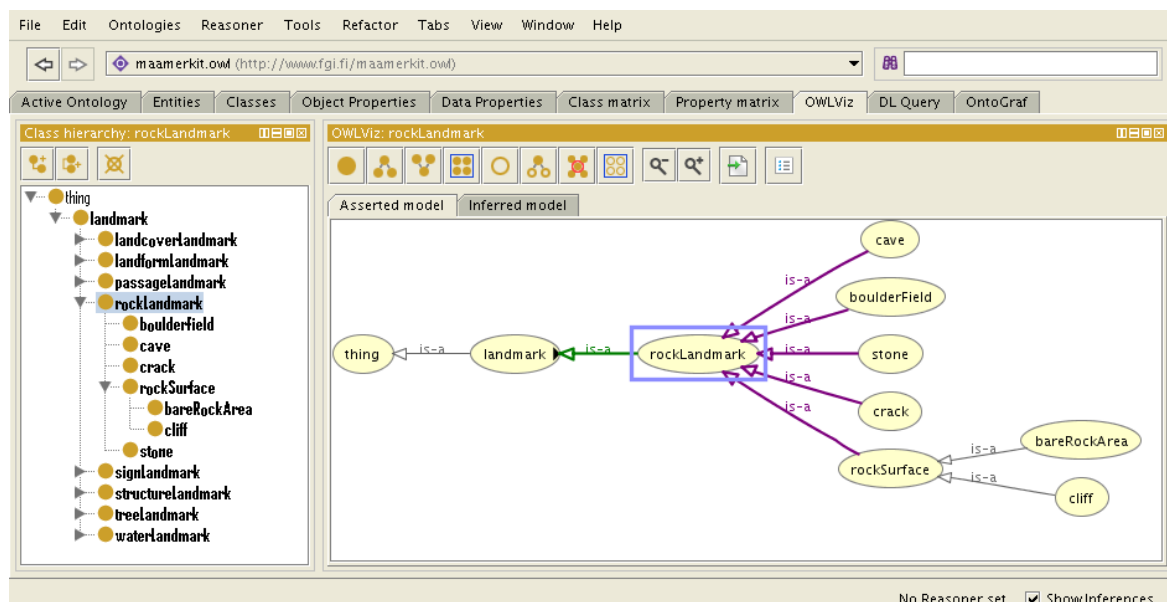


Figure 75 A view of a part of the hiking landmark taxonomy in the Protégé ontology editor.

The landmarks that were used in the route description experiments represented only a subset of all landmarks in Nuksio National Park. We wanted our landmark ontology to contain a rather complete set of landmarks found in Nuksio National Park, and therefore an expansion of the experiments-based taxonomy was necessary. The expansion of the taxonomy was done using additional sources such as legends and specifications of topographic and orienteering maps and the experience of the research group (Maanmittauslaitos 2008; Ordnance Survey 2008; International Orienteering Federation 2000). The International Specification for Orienteering Maps proved to be especially useful for the expansion of the taxonomy because orienteering maps are designed for moving by foot in forests, and as such, they present objects that hiking people are able to see.

The expansion of the taxonomy resulted in 42 new landmarks and one new mid-level class, after which the taxonomy contained 108 landmarks, 23 mid-level classes, and eight landmark groups. The depth of the taxonomy became five levels at maximum, including a top class ‘landmark’, which meant two mid-level classes at most between landmark group classes and landmark classes.

Our hiking landmark taxonomy was refined towards a more complete ontological model by making ontology classes correctly disjoint and by inserting object properties in order to describe the characteristics of landmarks (Figure 76). The value partition class ‘geometryType’ and the named class ‘season’ were added as well as object properties for denoting the geometry type and seasonal characteristics of landmarks. Every landmark was constrained to have a geometry type by creating a closure axiom between landmark and ‘geometryType’ classes using object property ‘hasGeometryType’, and every landmark was assigned a geometry type using this property. Those landmarks that were identified as difficult to see during winter because of snow were linked by ‘isUnreliableLandmarkDuringSeason’ object property to the associative season.

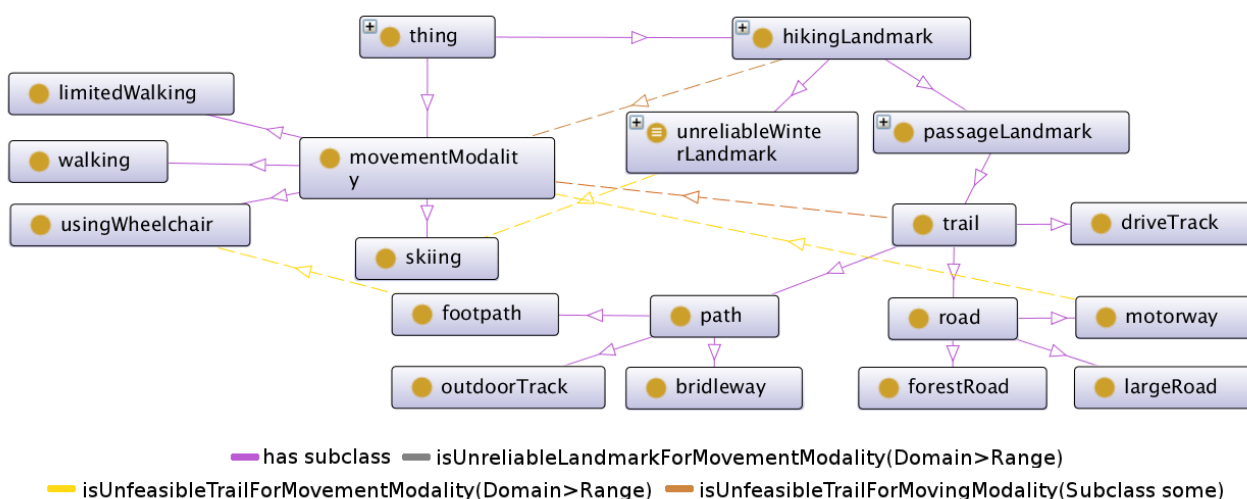


Figure 76 A graph of a part of the hiking ontology, containing both hierarchical (solid lines) and object property (dashed lines) relations.

Disjoint ontology classes and object properties allowed us to create defined classes in the ontology, the subclasses of which can be solved automatically based on the existing ontological relations. Such defined classes were created for every geometry type called ‘pointLandmark’, ‘lineLandmark’, and ‘areaLandmark’, and one was created for landmarks that are unreliable for use in the winter, called ‘unreliableWinterLandmark’ (Figure 77). An ontology reasoner would be able to collect classes that are denoted to be unreliable in the winter under this defined class.

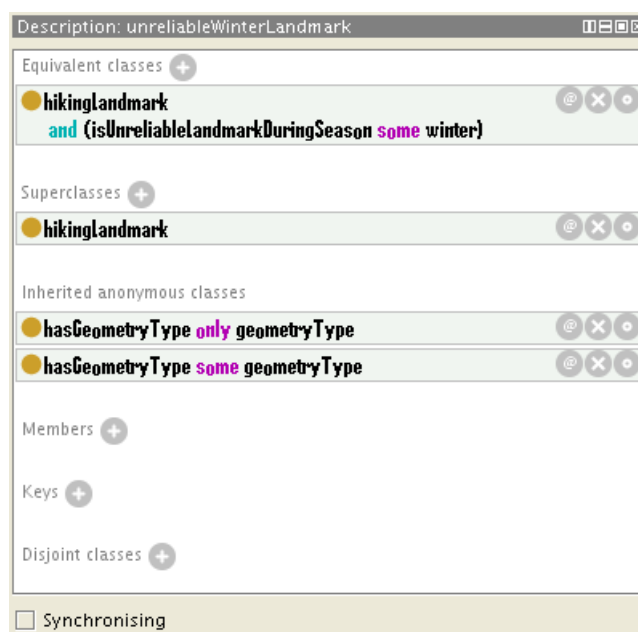


Figure 77 Construction of a defined class ‘unreliableWinterLandmark’ in the landmark ontology. The defined class allows automatic reasoning for acquiring compatible ontology classes.

In the context of pedestrian navigation, the term multimodality is often used to denote the usage of different types of movement and transportation for a single journey (NAVTEQ 2011; Liu 2010). In urban pedestrian routing the typical modalities are walking, use of public transportation (bus, tram, subway,...), driving a car etc. In the following text we extend the notion of modality to person's ability to move and to person way of moving. This viewpoint of modality is motivated by the assumption that the modality affects, which landmarks are suitable for him or her when moving and navigating in the natural environment. For example, an older person with limited walking ability may need to look at his or her feet on a rough surface so often that that he or she cannot observe minor landmarks.

In order to consider different kinds of use cases of the landmarks, we included four movement modalities in our hiking landmark ontology, regarding both seasons ('walking' and 'skiing') and moving constraints of a user ('limited walking' and 'usingWheelchair') (Figure 78). We also set up object properties for denoting when a landmark is ill-suited for a movement modality ('isUnreliableLandmarkForMovementModality') and that a trail landmark (e.g., a path or road) is unfeasible for a moving modality. As we had collected those landmarks that are unreliable in the winter in a defined class 'unreliableWinterLandmark', we could directly denote that landmarks in this class are unreliable when skiing, by using the 'isUnreliableLandmarkForMovementModality' object property.

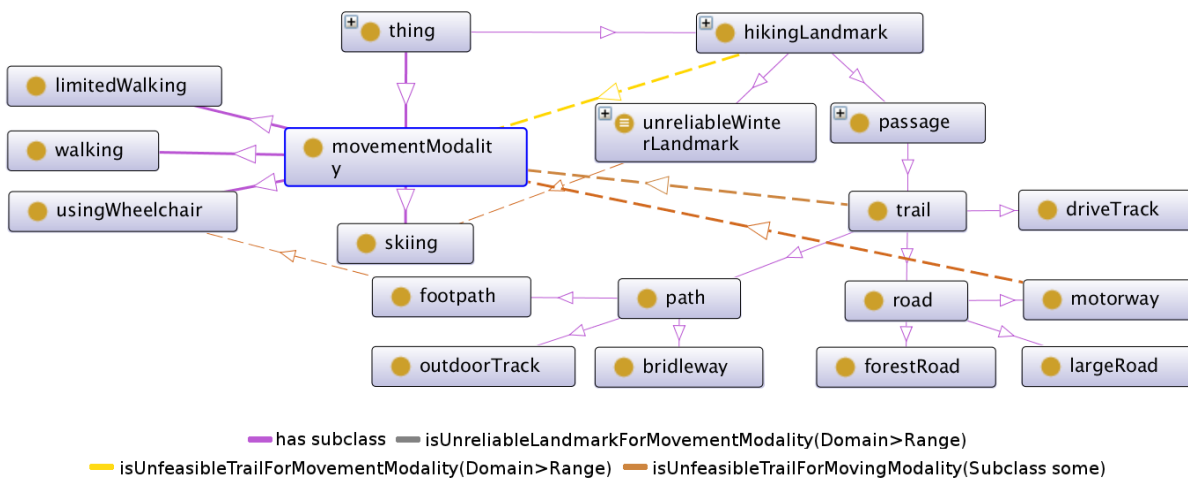


Figure 78 Modelling movement modalities in the hiking landmark ontology, in relation to landmarks and trails.

6.5 Discussion

Hiking in the forest is significantly different from walking in an urban environment where street names and well-known buildings support navigating. It was found from this study that landmarks had a central role in verbal route descriptions also in the hiking environment.

The Denis' classification of the propositions collected from the route description experiments resulted in dominant frequencies of landmark-related proposition classes both in the summer (79%) and in the winter (70%). The dominance of landmark-related propositions was similar to the earlier experiments that used the Denis' classification (Denis 1997; Daniel and Denis 2004; Brosset et al.

2008; Rehrl et al. 2009). However, the overall proportion of landmark-related proposition classes was smaller in our experiments since commentaries covered a larger proportion. The large number of commentaries partly arose from the use of free speech due to the thinking aloud method and partly, in the case of the winter, from the snow that inspired many commentaries. The results confirm the importance of landmarks in route descriptions in a natural park environment. The importance appears to be more significant in the summer when more landmarks are visible than in the winter when terrain and many landmarks are covered by snow.

The class-specific statistical analyses of our Denis' classification highlighted the usage amounts of two classes that differed significantly in summer and in winter. The 'action' class was used significantly more frequently in the winter and the 'landmark' class significantly more frequently in the summer. The differences originated from the propositions spoken at the decision points: the differences in 'action' and 'landmark' classes were larger at the decision points than along the whole route, whereas the differences did not show up between decision points. The difference of the 'action' class resulted from the introduction of route alternatives at the decision points that contained both actions and landmarks in the summer, while in the winter, landmarks were not included as often. The lack of landmarks in introducing the route alternatives in the winter was mainly due to the paths not being mentioned, most likely because they were not discovered under the snow and therefore were not considered. The significantly larger number of 'landmark' propositions in the summer originated from richer landmark descriptions, probably because there were more visible landmarks in the summer.

The analysis of landmark objects used in the route description experiments showed that 'structures' was the most frequently used landmark group both in the summer and in the winter, even when the number of structures was not very high along the route. The 'structures' objects were good and reliable landmarks because they were clearly visible in the natural park environment during both seasons. The experiments verify that 'structure' landmark group should always be included when providing route instructions in this kind of environment. Other important landmark groups during both seasons were 'tree landmark' and 'water landmark'.

The most important single landmarks in our experiments were 'house', 'lake', 'parking place', and 'creek', since they were among the six most used landmarks both in the summer and in the winter, and all participants in the experiments used them. Those landmarks that were used by every participant during one season can be regarded as seasonally important landmarks in a national park environment and are highly appropriate to be used in route instructions during the respective season.

Significantly quantitative differences between the summer and winter were detected in the usage of the 'passages' and 'landforms' landmark groups. The 'passage' landmarks were used significantly less in the winter mainly because of the lack of visibility of footpaths. The result suggests that footpaths should not be given a large role in creating route descriptions during a snowy wintertime. The 'landform' landmarks were used significantly more frequently in the winter than in the summer, which appeared to originate from the fact that landforms are more visible in the winter due to snow surface. Hence, landforms could be used in route descriptions in a national park environment in the winter, although they were the least used landmark group in our experiments. In the summer, the use of landforms as route landmarks must be considered more carefully.

A noteworthy phenomenon was observed in the usage of ‘landcover landmark’ and ‘tree landmark’ groups in summer and winter. The number of ‘tree landmark’ objects mentioned increased in winter compared to summer, and at the same time the number of vegetation landmarks decreased. The ‘tree landmark’ group consisted of single trees and the ‘landcover landmark’ group consisted of amalgamated vegetation objects. The differences in the number of landmarks suggests that in the summer, people’s visual attention focuses on the plant patterns because plants are too numerous to be observed separately, but in the winter, when there are no leaves and undergrowth, the attention focuses more on single vegetation objects such as trees. Route instructions in a national park environment should be adapted to vegetation conditions according to the season.

The extracted landmarks and landmark groups from the route description experiments were taken as a basis for a hiking landmark ontology, for which they provided a firm taxonomical frame. Mid-level ontological classes were added between the landmarks and landmark groups, and the taxonomy was expanded by adding landmarks from map legends and from our expertise. The resulting taxonomy can be regarded as a comprehensive hiking landmark taxonomy with 108 landmark classes, 23 mid-level classes, and eight landmark group classes that can be used in creating route descriptions in a national park environment.

The expressiveness and usefulness of the hiking landmark ontology increased with the use of associative relations (Section 6.2.2), such as disjoint classes and object properties. With these, we could model the reliability of the landmarks regarding season, geometry types of the landmark objects, and the usefulness of the landmarks considering the movement modality of the hiker. The insertion of associative relations also allowed us to create defined classes which could be used to automatically acquire ontology classes sharing specific properties by using an ontological reasoner.

6.6 Guidelines for D1.4

Landmarks are extremely important for navigation also in a natural environment such as a national park and should be considered as a means to increase the hikers’ safety and to ensure that they are on the right trail. The navigation instructions regarding hiking should be adapted to some extent to the respective season and the user’s movement modality.

A possible way to formalise the spatial concepts for implementation is through ontologies. However, creation of ontologies with semantically good coverage is dependent of extensive work.

6.7 Proposed Toolkit HCI Modules

The study on landmarks will primarily have an impact on the D4.4 (Accessible map and LBS content guidelines). There the landmark ontology will be used as the basis for the classification and attribution principles to be applied for the features that can have roles as landmarks. The way as how the content information about landmarks is utilized in a mobile application, such as the Terrain Navigator, is solely dependent on its purpose and design. The already existing toolkit modules can be used in the implementation of the needed functionalities. The described landmark types can be stored in the internal data storage of the HaptiMap toolkit. In the data storage every type of landmark

must be numerically coded to be of a certain feature type. Thus, the codes of the feature types stored in the corresponding Toolkit Resource File would require an extension to include all the important landmark types found in our study. Attributes such as ‘the season’ can also be stored in the data storage of the HaptiMap toolkit. A higher level HCI module should be constructed to embody these guidelines and based on the available user situations and map data available, create routes when appropriate that use the landmark. Therefore the majority of modules that are required for this work already exist, and it is likely the programmer will access the results of this work through those modules, rather than a new module itself.

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7 Task 2.3 – Context Sensing and Filtering

This section presents the results of the research conducted in WP2 within the theme of context sensing and filtering. Four partners contributed to the investigations which are headed:

- The Virtual Observer
- User Profiling
- Navigation Error Checking
- Context Sensing using Signal Analysis Techniques

The investigations, models proposed and the results obtained, are all described in terms of a study. The studies have been chosen in the context of the findings and conclusions outlined in D1.1 and D1.2.

Each study is presented in the same format: Beginning with a review of the state of the art and an introduction (set out in terms of initial user studies undertaken in WP1), the details of the study methods and theory are presented. Results of interest, their analysis, and appropriate conclusions are then reported. Each study is concluded with recommendations for the user studies to be reported in D1.4 and how it can lead to the development of a practical HCI module for the Haptimap toolkit.

The Virtual Observer study analyses navigation errors with a very precise meaning. This is followed up in the Navigation Error Checking study which considers the problems encountered when navigation errors are considered in too generic a manner.

The User Profiling study considers the need and requirements for context sensing without specifying how it is done, and the Context Sensing using Signal Analysis sets out in detail how to achieve context sensing using trusted algorithmic techniques. The Signal Analysis study is also linked to the Error Checking one, since it details how the Support Vector Machine classification algorithm can be employed as part of the overall process.

7.1 The Virtual Observer Study

From D1.1 we've learned that user studies are important and essential to discover the users' needs. As external literature points out, and we've experienced on our own, outdoor studies provide an additional value over lab studies. However, as in example experienced in the Biker Study (D1.1, Section 4.4), grasping the whole user context as an experimenter/observer is a challenge. In addition, a mobile navigation aid might also profit from additional knowledge on the users' context. As part of Task 2.3 we want to design methods to sense the context a user is in, which then potentially could be re-used to aid the user in the navigation task, or to aid an experimenter in understanding the context

afterwards. In this section we will present the Virtual Observer, a sensor-based observation utility. We give an introduction into our observation methodology and report from a study, where we compared the Virtual Observer against traditional video observation.

7.1.1 State of The Art

A few years ago, outdoor field studies were conducted less often than lab studies (Kjeldskov, 2003). A reason for this might be that field studies are more time demanding, and the data collection is difficult (Rowley, 1994; Kjeldskov, 2003). On the other hand field studies have the additional value that they incorporate the context, which has been reported to be important (Kjeldskov, 2004; Goodman, 2004; Kaikkonen, 2005; Rogers, 2007; Nakhimovsky, 2010). Especially in the area of pervasive and mobile applications, more and more field studies are conducted. Unfortunately the major challenges, i.e. scalability, obtrusiveness, situatedness, remained the same. To make field studies easier to conduct for the researchers as well as for the study participants, existing observation methods are modified and completely new methods are developed. This section will give an overview on the most important contributions to this methodological research in relation to our work on the Virtual Observer.

In contrast to sample the experience of users on their own, Larson and Csikszentmihalyi introduced and validated the Experience Sampling Method (ESM) (Larson, 1983; Csikszentmihalyi, 1987), which is capable to obtain the users in situ experiences through user feedback triggered on a regular basis. In contrast to a usual questionnaire, ESM is able to capture the experiences of a certain moment, by remembering the participant through e.g. a stopwatch or ringer to fill out a set of questions or scales.

In the time of mobile phones this technique has been adapted to our digital life for several times now, finding it's way to frameworks to conduct unsupervised user observations (Intille, 2003; Froehlich, 2007). These frameworks are capable to record photos, audio, video or text responses to either textual questions or any other kind of trigger for an experience sampling. In various applications, ESM has been proofed to be helpful (Consolvo, 2008). However, ESM is restricted by only relying on subjective user feedback, which is known to be limited as users tend to misunderstand situations or their reflections focus on particular aspects of individual preference.

In the last years there has been a lot of research conducted in the domain of logging. Jensen and Larsen (Jensen, 2007) report from a three-month longitudinal field study they conducted with a single participant. They stated that they learned a lot by only looking at the logged quantitative data. Healey et. al. (Healey, 2010) conducted a study with more specialized sensors to automatically measure emotion. They report from difficulties to align the automatically detected emotions with the user-reported feelings (i.e., ground truth).

In the last two years, logging has been used to conduct experiments and long-term analysis through a mobile application (e.g. a game), which is spread to the distribution platforms (e.g. Apple AppStore, Android Market, etc.), see (McMillan, 2010; Michahelles, 2010; Rohs, 2010; Henze, 2010). For example, McMillan et. al. (McMillan, 2010) ran a large scale trial on how to conduct user studies by using logging and a mobile distribution platform (i.e., Apple AppStore). Approximately 25% of the

downloaders registered to be part of the trial. This might be an indicator for the users' doubts about sharing any logged data. However, McMillan et. al. report from a total number of 24,408 logged participants which is an indicator for the high scalability and results in a much higher degree of confidence.

In contrast to earlier work in the field of logging, we are to our knowledge the first ones, which try to extend traditional logging of sensors to the observation of more complex events in the field of user studies. We do that through aggregation and combination of obtained context information through sensors. However, in comparison to state of the art activity recognition techniques, we are not using flexible machine learning techniques. Instead we try to keep our algorithms as simple as possible to ensure a high reproducibility of the concepts, as well as the scientific study results. Framed by the application field of (mobile) HCI, we are further evaluating our technique in the light of actual practical use and don't focus on theoretical assessment of our technique.

7.1.2 Three observation techniques

A literature review and experiences from D1.1 revealed that an experimenter is potentially interested in three navigation-related measures: navigation errors, disorientation events, and how visual distracting a navigation device is.



Figure 79 Detection of navigation errors.

For our concept to detect a navigation error, we decided to rely on the GPS position, which is correlated with the previous waypoint, a participant comes from, and the next waypoint, a participant has to reach. The beeline between these two waypoints is the ensured shortest path with a distance d , a participant can use and walk on. If the participant is on the path, the distance between the previous waypoint and the user $d(p)$ and the distance between the user and the next waypoint $d(n)$ are both equal to d . If the summarized distance $d(p) + d(n)$ is more than five percent longer, a navigation error is assumed. We decided on the 5% threshold to compensate a varying path width as well as GPS inaccuracy.

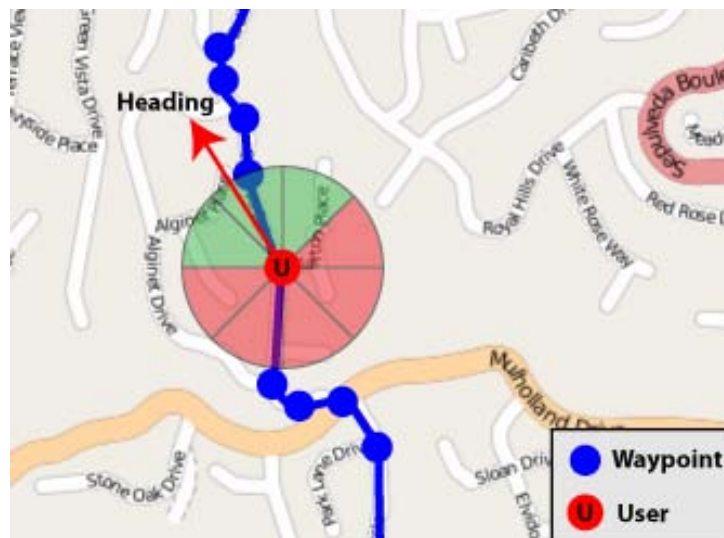


Figure 80 Detection of a disorientation event.

To detect disorientation we decide to use a device's internal compass to determine the user's heading. We assume that an ongoing change of this heading, especially when not facing towards the next waypoint, is an indicator for disorientation. Due to noisy values obtained from a common digital compass, some smoothing is needed. Thus, we decided to cluster the full 360° into 8 sections, each of them covering an angle of 45° . The current user heading is then determined by calculating the average over the last 10 measured heading classes. If the difference between the next waypoint and the current user heading is greater or equal than 2 sections for more than 4 seconds, a disorientation event is raised. We decided on 2 sections to each side because this would cover the angle 135° ahead of the user and heading the opposite to the way where a user comes from seems unlikely when one feels well oriented. However we also added the 4 seconds threshold to compensate short look backs of the participants.



Figure 81 The detection of the device posture is done by using the integrated accelerometer.

To detect if a mobile phone is held in front of a participant, we decided to rely on the device orientation. Usually a participant will only hold the device in front, if there is the intention to look on the visual display or to enable the scanning mode of the tactile feedback. In both cases the display would face upwards, approximately towards the users face. Defined through the orientation values *roll* and *pitch* it can be said that a device is held in front if *roll* does not exceed $\pm 40^\circ$ and *pitch* is smaller than 16° and greater than -100° .

7.1.3 Study Description

In this section we compare the three observation concepts of the Virtual Observer against the traditional gold standard observation technique in field studies: video observation. The goal is to identify how well the Virtual Observer performs compared to an established observation technique.

7.1.3.1 Method

We integrated the Virtual Observer into an early prototype of the PocketNavigator, one of the HaptiMap demonstrators. The user study has been conducted in a pedestrian area of Oldenburg, a city with approximately 150,000 inhabitants. The study is divided into three navigation tasks, one for each of the conditions. For each of the tasks we pre-defined a route, which is about 0.5 km and consists of 10 to 11 separate waypoints. 16 volunteers participated in the study, 8 of them were female. The average age of the participants is 23.69 years (SD 2.44), ranging from 20 to 29 years. None of the participants knew any of the routes before the study. The following analysis is two-fold. First, we analyse if there is a general correlation between the data points captured by each observation technique. Secondly, we do an in-depth binary classification analysis, treating video observation as ground truth. A fictive post-hoc analysis is done to identify if an experimenter would conclude differently between the observation techniques.

7.1.4 Results

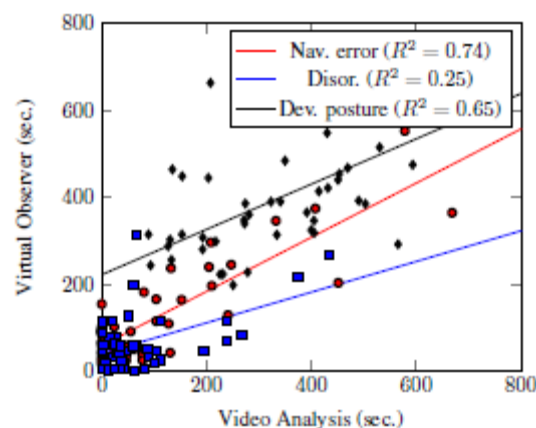


Figure 82 Coefficient of correlation visualised for all three observations.

The coefficient of correlation (R^2) indicates a correlation for navigation errors and device posture (see Figure 82). The binary classifier analysis shows high accuracies for the observed parameters. However, especially for disorientation the sensitivity is weak (see Table 11). The statistical analysis showed that a researcher can identify significant differences for both observation methods (see Table 12)

Parameter	Navigation error	Disorientation	Device posture
Accuracy	0.77	0.80	0.66
Error rate	0.23	0.20	0.34
Sensitivity	0.46	0.13	0.83
Specificity	0.83	0.88	0.29
False positive rate	0.17	0.12	0.71
False negative rate	0.54	0.87	0.17
Positive prediction rate	0.34	0.11	0.73
Negative prediction rate	0.89	0.90	0.43

Table 11: Details from the binary classification comparison.

Parameter	Test	Video Observation	Virtual Observer
Navigation error	ANOVA	$p < .05$	$p < .05$
	Condition 1	$p < .01$	n. s.
	Condition 2	n. s.	n. s.
	Condition 3	$p < .01$	n. s.
Disorientation	ANOVA	$p < .05$	n. s.
	Condition 1	$p < .05$	n. s.
	Condition 2	n. s.	n. s.
	Condition 3	n. s.	n. s.
Device posture	ANOVA	n. s.	n. s.
	Condition 1	n. s.	n. s.
	Condition 2	n. s.	n. s.
	Condition 3	n. s.	n. s.

Table 12: Details on the fictive post-hoc analysis.

7.1.5 Discussion

The coefficient of determination indicates correlations for navigation errors and device posture. For disorientation only a weak correlation can be obtained. The sensitivity (i.e., true positive rate) of the binary classifier is trending in the same direction. In fact the disorientation detection performed worst, while navigation errors and the device posture can be detected with sufficient accuracy.

The statistical analysis of both observation methods would result in a different conclusion for a potential researcher. For the device posture the statistics would result in the same non-significance, indicated by the ANOVA. For navigation errors the video observation is able to identify more

significant differences than the Virtual Observer. For disorientation the observation methods would lead to different results, because of a significant ANOVA for video observation and a non-significant ANOVA for the Virtual Observer.

One of the limitations of this study is that the comparison of the detected data is against a subjectively, human-defined ground truth, which are basically results from a video analysis. Because the results of the video analysis are completely subjective impressions, they might be the inaccurate factor compared to the objective detection through the mobile phone's sensors. On the opposite, the Virtual Observer can only observe what has been assumed and defined ahead of the study. Observations without a definition and theoretical validation ahead of a study are lacking an internal validity, as the effect causing the observation actually can be everything. As we identify later, it is hard to imagine every possible use case or situation in advance.

7.1.6 Guidelines for D1.4

Based on this study it can be said that the theory behind the user observation in studies is an interesting topic. The three named measures (navigation errors, disorientations, and how visually distracting a device is) are of high interest for navigation applications of almost any kind. So far the results of the Virtual Observer are not perfect, but given the potential high impact of this novel context observation technique, quite promising.

7.1.7 Proposed Toolkit HCI Modules

Based on this work, we recommend the development of a Virtual Observer toolkit module, which subjects the approach itself and proposed observations to further research in later evaluations of the toolkit.

7.1.8 References

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7.2 A User Profiling Study

7.2.1 State of The Art

Nowadays there are several tools and technologies applied to the adaptation of contents for any type of devices (Berhe, 2004), (Held, 2002), (Mohan, 1999), (Phan, 2002) (Lum, 2002), some of them include also some kind of adaptation depending on the users' profiles. But they refer to users that are perfectly able to use any kind of device; therefore, a missing feature is the need to focus the adaptation to the user disability. In order to achieve this, it is necessary to expand the standards, build new tools, improve the capability of the process and handling of contents according to the interrelationships among the presentation variables, establish protocols for interchange of disability attributes, and create standards for safety and security. In addition, there is a need to develop all these new applications on already existing commercial platforms.

During the studies carried out in WP1 (detailed in deliverable D1.1), it was remarked that the role of personalization for the localisation based services, and the ability to enrich the system with user-generated content: required that the dynamically changing information generated by other users at a given location maybe be better suited to the needs of next visitors than some kind of general information.

7.2.2 Study Description

How to provide the right information (content & presentation) to the specific needs of the user?

The use of ICT devices for location and navigation may represent a barrier for certain number of users classified as “dependant people”, i. e. a person who cannot perform, without help, some of the basic activities of daily life related to navigation in unknown environments. To ease the adoption of supporting multimodal technologies it is important to remove barriers in the mobile devices, and also in the use of the location and navigation services. The aim is to let any dependant people perceive such technologies as transparent as possible, fulfilling their expectations and offering good accessibility to the geographical information.

In order for these services to be truly useful, it is necessary that their functionalities evolve according to the changing and increasing needs of the users. The devices and applications adapted to users' needs and profiles will improve the type of information they are asking for, depending on the moment and environment where it is provided.

Partners ONCE and TECNALIA carried out a study in May 2009, developed in two stages: completion of a semi-structured questionnaire (a total of 188 were fulfilled via ONCE website), and meetings with 4 different groups of users (Mobility trainers, visually impaired users familiarized with technology, visually impaired users who are not familiarized with technology, and not disabled users with clerk profile).

The aim of this study was to know the opinion of users about outstanding information which must be known regarding items included in routes and navigation applications, in order that the system can establish and offer the most adequate route for every user having into account items and user needs. It was aimed to build a classification of user's profiles with visual impairment which could be used by the application, as well as standard POIs customizable by the user.

7.2.2.1 User profiles

There were four user profiles investigated in this workshop:

1. Visually impaired (V.I.) people used to interact with technological devices (7 persons), aged between 18 and 55. They have not been informed previously to the interview. They can move on their own using canes or guide-dog.
2. Visually impaired people not used to interact with technological devices (7 persons), aged between 18 and 55. They have not been informed previously to the interview. They can move on their own using canes or guide-dog.
3. ONCE staff (Rehabilitation trainers). They are 3 persons with more than 15 years of expertise in the ONCE organisation. They are interested in new technologies and they usually apply them in their daily work.
4. Administrative officers without any disability.

In order to obtain sufficient information structured interviews have been applied, using questionnaires for the different profiles (V.I. and staff). Open questions have been used, together with a round-table to allow dialogue within the group. Meetings have been held separately with each group, explaining the objective of the sessions and asking for their written permissions to record (text and audio) and use their responses in an anonymous way.

7.2.3 Results

Having into account the opinions of users, Mobility Trainers, technologists and the own opinions of the group which forms the research team of the HAPTIMAP project in Spain during the various workshops undertaken, we can conclude on the whole the following:

1. The user profile has much to do with setting the criteria to select the items to avoid or to use as obligatory points in a route.
2. The knowledge about technologies to support navigation, assisted navigation or preparing routes, is not widespread among not experimented user neither among the ones considered

as experts. But there is a big tendency to incorporate these techniques and technologies in their daily habits.

3. The ideal device user thinks of as a personal assistant for navigation and routing should meet some requirements such as the following ones:
 - ➤ Small size of the device to guarantee it can be easily carried (they have described daily life devices such as mobile phones)
 - ➤ Easy to use
 - ➤ Accessible system.
 - ➤ The system must have a high degree of personalization to fit their needs by means of a rich interface and easy to use.
 - ➤ An adequate communication interface which makes use of enough alternative methods to guarantee a good person/machine communication for each one of the user profiles (voice, vibration, alert sounds, etc.)
 - ➤ Using systems to improve the control of position regarding the environment when we are stopped or moving slowly.
 - ➤ Autonomy and easy to recharge.
4. It should be suggested a standardisation of the classification for the POIs, easy to use by the different systems. In this sense, an ideal system should include not only the items which are now present in the cartographies but also all that ones which are relevant for each kind of user.
5. Orientation in open areas as well as items of difficult tracing (squares, roundabouts, areas of parks and gardens...) has been highlighted by the different groups of technicians and users as one of the problems that needs to be solved by a modern navigation system.
6. Information issued usually by navigation applications are not sufficient, it has low resolution. The instructions given for the route are only useful if the user knows the details in advance.
7. Distance information based on “metres” is not used in the training sessions. More meaningful references are the direction and volume of traffic, number of streets crossed, in which side of the route they are located/sensed.
8. The training navigation program should be able adapt itself to the user needs and her/his abilities.
9. It would be helpful to define a method to decide whether a resource is accessible for a certain user profile (this accessibility will be also depending on the events associated with the resource).
10. Each type of event will affect in a particular way to each user profile. The user should be able to personalize how he/she is affected by each type of event, by modifying the level of relevance.
11. The user profile should be updated by the user.

7.2.4 Conclusions

An earlier version of the work reported here was also reported in D1.1. We report this work here as it is much closer to the development of design guidelines that can be combined with the other work in this WP, than general guidelines on users from WP2. The results show how key features about

interaction can be derived, based on the user profile or type of participants used. Practically, the results presented here should also be considered with those in D1.1. Both guidelines and toolkit modules that employ the results we have obtained are outlined below. However, all toolkit modules should embody the general findings outlined here.

7.2.5 Guidelines for D1.4

Having in mind the actual barriers of accessing information on mobile devices, Tecnia and ONCE proposed that the toolkit should include some applications related to the management of the users' profile. In addition, the management of the device's profile could be of interest, since the envisaged tools must cover a wide range of hardware devices and operating systems. And last, the context where the user is using the services must be detected, analysed and filtering techniques should be applied.

The profiling applications involve the adaptation of services and information, making use of different types of visual and non-visual interfaces for the mobile device.

The following set of applications could be included in the toolkit:

- Application for sensing the context
- Application for filtering the geographical information
- Detection of the profile (needs and preferences) of the users
- Detection of the profile of the mobile device (installed HW/SW and configuration)
- Adaptation of the contents and interfaces according to the above information

One task has been the definition of parameters which lead the profiling of the interfaces of the applications or services, always taking into account the technologies for accessibility. A first step has been the segmentation of the typology of users (elderly, partially sighted, blind,...), analysing their functional disabilities: cognitive disability, low vision, mobility disability... Also other features not linked with disabilities, but with specific context situations (hiking, bike cycling,...) are being considered. For each case, different aspects must be taken into account when designing the interfaces:

- Configuration of graphic representations: colours, contrast, text size, icons, distribution over the screen.
- Input modes by the user: voice, gestures, buttons, touch screen,...
- Output modes to show information: voice synthesis, vibration, text,...

In addition to these features which reflect the abilities of the users, the segmentation will also include the preferences of the users.

With this segmentation process the aim was to define a structure including explicit representation of the specific features of the users. Generic models of the users can be defined (representing a group of users of similar features). Changes over the time of the user's profile have to be taken into account.

Although the segmentation process depends on the type of disability, the profiling process should be transparent to the user (following the principles of Universal Design).

The adaptation applications should have the following features:

- Repository of interfaces to allow quick execution and adaptation.
- Monitoring of relevant context for the applications, from the point of view of interfaces.
- Mechanisms to create selection rules to link optimal functionalities/interfaces with the context.
- Mechanisms to configure resources of the device (volume of loudspeaker, screen brightness,...) to keep the usability of applications in unfavourable circumstances. This will have to be done on startup and dynamically.
- Selection of the optimal mode of application, on startup and on execution time, when changes in context require re-configuration of the application.
- Scalable to different types of mobile devices and platforms.

7.2.6 Proposed Toolkit HCI Modules

Taking into account the above mentioned needs about the adaptation of contents, the developments for WP4, WP5 are being integrated and tested for the following proposed applications:

The first one, TrainerTools, is a PC based application for the Mobility Trainer (MT), covering the user profiling tools and route editing. The Mobility Trainer is the person belonging to ONCE staff in charge of selecting the best option to perform a route for a blind or visually impaired user. He needs to identify potential obstacles, features and temporary conditions that may affect a safe journey to the target destination.

Figure 83 Menu for editing user profile

The second one is the *NavEscort*, a mobile application (using Windows Mobile) which performs the on-line assistance for navigation to the disabled user. This application can be managed by the user independently from the visual channel. It will provide navigation and POI information using audio (text to speech) with the possibility of integrating, in future versions, a haptic device such as Viflex.

This *NavEscort* demonstrator will provide:

- For blind users:
 - It makes mobile device application accessible for blind people.
 - It allows completing urban and semi-urban routes in an autonomous way.
 - It is focused on pedestrian navigation, making use of specific information of this kind of routes.
- For developers:
 - API to access to user profile content. The information recovered from the user profile could be used for:

For both applications the HCI modules will be:

- Non visual output:
 - Text-to-speech: Since Windows Mobile has no native text-to-speech engine, we will provide it using Loquendo TTS SDK. (Figure 81)
 - Stereo sound control: module which controls the intensity of a sound and selects which headphone will be used to generate the sound. This module will be used for non-visual navigation.
- Non visual input:
 - Voice input: since Windows Mobile has no native automatic speech recognition, we will provide it using Loquendo ASR SDK.
- API to create/access user profile content.



Figure 84 Menu access for visually impaired people

7.2.7 References

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7.3 Navigation Error Checking Study

This study summarises the development of a taxonomy of low level navigation errors and the subsequent design and construction of a system to predict and therefore prevent these errors in real life situations. This is important as navigation errors both simultaneously slow down and cause negative feelings in navigators who encounter or produce them.

7.3.1 State of The Art

Navigating through an environment using a map is a complex skill with many subcomponents (Waldron, 1917). At times this complex skill can fail in any of the various stages of execution due to myriad circumstances. In literature on navigation such failures of navigation performance are often termed “navigation errors” or “disorientation events”. However, this appellation was applied inconsistently with respect to the nature of the error. Denis *et al.* (1999) used navigation error in the narrow but general sense of deviation from a set route that had to be followed. Garden *et al.* (2002) followed this meaning. This definition was somewhat simplistic and missed many features of navigation that can go wrong. However, it did have two important features – it noted errors of direction and pausing as distinct types of errors.

Seager (2007) frequently used the terms “error” and “disorientation event” to mean only:
“...participants either walked too far in one direction before turning, or turned sooner than indicated by the route. Others were related to areas of map ambiguity.”

And

“Errors were counted whenever participants deviated from the shortest possible route (e.g. the participant turned too early, missed a turn, or chose the wrong turn at a junction).”

These navigation error types were not investigated further. They were also quite narrow in their interpretation of possible errors. This definition shared some qualities with Denis *et al.* and Garden *et al.* that made the term quite limited in scope.

Vainio (2007, 2009) used the term “navigation error” in the same way as Tversky (2003), with only three kinds of navigation errors – distance, direction and ‘other’. These kinds of errors are systematic errors on a large scale, such as between two cities, rather than between two nearby streets within a city.

Pielot and Boll (2010) defined a navigation error as follows:

“Navigation errors were counted when the participants entered a street they were not supposed to.”

This meaning of navigation error shared some basic similarities with the definitions used by both Denis *et al.* and Garden *et al.* and by Seager.

Bosman *et al.* (2003) defined an error as:

“An error was simply defined as a participant not making the right decision at a junction point (a point where they have to turn).”

This was quite a limited definition as it only took decision points into account. Decision points are parts of a navigation task where the navigators must make a decision that influences where they are going. Navigation errors can occur at any point in a wayfinding task. Navigation errors can come in forms other than not making the correct turn at a junction, *e.g.* the navigator may have misjudged a distance.

The use of this term unequivocally in the literature confuses the subject. Pielot and Boll used a narrow meaning of “navigation error” whereas Seager used the term too broadly to encompass many possible types of error without actually distinguishing or categorising errors. Both Vainio and Tversky used navigation error in a large-scale sense and in only a limited number of forms. Bosman *et al.* only defined navigation errors as occurring at decision points. Denis *et al.* and Garden *et al.* only classified pausing and deviation from a pre-defined path as an error. With these heterogeneous meanings of navigation error the question then arises: what exactly is a navigation error? This work aims to provide answers to this question by finding specific types of navigation errors a navigator may encounter and categorising them. There has been no work done in this important area of navigation therefore an experiment to uncover and form a taxonomy of navigation errors was devised. The top-level categorisation is based around the source of the error. A secondary level of categorisation is by the class of error, which is used in error taxonomies (Reason, 1990).

This knowledge of navigation errors was later used as a basis for a system that predicts, mitigates and helps correct the various navigation errors.

7.3.1.1 Sources of Errors

Pielot *et al.* (2009) observed that the paper map they had supplied in an experiment did not match the environment exactly, which caused several participants to become confused. Brown (2007) remarked that a group of tourists using both a guidebook and a paper map could not locate a specific street despite being on the street because it was known by one name in the guidebook and another name on the map. But both names were correct. Incorrect navigational materials principally caused these errors.

Another possible source of errors is the physical environment. The environment can be variable whereas maps are usually static. It is conceivable that an obstacle in the environment that is usually not there, *e.g.* road works, would cause similar problems to a map being incorrect, as in some sense the environment has changed but the map has not. Therefore a ‘new obstacle’ may simply be a case of the map not matching the environment. Furthermore, the environment itself may be difficult to navigate in, possibly due to the complex nature of some environments.

In addition to these two sources, the navigator incorrectly reading a correct map may seemingly have the same effect on the navigator as an incorrect map, albeit with a different cause. The problem is still there but the causation is essentially reversed.

Tversky (2003) gave only three kinds of navigation errors – distance, direction and ‘other’. These are all navigation errors with the source being the navigator. Tversky’s categorisation is not detailed or thorough enough as there are more specialised forms of these errors and different sources.

From these errors the sources of navigation errors can be formalised into three categories:

- Map errors – the map is incorrect;
- Navigator errors – the navigator has read the map incorrectly or moved through the environment incorrectly;
- Environment errors – the environment has changed (either temporarily or permanently) since the map was produced, rendering the map incorrect (possibly only for a limited time) or the environment itself is hard to navigate;

Overall the source of the error may not matter, merely the outcome. If errors can be accurately predicted via technology then even the outcome may not matter, as the error can be prevented.

7.3.2 Study Description

7.3.2.1 Hypotheses

The initial hypothesis, **H1**, is that when navigators are confronted with an environment that does not match the map they will take significantly longer to reach the destination. This hypothesis is useful as it can show if navigation errors caused by the map not being congruent with the environment actually make a difference to navigation. If **H1** has evidence to support it then it is reasonable to try to prevent or mitigate the error or aid the navigator when he/she feels the effect(s) of the error. If **H1** has no evidence to support it then it is not worthwhile further pursuing work to overcome navigation errors, unless there are other problems that are caused by navigation errors.

The second hypothesis, **H2**, is that when encountering an error, a navigator will invoke some standard tactics for recovery rather than a random method as a recovery attempt. If it is known which tactic overcomes a specific navigation error then a technology-based solution to aid a navigator in negating this error can be applied. This knowledge could also inform navigation training.

The final hypothesis, **H3**, is that all three navigation error sources—map, environment and navigator— have the same kind of outcome, *e.g.* a map-based error equates to an environment-based error. If there is evidence that this is true then the overall problem has been reduced to a single source, which decreases the number of solutions needed.

7.3.2.2 Experiment Design

To test the hypotheses, each participant was given a colour paper street map of the area they were to navigate in. Glasgow’s Botanic Gardens (Botanic Gardens, Great Western Road, Glasgow) were chosen as the area as it is safe and has features that are present on one map that are not on another map, which could induce errors. One possible critique of this choice of experimental area is that urban areas tend to have a more regular pattern and contain street signs. The response to this is that part of the experimental area is in a full urban environment and that the Botanic Gardens also

employs signs. Additionally, Platzer (2005) found that using street names and numbers was the least used urban wayfinding strategy, and the second least successful.

Each participant was given three tasks of navigating from one point to another. The first task, *T1*, was to navigate from Kew Terrace (labelled as Provost Park on the incorrect map) to the fountain in the Botanic Gardens. Task two, *T2*, was to navigate from the fountain to the top of the west-most river walkway steps. Task three, *T3*, was from these steps to the steps at the south-east end of Grosvenor Terrace. Using the destination point of *T1* as the starting point of *T2* and the destination point of *T2* as the starting point of *T3* may have prevented any learning effect of moving through the environment. For every task the experimenter walked the participant to the starting point and showed the participant the starting and destination points on the map. The participant was told to walk to the destination at a regular walking pace using only paths, *i.e.* not going overland. At the bottom of the map was the list of the destination points, *e.g.* for *T1* it is a fountain. Each participant was told that if he/she was to cross a road then he/she should do so safely. Additionally, the time taken by the participants when waiting to cross a road was subtracted from their overall time to obtain fair and accurate navigation times.

There were two conditions, *C1* and *C2*, presented in a between-subjects design. For *C1*, half of the participants were given a correct map of the area and for *C2* the other half of the participants were given an incorrect map of the area. The correct map was an A4 colour printout of the OpenStreetMap (openstreetmap.org) map of the area, taken on 25/02/10. The incorrect map was an A4 colour printout of the Google Maps (maps.google.com) map of the area, taken on 25/02/10. Seager (2007) showed that there was no significant effect on navigation errors between paper maps, PDA-based maps and GPS-based maps. Therefore, paper maps were chosen as they were cheaper, simpler to use and less likely to suffer from technological-based failure. There were many differences in the quality of these two maps of this area *e.g.* the main entrance is missing. North was added to each map, as there were no cardinal point indicators on either map. Each condition included the same number of males and females, with the navigational ability split between both conditions as well as possible. The navigational ability of each navigator was found out by administering the Santa Barbara sense-of-direction scale test and the object perspective-taking test.

Each participant was told that he/she was to be timed and should keep a walking pace rather than jog or run. No participant was told that the map was incorrect. They were told that they must use paths only, whether they are on the map or not. They were followed as they performed each task, with the experimenter timing them and video recording their walking and actions relating to map reading. They were asked to think-aloud about their navigation experience and why they were making such choices, *e.g.* “I am turning right here to get on to Byres Road so I can go through the main entrance.” These vocalisations were stored via a clip-on microphone and audio recorder. They were given a mobile phone to put in their pocket that logged their GPS position, digital compass and accelerometer data.

7.3.3 Results

7.3.3.1 Data Collection

The principal author watched and notated each video. Each action was noted, including the timestamp, *e.g.* “00:00 – glanced at map, headed down Grosvenor Terrace”. Each video was watched alongside the think-aloud recording. If the video did not provide enough insight into what had happened at a specific point then the think-aloud recording was consulted more thoroughly. The time to completion, minus the crossing of roads, was recorded for each navigator. The number of each error was counted for each navigator. The SBSOD and PT scores were also recorded.

The classification of these errors was from the 16 runs of the experiment. Once all the actions of each participant had been noted the full set of notes was consulted for similar behaviours. Then the maps and the questionnaires were re-read to infer the reasoning behind the behaviour of each action in the set of notes. The notes were then embellished with these analyses. From this more thorough set of notes the basic taxonomy of navigation errors was devised. At first this was simply the source, description and name of each error. After the list of errors was finalised, candidate errors were marked in the notes and the behaviour of the participant around that point in time was more thoroughly analysed. The behaviour around this time then allowed the effects and correction tactics to be identified. The videos and notes were then viewed again to find any further instances of existing errors or new types of errors that were not uncovered the first time around. This process was repeated until no more errors could be found. The next subsections describe each error individually, including an explanation of the tactics used to recover from an error.

7.3.3.1.1 Map – no path join (MNPJ) – frequency=8

The MNPJ error appears when two or more paths that connect in the physical environment do not connect on the map. This means that a navigator in an unfamiliar environment can have no knowledge of the real connection between the paths. The general outcome of this is that the navigator plans out an inefficient route. This route plan may be altered when the navigator sees and confirms in the environment that the paths actually do join. This is classed as a rule-based mistake ([Rea90]) where the navigator has misapplied a good rule, *i.e.* the rule of following the map. No errors with the opposite cause were found, *i.e.* the map showed that two paths joined when in reality they did not. However, this possible error should be noted for further investigation. MNPJ errors did not occur in *CI*. The recovery tactic was to explore the environment further, which allowed the navigator to either discover a suitable path or to find out that path actually did re-join in the physical environment. The number of times an individual error appeared over the course of the 16 runs of the experiment is also included.

7.3.3.1.2 Map – no path (MNP) – frequency=2

The MNP error occurs when there is a full path missing from the map that actually exists in the environment. This is different from the MNPJ error as it is a large individual path and not a small connecting path. It is also generally more serious than the MNPJ error, as in addition to causing the navigator to plan an inefficient route, it also may cause confusion in the navigator, and possibly make him/her take a wrong turn. The correction tactic is the same, however it was often harder to

notice that there is a full path missing from the map than in the MNPJ error when it is simply a smaller section of path that is missing. This is classed as a rule-based mistake where the navigator has misapplied a good rule, *i.e.* the rule of following the map.

7.3.3.1.3 Map – path not clear (MPNC) – frequency=2

The MPNC error occurs when a path is obscured on a map by other map features. This is a rare error as cartographers attempt to avoid this situation and when it happens navigators can often assume that a path exists under the features that are blocking it. In essence it is a rare form of the MNPJ or MNP errors and it gives navigators the same problems and has similar solutions. Like the MNP and MNPJ errors it is classed as a rule-based mistake where the navigator has misapplied a good rule, namely that they have taken the map too literally.

7.3.3.1.4 Map – feature missing (MFM) – frequency=16

MFM errors are when a map is missing an important feature, other than a path, and so a navigator may have difficulty forming an adequate cognitive map from the cartographic map. Examples of missing map features, at least in this experiment, were stairs and buildings. This error is separate from MNP as the type of map feature has different navigational use – a path is followed to get to another location, whereas other map features are used as reference points, destinations or landmarks. This can cause problems when trying to understand the environment in terms of the map. Distance judgment may also be affected as the navigator may think he/she is at one point on the map by confusing one feature in the environment with a different one on the map. This is classed as a rule-based mistake where the navigator has misapplied a good rule, *i.e.* the rule of matching features on the map with ones in the environment. Like the other errors with the map as the source, this is not strictly the navigator's fault.

7.3.3.1.5 Navigator – missed environmental clue (NMEC) – frequency=3

NMEC errors form when the navigator's attention is busy and he/she misses signals from the environment informing them where they are on the map. This skill-based lapse due to inattention can cause him/her to make incorrect turns, to form inefficient routes, to think he/she is heading in one direction when he/she is heading in another and contribute to the formation of a poor cognitive map. A good cognitive map likely helps prevent future errors in the same environment. Improving a cognitive map of an area is a desirable outcome of navigation, in addition to reaching a destination. To overcome this error it was shown that heading back using the path taken to a known position helped to relieve the problems from this error. Additionally, taking more care by sensing the environment when approaching vital parts of a path may prevent or alleviate NMEC errors.

7.3.3.1.6 Navigator – distance misjudgment (NDM) – frequency=22

The NDM error occurs when a navigator incorrectly scales between the map and the environment, thus placing him/herself in a position on the map that he/she is not actually occupying in the environment. This skill-based slip can cause the navigator to become confused with his/her position on the map in relation to his/her position in the environment and take wrong turns. To counter this error the navigator may go back to a known location and reapply the scaling to get a more accurate

judgement of distance. To prevent this error altogether more care could be taken when scaling between the map and environment.

7.3.3.1.7 Navigator – disoriented (ND) – frequency=6

ND errors are when a navigator becomes disoriented. The main effect is disorientation, which can cause confusion in the navigator. Such a feeling can be uncomfortable in a context such as navigation. This was shown in the questionnaire data. Disorientation and confusion can cause the navigator to take wrong turns and head in the wrong direction. This error happens when the complexity of the map-reading problem causes the map reading skill to break down and the navigator becomes unsure of their position on the map in relation to the environment. Backtracking to a known location and resetting the map so that the navigator can regain their connection between the map and the environment overcomes this.

7.3.3.1.8 Navigator – choice hesitation (NCH) – frequency=82

NCH errors are small but frequent errors. They occur when there are multiple choices of paths to take. If the navigator is unsure of which choice to make this can slow down the overall navigation time. As path selection is a complex skill this can take some time and can be over-thought when a simple choice can clearly be made. It can also be slightly confusing to a navigator. Planning out the turns to take in advance may save time overall as there is less hesitation at each decision point. Garden *et al.* (2002) put forward a similar error called a pause error. Best (1969) found that the number of choices at decision points was the primary factor behind the feeling of being lost, however Best's definition of lost fits more with a restricted form of the definition of navigation errors.

7.3.3.1.9 Navigator – wrong path (NWP) – frequency=1

An NWP error happens when a navigator thinks he/she is on one path but he/she is actually on another. This is quite a serious error as it can send a navigator on further wrong paths, in the wrong direction and can cause disorientation. This skill-based slip can be hard to overcome due to the disorientation and conviction that the navigator is on the correct path. If the navigator notices that he/she is on the wrong path then he/she can change his/her route to accommodate his/her mistake or backtrack to a known location.

7.3.3.1.10 Environment – redundant choice (ERC) – frequency=8

The environment having a large number of possible paths to the same goal causes ERC errors. The navigator tries to use his/her map reading skills to ascertain the best route but there are too many routes and it takes some time to calculate the best route. The amount of information to process at once may actually start to confuse the navigator. Such an effect is usually termed analysis paralysis. A better approach may be to use a heuristic or a good educated guess.

7.3.4 Discussion

An experiment was performed that aimed to answer three main questions:

1. Do navigation errors significantly slow a navigator down?
2. What tactics do navigators use to overcome navigation errors?

3. Are the three sources of navigation error superficially the same? By superficially it is meant in the sense that the errors from the disparate sources have similar outward appearance in the way that navigators encounter and recover from them.

The answer to question 1 is: yes. Therefore, preventing and mitigating errors is one method of improving the time performance of a navigator. Additionally, doing so may prevent such feelings as “annoying”, “frustrating” and “stressful”.

To answer question 2: various errors had different recovery tactics, and each error often had more than one recovery tactic. However, there were only seven distinct tactics used over all 10 errors. The two most common tactics were backtracking to a known point and exploring the surrounding area to gain more information. This information is useful as it can improve the training of navigation and help inform the design and creation of new navigation aids.

The answer to question 3 is: somewhat. Some errors have analogous effects on navigators, despite different sources. Specifically:

- MNP, MPNC, NWP and ND errors are superficially similar.
- NMEC and NDM errors are superficially similar.
- NCH and ERC errors are superficially similar.

From these observations the overall complexity of the host of navigation errors can be reduced to fewer cases with comparable effects.

7.3.4.1 ErrorCheck

ErrorCheck is the system resulting from the navigation error study. The function of ErrorCheck is to prevent a navigator from making navigation errors by monitoring their walking style and the directions they are facing. This is implemented by monitoring an accelerometer and compass in a mobile phone. These signals are then fed through a Support Vector Machine (SVM) that has been trained to recognise the walking style and directions associated with the individual types of navigation errors, as found from the previous study. Accelerometer and compass data is grouped in blocks 2 seconds long. The differences from the regular walking data is then found, averaged out and fed into the a different SVM for each 2 second block that checks a specific block of time before the error, up to 20 seconds before. If an error is found with high enough probability it will cause an audio or tactile output, which will be given at a suitable time that is relevant to that error. Over time the list of predicted errors lose a part of the probability if the error is not predicted again. If it is predicted again then the error has some amount of probability added on. At the appropriate time and at the appropriate probability cut-off for a specific type of error the output will be given for this type of error. The navigator is not notified of the errors immediately to allow ErrorCheck to build up an assurance that a predicted error will actually happen, so that the false-positive rate is lowered.

MNPJ, MPNC, MNP are all grouped together to produce the same output under the same probability and time conditions. This to reduce the cognitive load on the navigator and was justified as they all have very similar natures (essentially a piece of the map looks like it does not connect but in reality it does) and have the same recovery tactic. Their probability before they can be output is in the middle and they will be output far in advance. This is because although they cause long delays they

incite only a low negative emotional feeling. It is important to try to output them far in advance to allow the user to not waste so much time.

MFM is not grouped with any other error. Although seemingly similar to MNPJ, MPNC and MNP errors, MFM errors are based on point features and not linear features. The negative emotional feelings associated with MFM are more pronounced than the other map-based errors and the delay is moderate as well. The navigator should be notified of MFM errors almost directly before the error and with quite a low probability.

NMEC and NDM errors are grouped together to produce the same output under the same probability and time conditions. This is because they both share the same recovery strategy and it is important to reduce the number of errors and recovery strategies to allow a navigator to recall them all. Their probability before they can be output is low and they will be output close to the error, but not almost directly at it. This is because these errors have a high delay and negative emotional feeling associated with them, so the probability should be low.

ND and NWP errors are very serious. They can cause long delays and very negative emotions. It is best to avoid getting into this situation all together rather than having to resort to recovery tactics. Therefore it is best to output notification of these two errors as early as possible on a low-to-moderate amount of evidence.

On the other hand, both ERC and NCH errors are quite mild in both delay and negative emotion. These errors have the same recovery tactics and general appearance. Outputting false-positives can be more delaying and upsetting than actually encountering the error. Therefore, it is vital that the navigator is only informed of the error when he/she is almost at the error and with high confidence.

Non-speech audio or tactile outputs were selected, as the navigator should not be disturbed during navigation. Navigators will also be allowed to enjoy and learn about the environment, as they are not looking at the screen, as with visual aids. Due to the combination of similar errors there are only 8 audio/tactile messages that are needed to communicate effectively with the navigator. This reduces the cognitive load on the navigator. These 8 messages were further divided into 2 groups based on their use – either hints or imperatives.

There are hints to notify the navigator that he/she is about to encounter:

- MPNJ, MPNC, MNP errors (missing path)
- MFM errors (missing feature)
- NMEC and NDM errors (check environment)

The imperatives tell the navigator to do something, specifically a recovery tactic:

- Go explore, which follows MNPJ, MPNC, MNP and MFM errors (explore)
- Take care, which can follow NMEC and NDM errors (take care)
- Backtrack, which can follow NMEC and NDM errors (backtrack)

- Get phone map out or another navigation aid, which occurs when an ND and NWP error is encountered (map out)
- Do not delay, which occurs when an ERC or NCH error is encountered (no delay)

Additionally, the volume of the signal is based on how close to the error the output occurred and the pitch is adjusted based how much above the threshold the probability of the error is.

Table 13 shows how these audio/tactile output messages sound/feel. Each message was intended to be metaphorical so that navigators could easily associate the message with the appropriate hint or imperative.

Table 13 A table of the multimodal cues used for the determined error types and issues a navigator may encounter.

Hint/imperative	Structure and sound/feel
Missing path	Smorzando – to enforce that there is something missing. Narrowing outward – to show that it is a path, as in visually.
Missing feature	Smorzando – to enforce that there is something missing. Widening – to show that there is something large missing.
Check environment	Glissando misterioso – to show mystery. Low strings and wind chimes, sustained cellos, shimmery piano. 3D circling head – to enforce exploration.
Explore	Primo scherzo ma non troppo – to get the user to be more attentive. Subito lento – to make the user more serious about their surroundings now.
Take care	Pesante – to give the meaning of methodical, be conscious of what you are doing.
Backtrack	Retrograde – to enforce the message of 'backtrack'.
Map out	Staccato con forza – to tell the user how important this is. Sliding, clicking – to give the message that they need to take their phone out.
No delay	Primo amabile staccato – to show that this error is minor and that what the user will be thinking will be minor. Accelerando crescendo – to give the message that the user should speed

7.3.5 Guidelines for D1.4

The take-home messages are that:

- Low-level navigation errors exist and can be identified by a human coder;
- Navigation errors have three causes, which are the basis for the taxonomy, these are – map, navigator and environment;
- These errors come in various forms, with a difference in delays and negative feelings;
- Each error has one or more tactics for recovery from the error;
- These errors may be predicted with some certainty;
- Researchers should take navigation errors into account when designing novel navigation aids or augmenting existing navigation aids;

The remaining work to do is:

- To discover if these errors exist to the same degree in other environments;
- To find out if there are more kinds of errors;
- To investigate suitable methods to output the errors to the navigator;

7.3.6 Proposed Toolkit HCI Modules

No HCI modules would arise from this work. The sounds/tactile messages are simple to implement.

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7.4 A Study of Context Sensing Using Signal Analysis

Section 2.4 of D1.1 indicates that different *use situations* require different features to be brought to the attention of a mobile device. This is backed up in the survey studies of D1.1 chapter 3 and during the initial studies, particularly the Hiker and Biker cases. One major way in which information can be filtered for presentation to the mobile device user is by *context sensing*. With the inclusion of accelerometer, gyroscopic and GPS positioning sensors in all smart phone devices it is possible to use information, obtained from internal (or external) sensors about the user's current activity, to make a good estimate of their behavioural context and hence filter information. One of the vital conclusions drawn in chapter 6 of D1.1 is that all information presented to the user must be accurate. To accurately work out the context of the device user based on a few sensor signals requires a sophisticated signal processing algorithm. In the research presented in this section we present such an algorithm and demonstrate that it is extremely robust and accurate even when using minimal sensor input. This section also describes the advances made in our techniques, in terms of applicability, robustness and speed, since the initial work was presented in D2.1

7.4.1 State of The Art

As progress in the hardware, sensors and communication technique, commodity priced products portable handheld computers such as mobile phones are becoming popular. Mobile phones are often carried with people nearly everywhere they go, and people generally keep them functioning and charged. However there is still a dearth of software to meet the potential of these devices. Greater use of and access to contextual information, context sensitive services/applications, will considerably enhance the uptake of mobile computing.

Contextual information in this setting includes spatial location and temporal information about the user. The current physical activity of the user is one of the most significant pieces of contextual information. There has been an increasing interest in recognising human activity from accelerometer readings. In order to do this, effective algorithms are required to interpret the accelerometer data in the context of different activities (Mathie et al. 2004, Aminian and Najafi 2004). Particularly these algorithms should be efficient enough to be implemented on mobile devices where the computational resources are limited.

Activity recognition is normally formulated as a multi-class classification problem. An activity classification application includes two stages: a) building a classifier, and b) implementing the trained classifier. Key components thus include algorithms for feature selection and for classifier training.

Feature selection is of considerable importance in classification (Blum and Langley 1997, Gheyas and Smith 2010). A number of different techniques, of varying complexity, have been used to select appropriate features for classification. Guyon and Elissee classify existing feature selection methods into three types: Filter, Wrapper and Embedded methods (Guyon and Elissee 2003).

Filter methods select features in a preprocessing step independent of the chosen classifier. Example filter methods include t-test (Hua et al. 2008), chi-square test (Jin et al. 2006), mutual information (Peng et al. 2005, Brown 2009), Pearson correlation coefficients (Biesiada and Duch 2008) and principal component analysis (Rocchi et al. 2004). Filter methods are generally computationally cheap, but often not very effective.

Wrapper algorithms, for example Recursive Feature Elimination for Support Vector Machine (RFE-SVM) (Guyon et al. 2002), explore the feature space to score feature subsets (rather than individual features) according to their classification accuracy, optimising the subsequent induction algorithm that uses the respective subset for classification. Although often provide more accurate results than filter methods, existing wrapper methods are computationally demanding and not suitable for mobile device.

Embedded methods perform feature selection as part of the training process of the classifier. For example, Miranda et al (2005) (Miranda et al. 2005) added an extra term to the standard cost function of SVM that penalises the size of the selected feature subset, and optimised the new objective function to select features. However these approaches are limited to linear SVMs. Existing embedded methods involve training of classifiers initially with all the candidate features as the inputs. This is a computationally demanding process and difficult to implement in mobile devices.

Support vector machine (SVM) is employed as the classifier in this research due to its advantage of good generalisation ability (Vapnik 1982). Conventionally, constructing an SVM involves a constrained quadratic programming (QP) problem, of which the dual problem is formulated using Lagrange multipliers (Burges 1997). This Lagrange reformulation makes it straightforward to generalize SVMs to nonlinear cases. A QP tool is needed to solve normally the dual for the Lagrange multipliers that stand for the SVM coefficients. As the number of Lagrange multipliers is generally very large, which equals to the number of training patterns, large amount of memory is required.

Chunking (decomposition) algorithms reduce the memory requirement by using only a subset of the variables as a working set and solve for them while freezing the other variables. This just postpones the underlying problem of dealing with large sets of variables/patterns when the dot-product matrix of the training patterns cannot be suitably kept in memory. Sequential minimal optimization (SMO) (Platt 1998) puts chunking to the extreme case with the working set only of two patterns. In this extreme case, the closed-form analytic solution to the corresponding two Lagrange multipliers is available. In this research, we tested LIBSVM (Chang and Lin) and SVM^{Light} (Joachims 1999), two well-known SVM toolkits respective based on chunking and SMO, on a HP iPAQ personal data assistant (PDA). These methods may take several hours to approach a solution in some cases for activity classification problems with a few thousands of training patterns. This means the user needs to wait for several hours to update the classifier. More efficient algorithm is therefore desirable.

In (Chapelle 2007) it is show that when the goal is to find an approximate solution, primal optimisation is superior because it is more focused on minimizing what we are interested in the primal objective function. Motivated by this, a Newton method is applied to the primal problem for both linear and nonlinear cases. For the nonlinear case, the optimal solution to the SVM is expressed

in a linear combination of the kernel functions evaluated in all the training points based on the *representer theorem* of Kimeldorf and Wahba 1970. Given this linear combination solution, and using the representing property of the kernel, the problem is thus converted into optimising the linear coefficients in the combination. This requires the full kernel matrix to be invertible (positive definite) (Chapelle 2007).

A feature selection algorithm and an SVM training algorithm are proposed in this research. Both can be implemented on mobile devices and overcome the drawbacks of existing methods.

7.4.2 Study Description

Acceleration-based recognition of the physical activity of mobile device users was studied as part of work package 2. Acceleration signals are read from accelerometer(s) built-in the mobile device or external accelerometers mounted on some parts of the user's body and connected to the mobile device via Bluetooth.

Activity recognition is formulated as a multi-class classification problem and an SVM is employed as the classifier. Consideration is given to the fact that different users may generate different signal patterns for a particular activity, for example, the acceleration signals of disabled people could be quite different from that of the general population. It is difficult to build a classifier that works well for all range of users. Even if it existed, such a classifier would be too complex to be implemented in a mobile device. Calibration of the classifier using customised acceleration data for one or a few users can undoubtedly reduce the computational complexity of the classifier.

7.4.3 Research Questions

The key task of this research is to develop effective and efficient algorithms for feature subset selection, and SVM classifier training, given that mobile devices normally have limited computational resources available.

Feature selection algorithm aims to select a small and informative subset of features for input to the classifier. Small subset of input signals normally yields computationally simple classifiers, and this is very desirable/necessary for mobile devices where computational resources are limited. SVM classifier training algorithm aims to produce SVMs using a selected subset of features as inputs.

Note that both the algorithms should be computationally simple enough to be implemented in mobile devices so that the classifier for activity recognition can be calibrated using the same device.

7.4.4 Study Outline

7.4.4.1 An Efficient Feature Selection Method for Mobile Devices

A feature selection method is proposed for data classification, which combines a model-based variable selection technique and a fast two-stage subset selection algorithm. The relationship between a specified (and complete) set of candidate features and the class label is modelled using a full regression model which is linear-in-the-parameters. The term set included in the model is polynomials of the candidate features. That is each term is a linear or nonlinear function of one or a

few candidate features. The performance of a sub-model measured in SSE is used to score the informativeness of the subset of features involved in the sub-model.

A fast two-stage subset selection algorithm is used to search for a solution sub-model. In the first stage, an initial sub-model is produced using a fast sequential forward selection procedure. In the second stage the initial sub-model is refined by a procedure that combines a fast sequential backward selection. An insignificant term (denoted by T_s) in the sub-model is replaced by the most significant term (denoted by T_u) of the unselected terms, if $\Delta E(T_s) < \Delta E(T_u)$ holds, where $\Delta E(\cdot)$ is used to measure the significance of term ' \cdot ', which is the reduction of the SSE due to the term being selected into the sub-model while all other selected terms (except T_s) unchanged. This sub-model refining process is iterated until the SSE of the sub-model approaches a local minimum. The features involved in the locally optimal solution sub-model are selected as inputs to SVMs for data classification.

This algorithm is memory efficient, the memory requirement is independent of the number of training patterns. This property makes this method suitable for applications executed in platforms where physical RAM memory is limited.

7.4.4.2 Building SVMs in The Context of Regularized Least-Squares

(Note: a full mathematical description of the algorithms has been submitted to the Journal of IEEE Transactions on Neural Networks and is currently under review.)

SVM with linear kernels for classification problems is formulated as a regularized least-squares (RLS) problem:

$$\min_{\mathbf{w}, b} J(\mathbf{w}, b) = \mathbf{w}^T \mathbf{w} + C \sum_{k=1}^N \max(1 - y_k(\mathbf{x}_k \mathbf{w} + b), 0)^2,$$

where $C > 0$ is a penalty parameter for classification errors, \mathbf{x}_k and y_k the k 'th training pattern and the associated pattern label of a given set of labelled training patterns, respectively, N the size of the training set, \mathbf{w} and b the normal vector and perpendicular to the hyperplane separating boundary.

The solution to the RLS problem is represented as an equation with regard to the error vector and a set of indicator variables that depends on the errors. Partitioning the training pattern set and the associated pattern labels into two parts as $\mathbf{X} = [\mathbf{X}_s^T, \mathbf{X}_0^T]^T$, $\mathbf{y} = [\mathbf{y}_s^T, \mathbf{y}_0^T]^T$, results in the solution SVM with linear kernel with the coefficients $\mathbf{?}$ and b given by

$$\begin{cases} \mathbf{?} = \mathbf{Y}_s (C^{-1} \mathbf{I}_s + \mathbf{X}_s \mathbf{X}_s^T)^{-1} (\mathbf{y}_s - b \mathbf{1}_s) \\ b = \frac{\mathbf{1}_s^T (C^{-1} \mathbf{I}_s + \mathbf{X}_s \mathbf{X}_s^T)^{-1} \mathbf{y}_s}{\mathbf{1}_s^T (C^{-1} \mathbf{I}_s + \mathbf{X}_s \mathbf{X}_s^T)^{-1} \mathbf{1}_s} \end{cases}$$

The linear SVM separating boundary is hyperplane $y = \mathbf{x} \mathbf{X}_s^T \mathbf{Y}_s \mathbf{?} + b$ with the normal vector $\mathbf{w} = \mathbf{X}_s^T \mathbf{Y}_s \mathbf{?}$, where \mathbf{x} is a row vector representing a pattern to be classified by the SVM, \mathbf{X}_s is the support vectors with each row for a support vector/pattern and column \mathbf{y}_s collects the corresponding pattern labels, \mathbf{X}_0 and \mathbf{y}_0 respectively collect the other patterns and labels.

Note that patterns presenting in the solution only in the form of inner product: $\mathbf{x} \mathbf{X}_s^T$ in the hyperplane equation is the inner products of \mathbf{x} and the support patterns, $\mathbf{X}_s \mathbf{X}_s^T$ the pair-wise inner

product matrix of the support patterns. It is natural to generalise the solution to nonlinear cases simply by replacing the inner product of any two patterns, say \mathbf{x}_i and \mathbf{x}_s , using a kernel function as $\mathbf{x}_i \mathbf{x}_s^T \leftarrow k(\mathbf{x}_i, \mathbf{x}_s)$. For example, the polynomial kernel of degree d and offset γ is given by $k(\mathbf{x}_i, \mathbf{x}_s) = (\mathbf{x}_i \mathbf{x}_s^T + \gamma)^d$.

To determine the support patterns, an iteration algorithm is employed: Suppose a set of support patterns \mathbf{X}_S . Compute \mathbf{w} and b and evaluate the classification errors of all the training patterns as $e_k = 1 - y_k(\mathbf{x}_k \mathbf{X}_S^T \mathbf{w} + b)$ for $k = 1, \dots, N$. Then those patterns with $e_k > 0$ are then selected to update the support pattern set \mathbf{X}_S . This process is iterated until the support pattern set keeps unchanged. Initially, the support pattern set can be all or a randomly selected subset of the training patterns.

Compared with conventional methods, this method builds SVMs merely in the context of least squares with neither making use of Lagrange multipliers, KKT conditions, duality theory and representer theorem, nor a QP solver. In addition, the full-rank assumption for the kernel matrix to be fully ranked is not required. Furthermore, it is very effective and efficient for linear SVMs, it converges using no more than 3-5 iterations in all the test cases.

Particularly, the least-squares nature of this method makes it straightforward to implement this algorithm in a sequential way by borrowing the well-studied recursive least-squares techniques. Sequential implementation requires much less memory. We employ a batch implementation in this research, which satisfies the requirement for the SVM calibration to be carried out in mobile devices.

7.4.5 Results

In this research, a set of acceleration data was recorded for three subjects. We used four Wiimotes devices to provide multiple accelerometer signals. These were mounted on the left-ankle, right-ankle, left-wrist and right-wrist, respectively. The three subjects performed three different activities: a) walking slowly, b) walking quickly and c) browsing, i.e. stopping and starting, looking around, erratic movement. Each Wiimote device contains a tri-axial accelerometer, and 12 acceleration signals were sampled synchronously at a uniform sampling rate of 100Hz.

Table 14 Used memory and running time of the two algorithms

Method	Number of features	Case 1		Case 2		Case 3		Case 4		Case 5	
		Mem.	Time (sec.)	Mem.	Time (sec.)	Mem.	Time (sec.)	Mem.	Time (sec.)	Mem.	Time (sec.)
TSM	4	6.4	1191	6.4	1201	6.4	1211	6.4	1216	149.6	1413
	8	7.4	1237	7.4	1232	7.4	1243	7.4	1241	155.5	1452
	12	8.5	1265	8.5	1264	8.5	1268	8.5	1262	161.5	1451
	16	9.5	1303	9.5	1302	9.5	1307	9.5	1304	167.4	1513
	20	10.6	1358	10.6	1354	10.6	1351	10.6	1353	173.4	1568
FOU	4	2.16	312	2.16	396	2.16	572	2.16	812	11.62	2068
	8	2.16	416	2.16	721	2.16	1554	2.16	1482	11.62	4498
	12	2.16	604	2.16	1092	2.16	3224	2.16	2551	11.62	6092
	16	2.16	910	2.16	2450	2.16	3392	2.16	2880	11.62	7392
	20	2.17	1775	2.17	2704	2.17	3087	2.17	4320	11.62	10166

Table 15 SVMs training using the selected features by the two algorithms

Method	Number of features	Case 1		Case 2		Case 3		Case 4		Case 5	
		#SV	Prec. (%)	#SV	Prec. (%)	#SV	Prec. (%)	#SV	Prec. (%)	#SV	Prec. (%)
TSM	4	687	81.52	625	81.26	515	80.91	368	80.10	432	80.91
	8	641	90.26	557	90.17	475	89.28	327	89.18	417	90.25
	12	519	99.56	467	99.87	388	98.93	249	98.98	331	99.94
	16	514	99.61	449	99.87	372	99.15	225	99.18	312	99.95
	20	515	99.66	432	99.88	366	99.17	224	99.28	307	99.98
FOU	4	1807	83.35	2188	79.25	2698	76.38	2230	78.88	1895	83.16
	8	1410	90.78	1865	86.26	2590	78.43	2098	84.09	1708	87.88
	12	1519	90.78	1980	87.28	2395	83.98	2144	85.88	1695	90.02
	16	1545	92.39	1913	88.22	2191	87.36	2042	87.31	1348	95.35
	20	1557	92.98	1932	88.58	2134	89.15	2026	88.30	1288	96.85

A sliding window is applied on the acceleration signals, producing signal segments of 256 signal samples for feature extraction. We defined 186 candidate features, which are extracted from the 12 acceleration signals, including 66 axes correlations (there are 66 possible pairs from the 12 accelerations). From the recorded acceleration data, 15819 patterns (each of which includes 186 candidate features) are extracted and labeled for use in this project for test purposes. All the following tests are performed on a HP iPAQ personal data assistant (PDA).

The two-stage feature selection algorithm (TSM) is used to select subsets of 4 to 20 features from the candidate features for five different sensor configurations, referred to as cases 1 to 5 respectively. For cases 1 to 4, one accelerometer is used mounted, firstly on the left-ankle, then the right-ankle, the left-wrist and finally the right-wrist. Only 3 axes-correlation features (of the 3 accelerations of the involved accelerometer) are available, and the total number of candidate features is 33. For case 5, all the 4 accelerometers are used, and there are 186 candidate features for the 12 accelerations. An information gain based feature selection method (Brown 2009) is used as a comparison. This algorithm defined the first-order utility (FOU) as the scoring criterion, which takes the first-order (pairwise) interaction information into account.

The memory usage and the running time of both the algorithms for the five cases are compiled in Table 14, where the memory used by TSM is in kB, while that by FOU is in MB. The numbers of support vectors (#SV) and prediction precision of the trained SVMs using the selected features by the two algorithms are compiled in

Table 15. The SVMs are trained using LibSVM (Chang and Lin) with a training data set of 5421 points (1/3 of the full data set). The number of support vectors indicates the sparseness and the complexity of an SVM. Prediction precision of an SVM is the percentage of the patterns out of the 15819 ones that are correctly predicted by the SVM.

The proposed SVM training algorithm (RLSSVM) is tested for linear SVMs with the 16 features selected by TSM in case 5, i.e. with all the four accelerometers. One third of the data, i.e. 5164 patterns, are used for SVM training. The trained SVMs are then tested on all the 15819 patterns. The prediction precision and running time of RLSSVM is compared with that of LSVM (Mangasarian and Musicant 2001) and Liblinear (Fan et al. 2008) in Table 16 and Table 17, for different settings of the penalty parameter C .

Table 16 Predict precision (%) of the three algorithms

	C=0.001	C=0.01	C=0.1	C=1	C=10	C=100	C=1000
RLSSVM	89.58	90.23	90.30	90.38	90.36	90.36	90.36
LSVM	66.66	67.22	71.29	80.55	86.13	88.58	89.50
Liblinear	89.90	90.29	90.38	90.36	90.61	88.69	75.11

Table 17 Running time (seconds) of the three algorithms

	C=0.001	C=0.01	C=0.1	C=1	C=10	C=100	C=1000
RLSSVM	0.905	0.998	0.818	0.725	1.177	0.812	0.812
LSVM	0.452	0.452	0.452	5.620	9.245	11.873	20.300
Liblinear	0.812	1.630	10.602	25.288	28.913	33.710	34.980

7.4.6 Discussion

It is also shown in Table 14 and

Table 15 that, in all the cases, TSM produces sparser SVMs than the FOU algorithm. SVMs produced by TSM have only 1/3 to 1/4 SVs of that produced by the FOU algorithm. However, SVMs produced by TSM have significantly higher prediction precision than that produced by the FOU algorithm, except for a very few cases, particularly where the more features are selected. FOU needs to store all the quantised patterns (integer valued) to generate high-dimensional joint frequency tables. Otherwise frequent data swapping between RAM and external storage (e.g. hard disk or flash memory card) of smart device becomes very time consuming. Compared with FOU, TSM requires much less memory; the memory requirement of TSM is independent of the number of samples. The running time for TSM to achieve a subset of feature is 20 to 25 minutes.

As shown in Table 16, for linear SVMs with 16 data features as the inputs, the three algorithms, RLSSVM, LSVM and Liblinear, can achieve 90% correctness of prediction for the 15819 points of test data. For different settings of parameter C , RLSSVM achieves nearly the same predict precision. However the predict precision of LSVM increases as C increasing, in contrast Liblinear decreases as C . Table 17 shows that the running times of both LSVM and Liblinear varies as C changes, while the running time of RLSSVM has not significant changes (about 1 seconds).

7.4.7 Guidelines for D1.4

Users should ideally have access to a device that has one or more accelerometer sensors. The default classifier for user activity recognition that is shipped with the software package is preset with general data for three tasks described in this section. By connecting the classifier with one or more accelerometer sensors, the current activity of the user can be classified in terms of these default activities from the accelerometer readings. The built-in classifier can later be calibrated using customised acceleration data to meet the needs of the user.

7.4.8 Proposed Toolkit HCI Modules

The HCI module for activity recognition will include the following fundamental functions.

Signal buffering and segmentation function provides a connection between sensors and feature extractor. It reads data from any hardware supported by the toolkit core (providing a device independent interface) e.g. the built-in and external accelerometers, location sensors etc. The acceleration signal segments are passed to the feature extractor.

Feature extractor extracts specified features from acceleration signal segments. It can extract time-domain statistic features including axes-pair correlation, and frequency-domain features. Extracted features are passed to a classifier for activity classification or to the feature selection function for feature selection.

Feature selection function selects an informative subset from all the features available from the feature extractor. The selected subset of features is passed to the classifier training function to produce new customised classifiers or calibrate the default classifier.

Classifier training function uses a selected subset of features and a set of labelled patterns to produce a classifier. SVM is employed as the classifier in this research.

Classifier activating function connects a specified classifier and a signal source (i.e. one or more accelerometer sensors) via the signal buffering and segmentation function. The connected classifier is then implemented for on-line activity recognition and the feature extractor extracts the features selected as inputs to the classifier.

Taken together these functions will comprise a mantle module in the toolkit with a simple interface that application developers can call on to adapt the behaviour of their application and its user

interface to the user's current activity. For example, displaying footpaths when walking or building information when touring a city.

The expected use of this research is as a module of functions in the toolkit mantle. The theory outlined above gives us an advantage over any other method of context sensing because not only it is a very efficient discriminant, but it is also a very efficient implementation in terms of memory requirements, and thus it is most amenable to use in smart phones.

The experiments conducted using 4 Wiimotes indicated that even a single accelerometer, appropriately placed, can make robust and accurate determinations of activity, and hence offer a good indicator of the context in which the device is being used. The role of the Wiimotes within the research were that they provided a cheap, simple sensor pack, with technologies similar in quality to those found in current mobile smart phones. These have allowed rapid prototyping and investigation in a cheap way to explore the sensor space.

The toolkit mantle module (implementing a single accelerometer version of system) will be used in applications such as a phone app to aid in evaluating the energy expenditure of athletes in training and the calorie consumption of members of the general public "out for a bit of a jog". This is illustrated in our iPod/iPhone app depicted in Figure 85.

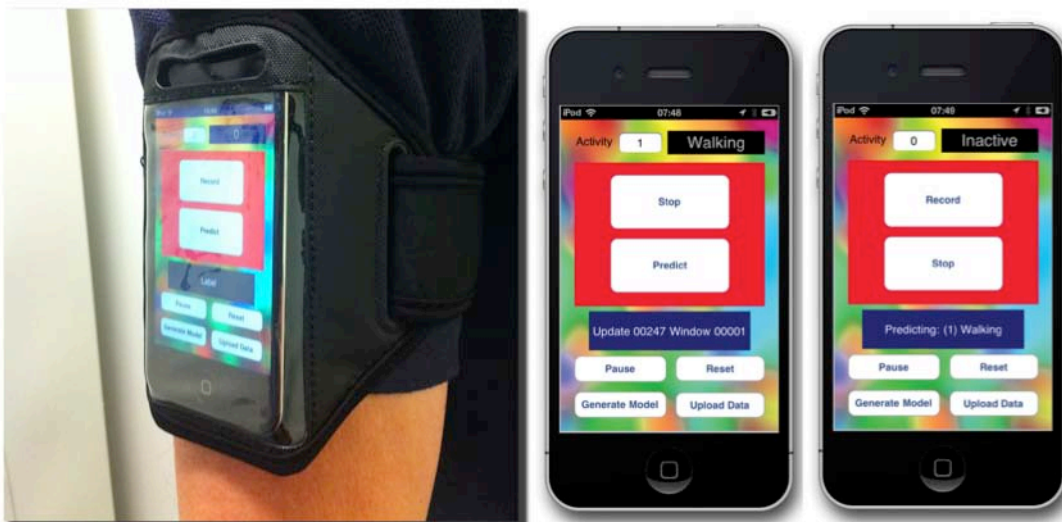


Figure 85: Example iPod/iPhone App using context sensing to classify activities such as running, jogging and power walking.

In this application the mobile device is worn in a holder on the upper arm. The users can train the device to recognise any number of activities. (e.g. walking, walking fast, jogging, or resting) these activities have well known energy consumption equivalents and after performing a programme of mixed activities the user can read off the device the total energy expended. (This work is to be presented at PERMOBY 2012.)

The mantle module is composed of two basic library functions (written in ansi C and usable on any Linux, IOS or Android mobile device.)

The first function will use the signal from any attached accelerometers to train the classifier algorithm to recognise the activities chosen by the user. The second function will use the signals from any attached accelerometers (and the parameters of the trained model) to classify the activity into one of the categories it has been trained to recognise.

The functions take a number of arguments that govern the behaviour of the model, for example the sampling rate and window size. The toolkit documentation will give developers information about how best to choose the model settings for their specific applications.

7.4.9 References

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8 Task 2.4 – Hardware Interfaces

8.1 Executive Summary

Task 2.4 targets the development of novel hardware interfaces to present geographical information. In consequence, this part of the deliverable presents the consortium's recent developments in this field. It is a follow-up of the developments and experimental results presented in D.2.1. The same three hardware interfaces, namely the refreshable tactile display, the tactile wristband and the 2DOF force-feedback platform are presented.

The first section presents the improvements of the tactile refreshable display. Some new experimental results are described and guidelines for the Haptimap demonstrators are suggested. A discussion on the applicability of this hardware device to mobile contexts and navigation are also presented.

The second section presents the recent developments of the tactile wristband. Again, experimental results and usability and application guidelines are also presented.

The third section of this part presents an experimental evaluation of the memorisation of haptic patterns presented on the 2DOF force-feedback platform, called VIFLEX.

The major achievements covered by this report can be summarized as follows:

- The tactile refreshable display based on magnetorheological fluids has been improved and assembled to form a compact surface composed of 16 individual cells. The system was connected to a graphical interface to facilitate its characterisation and feasibility evaluation. The resistance of the fluid/particle plug of a single cell for varying pressures applied was then investigated. The results show that the system is quite efficient because energy is only required to change between different states. However, further research (e.g. a PhD work) has to be done in order to improve the prototype. As WP2 is now ending, this research will not be done in the framework of Haptimap.
- The tactile wristband using Shape Memory Alloys (SMAs) as actuation technology was also improved. Two new prototypes have been developed. The first one is an optimisation of the SMA principle. Thanks to this optimisation, the some problems of the first design such as fabrication process, heating problems, and flexibility were overcome. As for the third prototype, it changed completely the wristband design. Instead of integrating the actuators directly into the wristband, we decided to decouple them, which gives us much more design space. Furthermore, the actuation technology has been changed from SMAs to electromagnetic actuators because of their large dynamic range and ease of integration. The third prototype of the tactile wristband incorporates 8 individually addressable actuators and shows very high displacement amplitudes which make it a prospective candidate for navigational tasks.

- As for the VIFLEX, it has been used in order to study the memorisation of abstract vibrational patterns transmitting geographical information. Both short-term and long-term haptic memory was tested. The results of the study on the memorisation of vibrational patterns presented on the VIFLEX are very satisfactory. Thus, around 80% of the presented patterns were correctly recalled by the majority of test participants. This tendency is observed both for short- and for long-term memory. In addition, patterns based on visual analogies (such as the roundabouts or the Y-junction) or on vibrational dynamics (such as the error message) allow better learning and recall. These results suggest a connection between visual, haptic and sensorimotor memory, which should be investigated in future studies. This study is fully reported in Section 5.5.

8.2 Tactile Refreshable Display: Recent Developments

Tactile refreshable displays were inspired from dot matrix printer technologies and Braille systems. These displays are usually divided into deformable cells called “taxels” (tactile pixels). Using the dynamics of these taxels, tactile refreshable displays are expected to display different shapes, which can be perceived and interpreted by users. A typical example of such a display for navigational applications is presented in Figure 86.

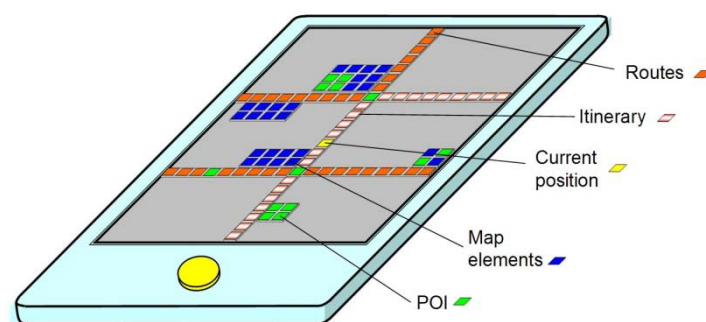


Figure 86 The concept of a tactile refreshable display for navigation tasks

Coupled to LCD screens, tactile refreshable displays can present multimodal (visual and tactile) information.

8.2.1 State of the Art

Research prototypes of tactile refreshable display based on different types of technologies have been developed. Thus, there are existing solutions based on:

- mechanical needles actuated by electromagnetic technologies such as solenoids and voice coils (e.g. Deng & Enikov, 2010; Fukuda *et al.*, 1997; Wagner, Lederman, & Howe, 2002),
- piezoelectric materials (e.g. Maucher & Meier, 2001; Pasquero & Hayward, 2003),
- shape memory alloys (SMA, e.g. Poupyrev *et al.*, 2004; Poupyrev, Nashida, & Okabe, 2007; Taylor, Moser, & Creed, 1998),
- pneumatic systems (e.g. Harrison & Hudson, 2009),

- heat-pump systems based on Peltier modules.

Other technologies such as electrorheological and magnetorheological fluids, which cause an apparent change in the viscosity under the application of an electric or magnetic field, have also been investigated (Jansen, Karrer & Borchers, 2010; Kenaley & Cutkosky, 1989; Liu *et al.*, 2005; Taylor *et al.*, 1998). Comprehensive state of the art surveys on tactile displays have been published by Benali-Khoudja *et al.* (2004) and Kwon, Yang & Cho (2010). However, the proposed solutions cannot yet reach mass production, since the assembling of different parts is time-consuming and sometimes impossible because of the small sizes of the micro-actuators. Also, the potential applications and some issues of user experience and user acceptability are not clear enough yet.

The existing prototypes generally display shapes (e.g. Deng & Enikov, 2010; Wall & Brewster, 2006), physical controls (e.g. Jansen, Karrer & Borchers, 2010), drawing surfaces (e.g. Marquardt *et al.*, 2009), flexible keyboards (e.g. Bau, Petrevski & Mackay, 2009) and geographical information (e.g. Leithinger & Ishii, 2010; Petit *et al.*, 2008). We present a prototype based on magnetorheological fluids which should be used for navigational tasks.

The concept has been introduced in D2.1. We will review some details and present some new developments below.

8.2.2 Presentation of the Concept and New Developments

The basic principle includes a pressurized magneto-rheological fluid which can inflate or deflate an elastomeric membrane placed on the top of a fluid chamber. The fluid has to be pressurized by an external micro-pump. The supply channel to the fluid chamber can be individually opened and closed using the magneto-rheological properties of the fluid. A permanent magnet forms a closed magnetic field with a surrounding armature. This magnetic field interacts with the fluid inside the supply channel and prevents the filling or draining of the chamber. Applying a current to a coil placed above the magnet counteracts the magnet's field and allows the fluid to circulate freely in order to inflate or deflate the membrane. The valve created by the fluid is normally closed in order to keep a displayed pattern without further energy supply.

Figure 87 presents the design of a single cell. A main fluid channel which is connected to the micro-pump supplies all cells. At the lower end of the cell a permanent magnet is placed to create a static magnetic field. The magnet is connected to a ferromagnetic core which is surrounded by a coil. The magnet field of the coil is strong enough to counteract the permanent magnet field. The magnetic field is closed by an armature surrounding the coil and the magnet. Finally, an elastomeric membrane is encapsulating the fluid circuit at the top level.

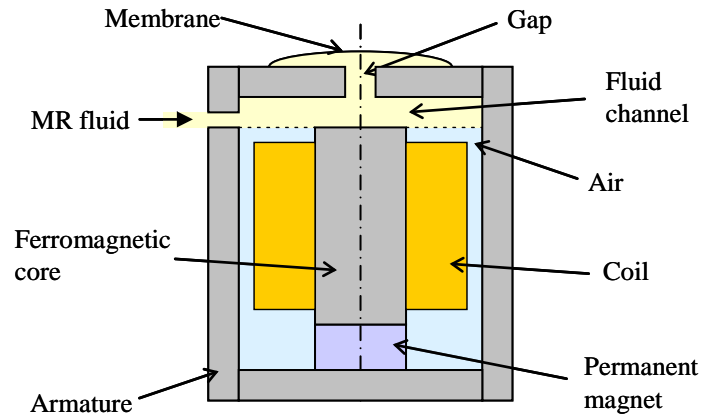


Figure 87 Design of an individual cell.

The functional principle of a single cell is shown in Figure 87. Without electric power in the coil, the magnetic field is only provided by the permanent magnet forming a plug in the supply channel in order to encapsulate the fluid chamber. The magnetic field is closed via the ferromagnetic armature (see Figure 88 (left)) forming an active volume inside the supply channel. The permanent magnet's field creates chain-like structures in the active volume increasing the apparent viscosity of the fluid. This state prevents the fluid to flow and allows maintaining the deformation of the membrane (see Figure 88 (right)) without further energy requirements.

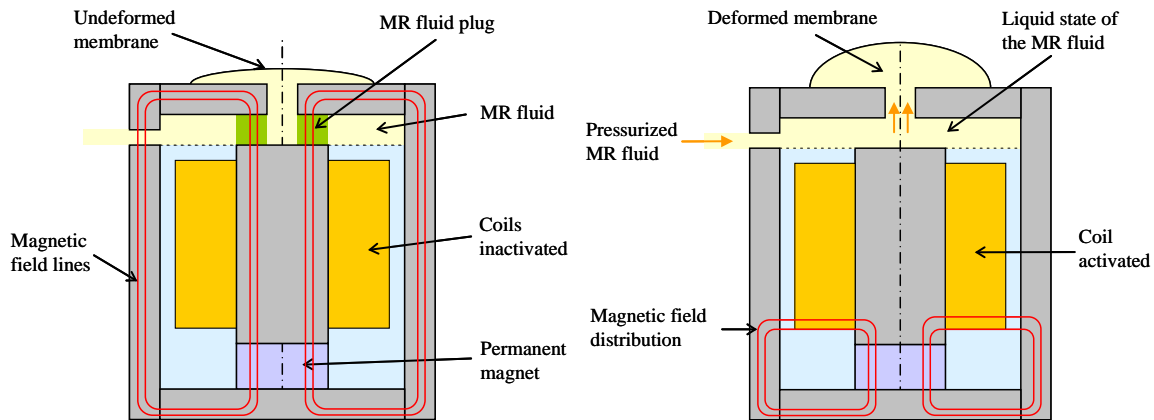


Figure 88 Drive principle of a unit cell; coil inactive (left) and active (right)

In Figure 88 (b), a current is applied to the coil counteracting the field of the magnet. The apparent viscosity of the fluid is decreased allowing free circulation in order to inflate or deflate the membrane.

Figure 89 shows the functional principle for displaying a pattern. In a all valves are closed by forming plugs with ferromagnetic particles inside the supply channels due to the field of the magnets. The application of a current to the two middle coils cancels out the permanent magnet field and allows the pressurized fluid to penetrate the fluid chamber and to inflate the elastomeric

membrane (b). Deactivation of the coils closes the valve while keeping the deformed shape of the membrane (c). At this state, the micro-pump can be deactivated as shown in d. To deflate the membrane, the coils are activated once again (e) and the fluid pressure is reversed by the micro-pump. Finally, the micro-pump can be deactivated in order to maintain the new pattern as depicted in f. The proposed system allows the generation of bumps and dimples with various displacement amplitudes.

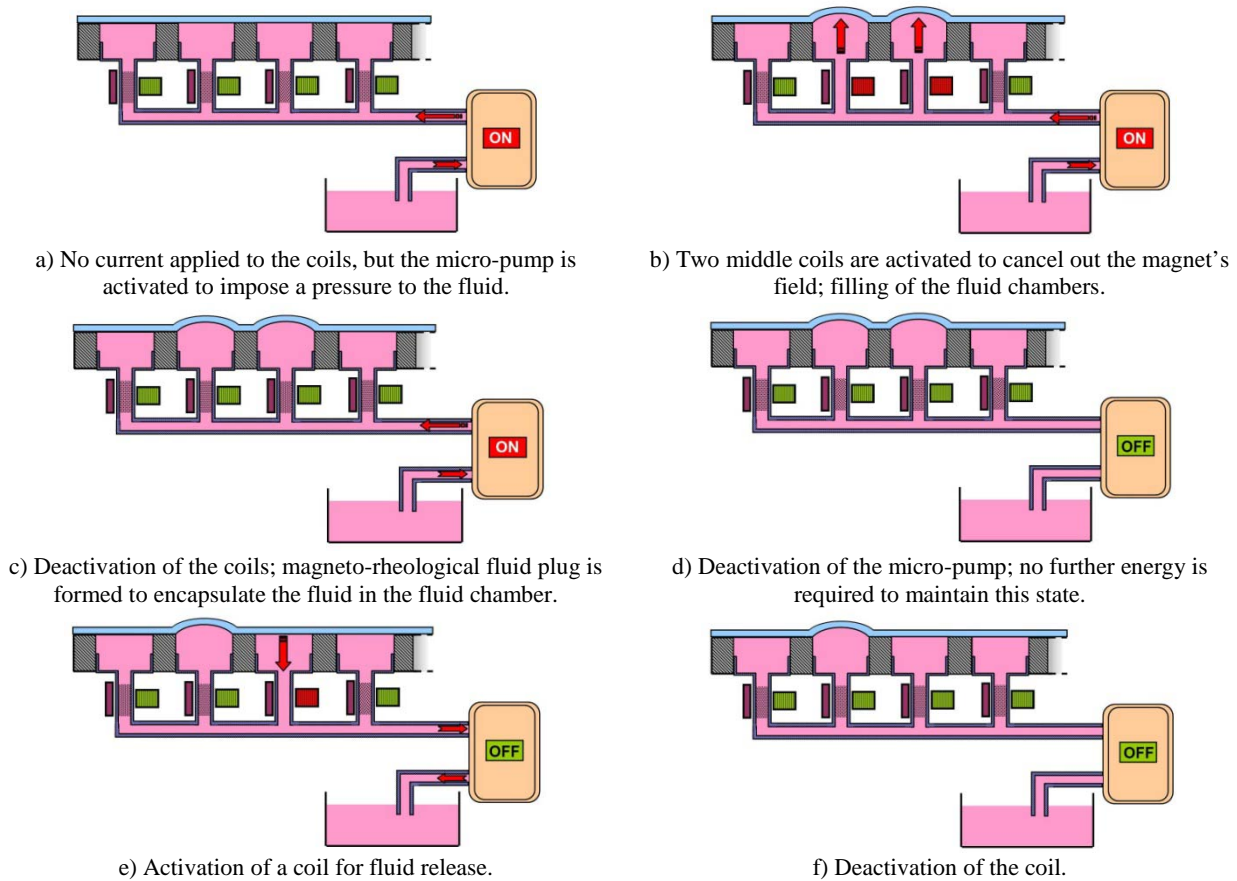


Figure 89 Schematic views of the pattern drive principle

The first realized prototype of the proposed interface includes 16 individual cells arranged in a 4x4 matrix (Figure. 90). This prototype is meant as a first concept study with the goal to investigate the systems' performance. Each cell has a diameter of 4 mm with an inter-cell spacing of 5 mm. The total interface height is 12 mm.

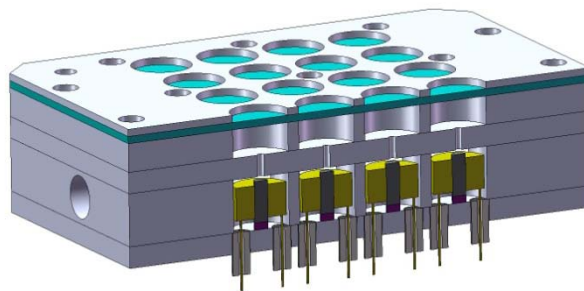


Figure 90. First prototype of the tactile refreshable screen with 16 taxels

8.2.3 Simulation

A 2D axis symmetric finite element simulation was carried out in FEMM (Finite Element Method Magnetics) for the dimensioning of the magnetic circuit. The disc magnet (diameter 1 mm, thickness 1 mm) made of Neodymium-Iron-Boron (NdFeB) has a magnetization of 1.35 T. Each coil (OD 3.8 mm, ID 1 mm, and thickness 2.3 mm) is made of 0.1 mm copper wire with 270 turns. The surrounding iron armature and the ferromagnetic core (iron) have a relative permeability of 529. In Figure 91, on the left hand side, no current is applied to the coil.

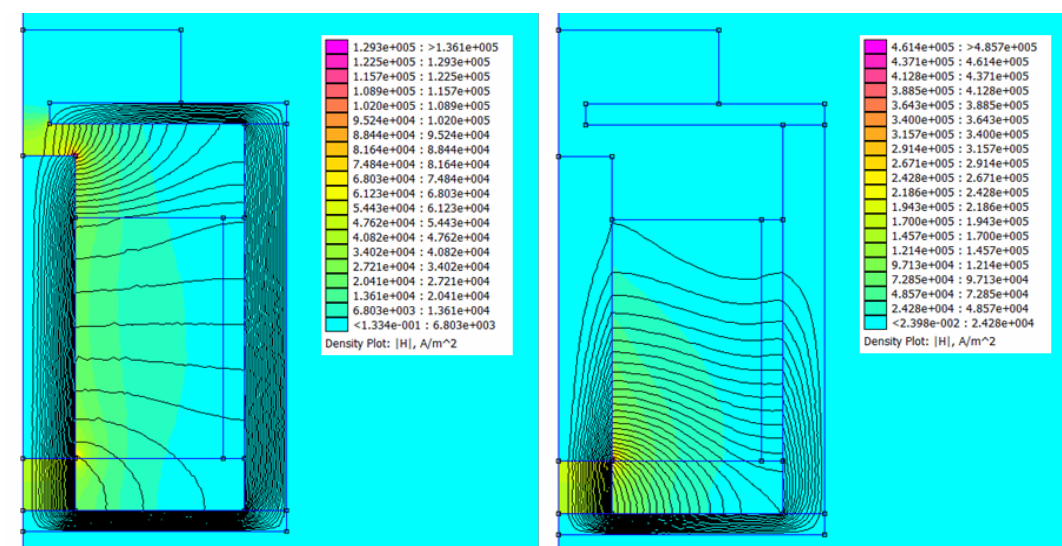


Figure 91. Simulation of the magnetic field distribution in a single cell; inactivated coil (left) and activated coil (right)

The field of the permanent magnet is closed via the armature with strong magnetic coupling effect in the gap between the ferromagnetic core and the armature. The current required to cancel out the magnet's field was determined by simply increasing the current applied to the coil.

Figure 92 shows the magnetic field inside the gap for various drive currents. At 0.3 A, the magnet's field is completely compensated. For increasing coil currents the field is inverted and reappears

inside the gap. On the right hand side in Figure 91, the magnetic field for a single cell and a drive current of 0.3 A is shown. The compensating effect can clearly be seen compared to the inactivated coil shown on the left hand side in Figure 91.

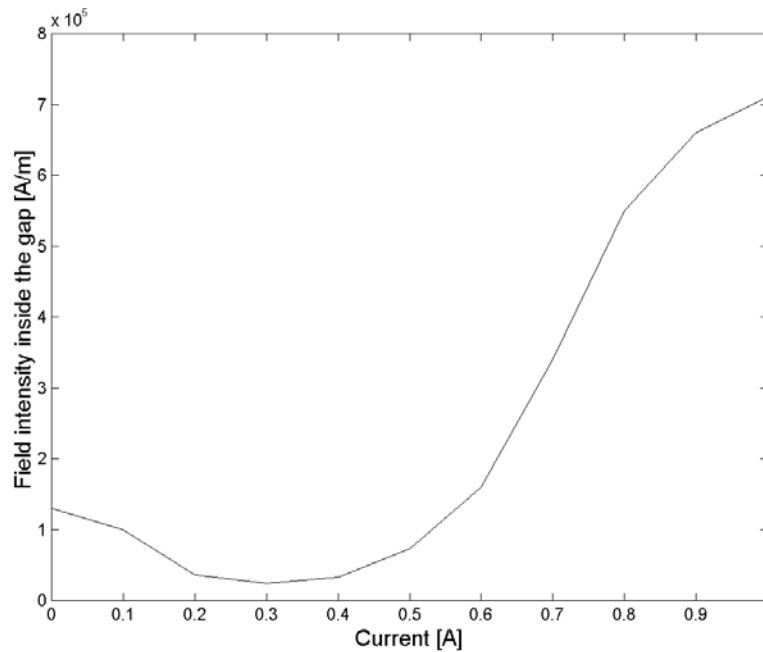


Figure 92 Simulation of the field intensity inside the gap for various drive currents

8.2.4 Fabrication and Integration

The proposed tactile refreshable interface consists of a multi-layer which were assembled to form a compact system. In D2.1, we presented a preliminary integration of a matrix of 3x3 cells. In D2.2, we present a matrix of 16 cells. The fabrication and integration process is detailed below.

At the lower end, the armature (8) made of iron accomplished with holes for the electrical connection of the coils (7) is placed as schematically shown in Figure 93. The next layer (6) serves as support for the coils and provides the side walls of the armature. The coils with hybrid magnet-iron core are placed inside this layer. Furthermore, the fluid supply channel is integrated in this layer connecting all 16 individual cells. The coils are encapsulated by a resin in order to keep in the place the fluid as shown in Figure 94. The armature is closed by another iron layer (5) with small holes accessing the fluid chamber (4) made of aluminium. The iron core inside the coils is placed exactly underneath these holes respecting a certain distance to allow the fluid filling up the fluid chamber on top. The plug is formed between the top layer of the armature and the iron core when no current is applied to the coils. Finally, the membrane (3) made of nitrile rubber is placed on top of the fluid chamber. The rubber is fixed by a thin aluminium plate (1) on its upper surface. The system is held together by screws (2).

The system was connected to a graphical interface with the goal to facilitate its characterisation and technical evaluation. For a simplified control, the coils are connected by rows and by columns reducing the number of wires significantly. Each row and column is coupled to a transistor to ensure individual addressing. The gate of each transistor is connected to a microcontroller (Silicon Laboratories C8051F020). The microcontroller can be addressed via a RS232 serial port connected to a computer. Patterns can therefore easily be programmed to be displayed on the tactile display. Figure 95 shows the complete setup.

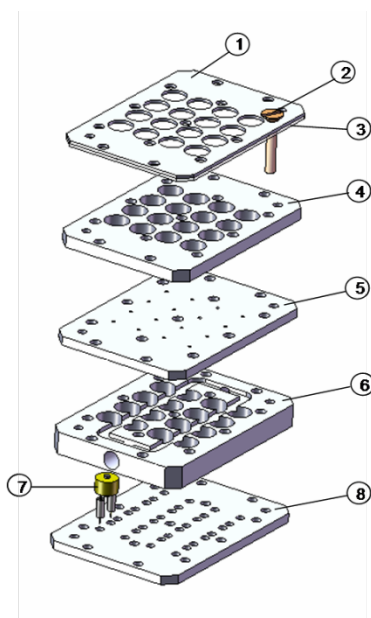


Figure 93 Assembly of the different parts.



Figure 94 Supply channel with integrated coils and ferromagnetic core and on the bottom the assembled prototype

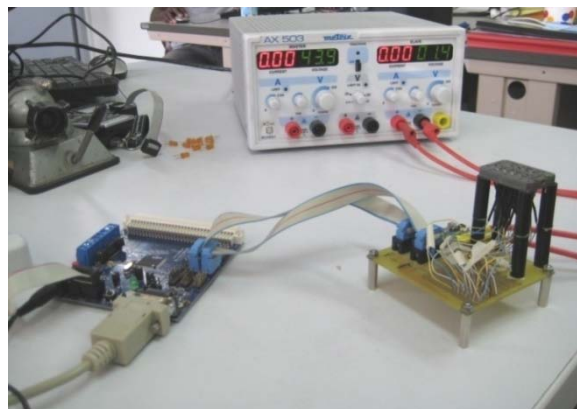


Figure 95 Tactile refreshable screen mounted on the drive electronic board and connected to a microcontroller

8.2.5 Feasibility Tests: Results and Discussion

After the final assembly a first feasibility evaluation was carried out. The device was connected to a reservoir with magneto-rheological fluid (MRF-122DG, Lord Corporation) and was set under pressure. A voltage of 1.6 V and a current of 0.3 A was applied to the coils in order to counteract the permanent magnet field. Figure 96 shows the result with 8 active taxels on the left hand side and 15 active taxels on the right hand side.



Figure 96 Eight activated taxels (on the left) and 15 activated taxels (on the right)

The resistance of the fluid/particle plug of a single cell for varying pressures applied was then investigated. First, no current was applied to the coil and the pressure was increased with time. The blue line in Figure 97 shows an exponential increase of the pressure up to 1.28 bars at 4.6 s where a fast drop in pressure was measured. At this point the plug was mechanically removed by the fluid pressure. Further tests were carried out for varying coil currents. It can be deduced from Figure 97 that the maximum pressure which can be applied to the fluid decreases with increasing coil current. The maximum pressure is 0.57 bars, 0.48 bars, and 0.19 bars for 0.05 A, 0.15 A, and 0.3 A respectively. At a coil current of 0.3 A the fluid can be considered to circulate freely.

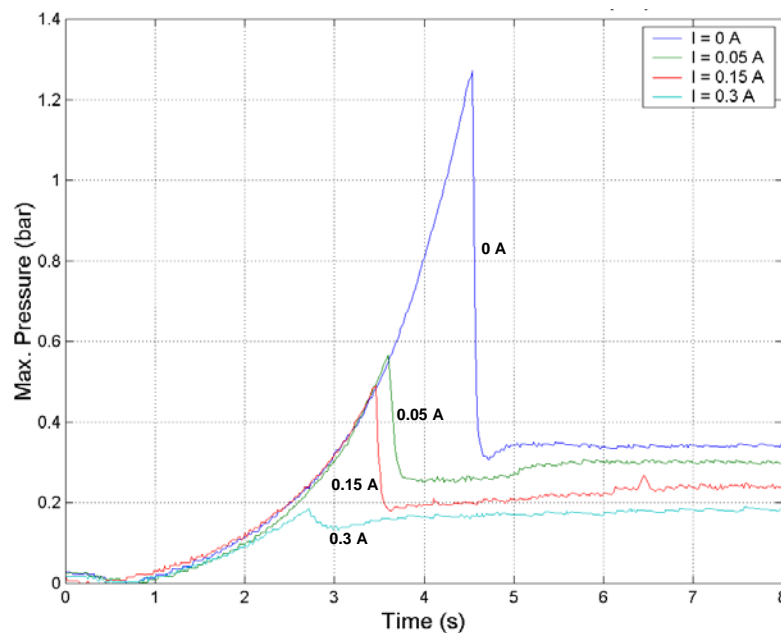


Figure 97 Resistance of the magneto-rheological fluid plug against the applied pressure for various drive currents

It is known from literature that the force induced by a finger exploring a surface is between 1.5 N and 5 N depending on the interface type. Initial work has shown that forces of 2 N to 3 N provide adequate feedback to the user for this type of tactile interface. This force represents a pressure of about 0.3 bar ($P=F/S$ where S is the contact surface of the finger tip). Taking into account a safety factor, a minimum pressure threshold of 0.75 bar has to be set for this type of interface. This is much lower than the actual pressure delivered by the system.

These results show that the system is quite efficient because energy is only required to change between different states. However, many points have to be addressed in order to provide an easy to fabricate and robust interface for navigational applications. One major technological point is the sealing of the magnetorheological fluid which is very corrosive to many materials causing leakage after some time. Other challenging points are:

- the implementation of an external micro-pump for mobile interfaces. Most pumps and fluid reservoirs are quite bulky and therefore complicated to integrate.
- Also, as the fluid contains iron particles, it is opaque and only top projection can be currently used. Research on new materials has to be done in order to obtain a thin and highly flexible display, which can substitute the currently used cover.
- It is difficult to associate the metallic particles of the magnetorheological fluids to capacitive sensing technologies.

Further research has to be done in order to improve the prototype of the tactile refreshable display. As WP2 is now ending, this research will not be done in the framework of HaptiMap. Nevertheless, some preliminary user tests of the concept will be done and results will be reported in WP1.

8.2.6 Guidelines for D1.4

Refreshable tactile displays based on magnetorheological fluids are a promising approach for displays shapes and, later, geographical information. They present the following advantages which can be used in future demonstrators:

- Particle alignment and dealignment in the magnetorheological fluid happen very quickly. Typical response times are less than 2 ms (Jansen, Karrer & Borchers, 2010). This allows to locally actuate the fluid using frequencies up to 600 Hz, which covers the full range of frequencies observed in human tactile perception. This allows a large number of varied stimulations.
- Since arbitrary waveforms can be used, a rich set of haptic textures can be presented.
- As the actuation is based on fluids, much “softer” stimulations can be achieved, compared to the ones achieved using classical mechanical actuation.

However, as mentioned earlier and shown in the preliminary feasibility tests, the technological is not mature enough yet and it cannot be directly used in the demonstrators developed in Haptimap.

8.3 Tactile Wristband: Recent Developments

An approach to convey directional information in both a direct and an unobtrusive way is the use of body-based interfaces such as tactile belts, vests or wristbands. During the Haptimap project, we were developing a wristband-type tactile display incorporating Shape Memory Alloy (SMA) actuators. The concept has already been presented in D.2.1. In this section we begin by reviewing the concept and then proceed to present some improvements and recent developments.

SMA actuators exhibit outstanding actuation characteristics in terms of strain and applied stress. SMAs “remember” their martensitic (cold-forged) state when heated after deformation. This fact allows a deformed SMA wire to undergo large deformation when heated.

8.3.1 Presentation of the Concept and New Developments

When applied to a tactile wristband, the geometry has to insure a deformed state of normally straight wires in the martensitic state. Upon heating the bent wires become straight again while inducing stress to the surrounding structure. Figure 98 shows the implementation of such wires in a tactile wristband.

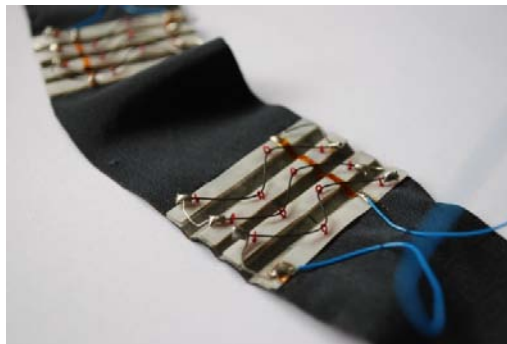


Figure 98 The initial tactile bracelet

Three wires are arranged in parallel and connected in series. An applied current heats up the wire until the phase transition takes place. This phase transition reduced the actuator length and therefore the total length of the wristband. An accordion-like structure placed underneath the actuator applies directional forces to the skin. The characterization of a first prototype has proven the effectiveness of the system in terms of deformation. Figure 99 shows the complete setup with drive electronics, battery for mobile use and Bluetooth interface.

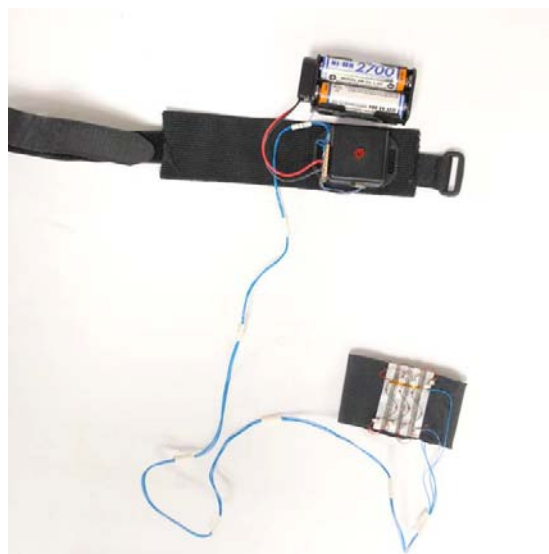


Figure 99 Complete wristband with supply electronics and Bluetooth interface

Based on the technology of the first tactile wristband prototype, an optimized device has been proposed to overcome some limitations of the first design (e.g. fabrication process, heating problems, flexibility). These improvements are presented below.

First, the fabrication process has been improved by implementing a monolithic flexible support structure for the SMA wires (see Figure 100). Moreover, this support structure reduces the heat transport from the wires to the skin.



Figure 100 Second prototype of a tactile wristband with SMA actuators integrated into a monolithic structure

In a second step, the connections to the wires have been changed with mechanical connections because the soldering connection of the first prototype did not support the high flexibility of the system. The wristband can now be adapted to various arm sizes ensuring optimal contact between the actuators and the skin. The characterisation of the system under real conditions and if worn on the forearm has shown that the mechanical constraints to keep the wristband in place are too important to be overcome by the SMA wires. Improvement could be achieved by decoupling the actuator from the wristband. However, we think this is not a relevant alternative to other actuation technologies, having in mind the low dynamic range of thermally driven actuators.

Based on the insight gained during the development process of the first two prototypes, a third approach has been proposed. It changed completely the wristband design. Instead of integrating the actuators directly into the wristband, we decided to decouple them, which gives us much more design space. Furthermore, the actuation technology has been changed from SMAs to electromagnetic actuators because of their large dynamic range and ease of integration.

As shown in Figure 101 the new geometry resembles a compass with eight individual actuators which can stimulate the skin by vibration and thus display various more complex patterns.

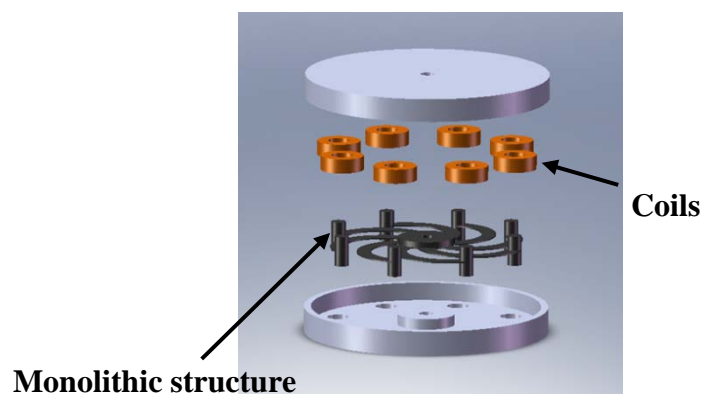


Figure 101 New actuator concept

The tactile device consists of a monolithic structure of eight cantilever bars. Permanent magnets are stuck on one of the sides of each extremity. A tactile stimulator is stuck on the other side of the extremity (see Figure 102). The magnets are interacting with the coils in order to displace the cantilever beams. Since the system is normally decoupled from the human body and the wristband support structure, a certain amplitude has to be reached before stimulation takes place. This reduces the damping behaviour of the human skin applied to the actuator and allows precise control of each actuator with improved tactile stimulation.



Figure 102 Monolithic structure with 8 lever beams

8.3.2 Simulation and Electronics

Finite elements simulations were carried out in Comsol Multiphysics in order to determine the geometrical aspects of the monolithic structure with regard to the cantilever's first eigenmode (Figure 103). The structure was optimized for the first resonance frequency creating out-of-plane motion around 230 Hz.

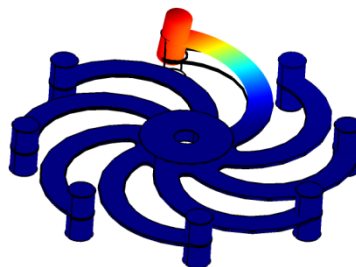


Figure 103 Eigenmode simulation of the monolithic structure with Comsol Multiphysics

The eight coils are driven with alternating binary signals provided by a microcontroller in order to set various output frequencies to convey different tactile patterns. The composition of the different electronic modules and its connection are shown in Figure 104.

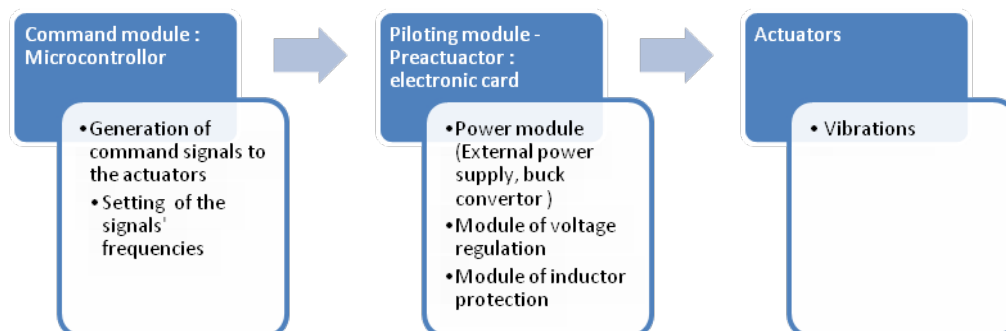


Figure 104 Different parts of the drive electronics

The command module delivers command signals to the active part of the system through a microcontroller. As the command module cannot supply enough current to activate the actuators, a piloting module is necessary. This module has the role of the power interface between the command part and the operating part. The piloting module has a low voltage input and switches a certain quantity of electric power according to the output charge. The components used to realize the power interface are an external power supply and transistors which permit the switching of continuous voltages and currents to the inductors. The voltage regulation module contains a DC-DC converter. In order to protect the inductors, a current limitation module is employed. This module contains a network of resistors and free-wheeling diodes. A functional diagram of the actuator control system is shown in Figure 105.

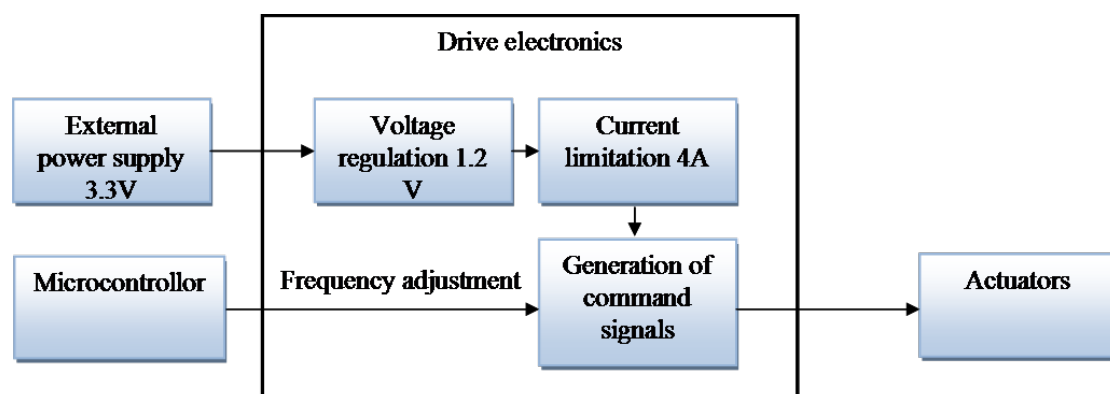


Figure 105 Functional diagram of the actuator control system

The electrical characteristics of the actuators and the following coil parameters required for the design of the wristband electronics have been identified:

- Internal resistor r : $1\ \Omega$
- Inductance: $60\ \mu\text{H}$,
- Wire thickness: $0.15\ \text{mm}$

- Number of turns: 50
- Length of wire: 900 mm.

The frequency of the coil is limited to some hundreds of Hertz. In fact, in this frequency range, the inductor is equivalent to an internal resistor r and an ideal inductance Li in series ($Z = r + Li$) as shown in Figure 106.

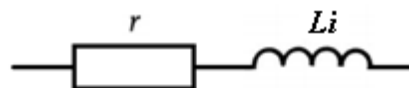


Figure 106 Electrical diagram of a coil at low frequencies

The complete electrical diagram of the drive electronics is shown in Figure 107 for one actuator (coil) only. It is represented as the inductor L which has an internal resistor of $1\ \Omega$ and an ideal inductance of $60\ \mu\text{H}$. As a single power supply of $3.3\ \text{V}$ can deliver enough current (more than $4\ \text{A}$) to actuate the 8 inductors at once, all components use this external power supply as the common source. The voltage delivered by the power supply is regulated using a DC-DC converter which delivers a fixed voltage of $1.2\ \text{V}$ and $4\ \text{A}$ of maximum current. Each coil can bear $0.5\ \text{A}$ current (limited by joule heating) leading to a total current of $4\ \text{A}$ to supply the 8 inductors.

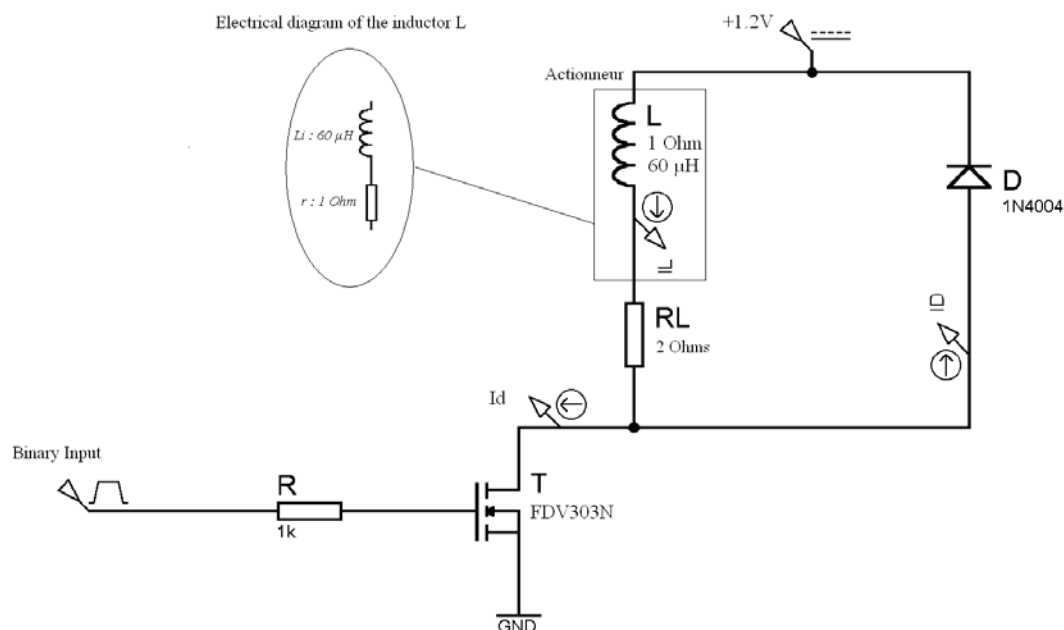


Figure 107 Schematic view of the complete electrical circuit

The inductors' command signals are generated by a microcontroller (Silicon Laboratories C8051F330) which has 8 digital outputs. These command signals permit the transistors to behave like logic gates. Thus, binary signals are applied to the coils. The switching frequency of the transistors is adjustable in order to drive the actuators at various frequencies controlled

directly by the microcontroller. The resistor R_L is used to limit the current of the inductor. The current passing through the inductor is

$$V_{RL} = \frac{R_L}{r + R_L} * V_{CC} = \frac{2}{1 + 2} * 1.2 = 0.8 \text{ V}$$

$$I_L = \frac{V_{RL}}{R_L} = \frac{0.8}{2} = 0.4 \text{ A}$$

with V_{RL} =resistor R_L voltage, R_L =resistor resistance, r = coil resistance, V_{CC} =voltage of the source, and i_L =coil current.

The forces created by the actuators are directly linked to the current applied to the coils. From simulations it is known that a minimum current of 0.25 A is needed and the maximum current is limited by joule heating (0.5 A). Thus, the value of the resistor R_L is chosen to establish a current of 0.4 A per inductor. When the gate of the transistor is interrupted, the “off” state of the transistor enforces the discontinuity of the current. That discontinuity produces an overvoltage in the inductor. A free-wheeling diode is used to eliminate this overvoltage in order to not damage the transistor.

The monolithic structure and the coils are placed in a Delrin® housing as shown in Figure 108 on the left hand side. The eight stimulators are placed slightly above the human skin in their inactivated state. Once activated the cantilever beams undergo an out-of-plane movement and the stimulators are in contact with the skin. On the right hand side in Fig. 23, the complete system including its drive electronics is shown. The piloting module generates the current for the coils. The microcontroller is used to pilot the transistors permitting the individual activation of the actuators.

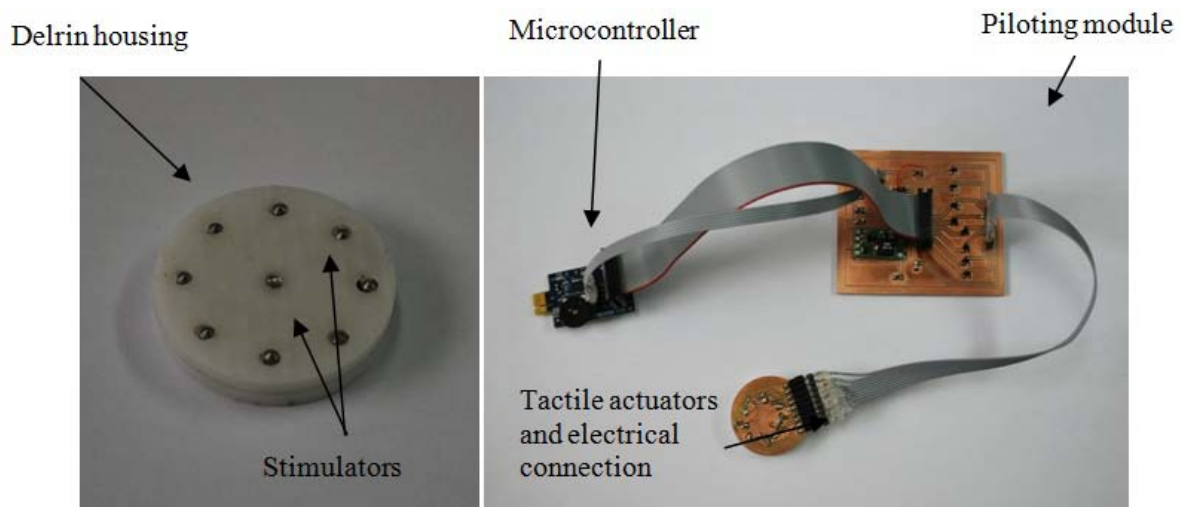


Figure 108 Actuator for a tactile wristband; Bottom-up view of the stimulator (left) and the complete system with drive electronics and microcontroller (right)

8.3.3 Feasibility Tests: Results and Discussion

Finally, the system was characterized using a laser displacement meter. Figure 109 shows the displacement amplitude of a single cantilever beam for a representative frequency range in logarithmic representation. It can be seen that at resonance (115 Hz) amplitudes as high as 3.5 mm were observed.

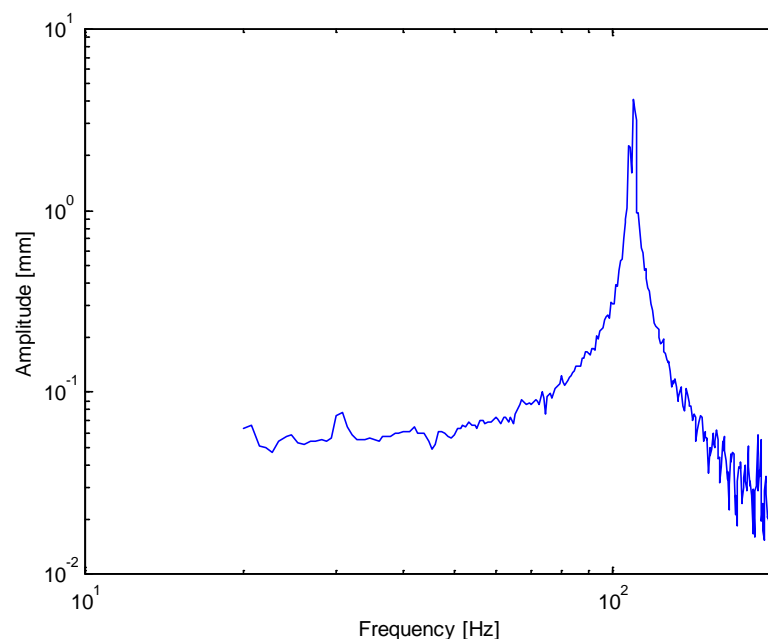


Figure 109 Dynamic displacement amplitude characterization of a single cantilever beam

The third prototype of the tactile wristband incorporates 8 individually addressable actuators and shows very high displacement amplitudes which make it a prospective candidate for navigational tasks. Next steps include the matching of the resonance frequencies to the human skin and the coupling of the complete system to a mobile phone through a Bluetooth module.

8.3.4 Conclusions

The work carried out in subtask 2.4 has yielded a significant improvement in hardware to allow users to access location based information. The work carried out on Subtask 2.1 has significantly influenced this hardware development. This work allows many of the techniques (such as the pocketnavigator) to be more discreetly created. The tactile wristband for example, is able to be easily integrated into different worn technologies and offers significant commercialisation opportunities. We are now handing over the hardware to WP1, WP4 and WP5, to allow it to be integrated into the demonstrators and evaluated to determine its full usefulness.

9 Appendix A – Reviewed Publications from WP2

The following publications were produced from the work carried out on WP2. All of these publications have been peer reviewed and published, or accepted for publication, at their respective venues. We include a list of publications that are currently under peer review and awaiting publication.

9.1 Published

Kovanen, J., Sarjakoski, L. T. and Sarjakoski, T. (2009). Studying iPhone as a Media for Context-Aware Map-Based Mobile Services. *Proceedings of the 6th International Symposium on LBS & TeleCartography*, Sep 2-4, 2009, CGS, University of Nottingham, UK.

Laakso, M. and Sarjakoski, L. T. (2010). A Map to Hear - Use of sound in enhancing the map use experience. *Proceedings of the GIS Research UK Conference 2010*, April 14-16, London.

McGookin, D. and Brewster, S.A. (2009). *Audio Bubbles*: Employing non-speech audio to support tourist wayfinding. In *Proceedings of HAID 2009 (Dresden, DE), Springer LNCS*, Vol 5763, pp. 41-50.

McGookin, D. Robertson, E. and Brewster S. (2010). Clutching at Straws: Using Tangible Interaction to Provide Non-Visual Access to Graphs. *Proceedings of CHI 2010*, ACM 2010.

McGookin, D. and Brewster, S.A. *Eyes-free overviews for mobile map applications*. In *Proceedings of MobileHCI 2009 (Bonn, DE)*. ACM Press.

Pielot, M.; Krull, O. and Boll, S.(2010). Where is my Team? Supporting Situation Awareness with Tactile Displays. *CHI '10: Proceeding of the twenty-eighth annual SIGCHI conference on Human factors in computing systems*, ACM.

Pielot, M.; Poppinga, B. and Boll, S. (2009). Understanding Tourists on a Bicycle Trip "In The Wild". *Mobile Living Lab '09 Workshop in conjunction with MobileHCI '09: The 11th international conference on Human computer interaction with mobile devices and services*.

Pielot, M., Henze, N. and Boll, S. (2009). Supporting map-based wayfinding with tactile cues. *MobileHCI '09: Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services*, ACM.

Schwarzbach, F., Sarjakoski, T., Oksanen, J., Sarjakoski, L.T. and Weckman, S. (2009). Physical 3D models from LIDAR data as tactile maps for visually impaired persons. Abstract book of ICA SPIE Europe Symposium True-3D in Cartography, Aug 24-28, 2009, Dresden, Germany, pp. 70-71.

Poppinga, B., Pielot, M. and Boll, S. (2009). Tacticycle: a tactile display for supporting tourists on a bicycle trip. *MobileHCI '09: Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services*, ACM.

Pielot, M., Boll, S. (2010). Tactile Wayfinder: Comparison of Tactile Waypoint Navigation with Commercial Pedestrian Navigation Systems. In *The Eighth International Conference on Pervasive Computing*.

Magnusson, C., Anastassova, M., Tollmar, K., (2010), User and context centred design methodology for location based services, *Workshop on Methods and Techniques of Use, User and Usability Research in Geo-information Processing and Dissemination, Tuesday 13 April 2010 at University College London*

Magnusson, C., Rassmus-Gröhn, K., Tollmar, K., Stigmar, H. (2009). Exploring user requirements for non-visual mobile navigation systems. *Proceedings of INTERACT 2009*, Uppsala, Sweden.

Magnusson, C., Brewster, S., Sarjakoski, T., Roselier, S., Sarjakoski, L. T., Tollmar, K. (2009). *Exploring Future Challenges for Haptic, Audio and Visual Interfaces for Mobile Maps and Location Based Services*. Proceedings of CHI 2009 -LocWeb Workshop, Boston, USA.

Magnusson, C., Anastassova, M., Tollmar, K., Pielot, M., Rassmus-Gröhn, K., Roselier, S. (2009). *The Mobile Oracle - an on Demand Wizard of Oz Tool*. Proceedings of MOBILEHCI-09, Bonn, Germany.

Magnusson, C., Breidegard, B., Rassmus-Gröhn, K., (2009) *Soundcrumbs - Hansel and Gretel in the 21st century*. HAID 09(4th international workshop, Haptic and Audio Interaction Design), 10-11 September, 2009, Dresden, Germany

Rassmus-Gröhn, K., Magnusson, C. (2009). *Enhancing accessibility in mobile navigation services*. Proceedings of AAATE 09, Florence, Italy.

Magnusson, C., Rassmus-Gröhn, K., Szymczak, D., *Navigation by pointing to GPS locations*, to be published in Personal and Ubiquitous Computing special issue on extreme navigation

Magnusson, C., Molina, M., Rassmus-Gröhn, K., Szymczak, D., *Pointing for non-visual orientation and navigation*, NordiCHI 2010, October 16 - 20, 2010, Reykjavik, Iceland

Magnusson, C., Rassmus-Gröhn, K., Szymczak, D., *Methods for understanding the mobile user experience*, OMUE 2010, Observing the Mobile User Experience, Workshop at NordiCHI 2010, October 16 - 20, 2010, Reykjavik, Iceland

Magnusson, C., Rasmus-Gröhn, K., Szymczak, D., *The influence of angle size in navigation applications using pointing gestures*, The fifth International Workshop on Haptic and Audio Interaction Design (HAID), September 16-17, 2010, Copenhagen, Denmark

Magnusson, C., Rasmus-Gröhn, K., Szymczak, D., *Scanning angles for directional pointing*, poster presentation at MobileHCI 2010. ACM Press

Magnusson, C., Rasmus-Gröhn, K., Szymczak, D., *Angle sizes for pointing gestures*, Pervasive 2010 workshop: Multimodal Location Based Techniques for Extreme Navigation.

Pielot, M.; Vester, B.; Kazakova, A.; Brammer, L.; Poppinga, B. & Boll, S. (2010) Natch : A Watch-like Display for Less Distracting Pedestrian Navigation. In *Mensch & Computer (Human & Computer) '10*.

Pielot, M.; Poppinga B. & Boll, S. (2010) PocketNavigator: Vibro-Tactile Waypoint Navigation for Everyday Mobile Devices. In *MobileHCI '10: Human computer interaction with mobile devices and services*.

Pielot, M.; Poppinga, B. & Boll, S. (2011) A Tactile Friend Sense for Keeping Groups Together. In *CHI EA '11 Proceedings of the 29th of the international conference extended abstracts on Human factors in computing systems*.

Pielot, M.; Poppinga, B.; Schang, J.; Heuten, W. & Boll, S. (2011) A Tactile Compass for Eyes-Free Navigation. In *INTERACT '11 13th IFIP TC13 Conference on Human-Computer Interaction*.

Poppinga, B.; Pielot, M. & Boll, S. (2010) Unsupervised User Observation in the App Store: Experiences with the Sensor-based Evaluation of a Mobile Pedestrian Navigation Application. In *OMUE '10: Observing the Mobile User Experience (in conjunction with NordiCHI '10)*.

Kovanen, J. and Sarjakoski, L. T. (2010). Displacement and Grouping of Points of Interest for Multi-scaled Mobile Maps. *Proc. of the Conference on LBS & TeleCartography (LBS2010)*, September 20-22, 2010, Guangzhou, China.

Laakso, M. and Sarjakoski, L. T. (2010b). Sonic Maps for Hiking- Use of Sound in Enhancing the Map Use Experience. *TheCartographic Journal*, **47**(4):300–307.
Schwarzbach, F., Sarjakoski, T., Oksanen, J., Sarjakoski, L.T. and S. Weckman, 2011. Physical 3D models from LIDAR data as tactile maps for visually impaired persons. *Lecture Notes in Geoinformation and Cartography*, Springer, in print.

9.2 Under Review Awaiting Publication

Peng J, Ferguson S, Rafferty K, Kelly P *An Efficient Feature Selection Method for Mobile Devices with Application to Activity Recognition* Under Review for journal: Neurocomputing (pub: Elsevier)

Peng J, Ferguson S, Rafferty K, Kelly P *Building Support Vector Machines in The Context of Regularized Least-Squares* Under review for journal: IEEE Transactions on Neural Networks. (pub: IEEE)

Mao B., Harrie L, Ban Y . Real time visualization of 3D city models in street view based on visual salience, International journal of geographic information science.

Pielot, M.; Poppinga, B.; Heuten, W. & Boll, S. (2011) The Tactile Compass: Private Non-Visual Navigation for Handheld Devices. In *MobileHCI '11: Human computer interaction with mobile devices and services*.

Sarjakoski, L. T., Kettunen, P., Flink, H.-M., Laakso, M., Rönneberg, M. and T. Sarjakoski, 2011. *Analysis of Verbal Route Descriptions and Landmarks for Hiking*. Personal and Ubiquitous Computing: Special Issue on Extreme Navigation, conditionally accepted.

Poppinga, B.; Magnusson, C. Pielot, M.; & Rassmus-Gröhn, K. (2011) TouchOver Map: Audio-Tactile Exploration of Interactive Maps. In *MobileHCI '11: Human computer interaction with mobile devices and services*.