Non-Intrusive Somatosensory Navigation Support for Blind Pedestrians

Niels Henze[*]
Department of Computing Science
University of Oldenburg
Oldenburg, Germany

Wilko Heuten [†]
OFFIS
Institute for Information Technology
Oldenburg, Germany

Susanne Boll [‡]
Department of Computing Science
University of Oldenburg
Oldenburg, Germany

Abstract

Navigation and wayfinding are difficult tasks for blind or visually impaired pedestrians. A long cane and maybe a guide dog are the helping companions for avoiding obstacles on the way. Gross navigation, i.e., the task to find the way from one point to another can only partly be achieved by this support. With the advent of positioning and navigation systems, electronic navigation aids for the blind have been proposed. However, the existing speech-based systems use the most relevant modality of blind persons, the ears, and do not allow a non-intrusive navigation support. Haptic approaches which provide continuously and non-intrusively navigation information and which are suitable for blind people do not exist. A major challenge for such a system is to present not only directional cues for specific points of interests, but rather to keep a blind or visually impaired person on track of the route during the whole navigation process. In this paper, we present an approach of a somatosensory navigation support that uses three vibrators to provide a pedestrian continuously and non-obtrusively with information about the way, deviations from the path, and directions. Controlled by a PDA and based on the input of a GPS receiver and a digital compass, the lightweight prototype delivers vibration signals of different intensity to the upper arms and the back. Additional, infrequent speech commands support the wayfinding task. Our first tests are promising and we plan a revised version of the prototype that further reduces the necessary hardware and also include additional interaction and information patterns.

Keywords: human computer interaction, somatosensory user interface, tactile interface, navigation, wayfinding, orientation

1 Introduction

Navigating in real environments is a complex activity for pedestrians: it consists of several challenges such as route planning, exploring the environment, orientating, wayfinding, and obstacle detection. Even if all our senses are fully functional and we are able to concentrate to the navigation process, it is difficult to solve all these challenges in unknown areas without the help of tools. Currently, we find different kind of traditional navigation aids such as maps, signs, and other people telling us the right way and helping us to orientate. However, these typically rely on visual capabilities like reading a map or finding someone across the street to help us finding the way. With the advent of positioning techniques such as GPS integrated with personal mobile devices, orientation and navigation became supported by location-based orientation and navigation systems. These systems typically use a digital map with text and/or speech-output-based navigation instructions that inform the pedestrian where to go. These systems, however, are only partly helpful for blind and visually impaired people. First, the visual map is not accessible for them and second, a speech output interferes with one of the most important senses of blind and visually impaired people: the auditory sense.

Therefore, we aim at somatic sensation as an input to navigation and orientation information: "The Somatosensory System allows us to make accurate inference about the outside world by using information from receptors that respond to touch and vibration, our own movements, temperature, and noxious stimuli." [4] The sensory scope we deal with in our approach is somatic sensation of touch and pressure of the skin, which is also called the cutaneous sense. As Brewster and Brown stated in [3], cutaneous sense is rich and a powerful communication medium, but currently little utilised in human computer interaction (HCI). Tactile displays have the potential to improve interaction, where the visual display is overloaded or not available. We employ gentle vibration to convey direction information to a blind person while walking along a predefined route and to find the route's waypoints and points of interests. With three vibrators placed at the upper arms and the back we can seamlessly and non-intrusively pilot the walking pedestrian into the right direction and - more important - prevent that the blind or visually impaired pedestrian goes astray. The vibration is used only when necessary and forms a present but ambient navigation aid for gross navigation. This navigation aid provides the necessary information through a somatosensory interface, so that the user can concentrate the attention on other important tasks. The system was specifically developed for blind and visually impaired users and forms a perfect complement for their long cane and guide dog.

Section 2 introduces the different tasks and phases of navigation and orientation, illustrates this along a navigation scenario for a blind person, and derives the central requirements to a mobile navigation aid system. Section 3 presents related approaches for guiding blind and visually impaired pedestrians based on different modalities and distinguishes our approach from the related approaches in the field. In Section 4, we present the requirements and design of our somatosensory navigation aid for pedestrians. The implementation in software and hardware is presented in Section 5. We come to a conclusion and an outlook to our future work in Section 6.

2 Navigation Tasks

In the following sections, we analyse the central requirements for a navigation support system. In the following the presentation of the different navigation phases, a navigation scenario for a blind person is illustrated. This scenario helps us to understand and to identify the detailed tasks a visually impaired person has to perform while navigating.

2.1 Phases of the Navigation Process

Navigation is the task of finding a way in real or virtual environments from a start to a destination. Navigation is therefore a fundamental part of mobility and thus one of the essential human skills.

[*]e-mail: niels.henze@informatik.uni-oldenburg.de
[†]e-mail: wilko.heuten@offis.de
[‡]e-mail: susanne.boll@informatik.uni-oldenburg.de

Adams [1] proposed a heuristic model of human locomotion that divides the navigation from point to point into three phases: preliminary planning, gross navigation and fine navigation.

1. In the *preliminary planning phase* a person decides, where she wants to go and considers various routes to get to the destination. Finally the person chooses the "best way" which is determined by many factors like distance, available time, safeness, and other personally important impacts. The result from this phase is a route that consists of a couple of waypoints with road sections between them.
2. *Gross navigation* describes the tasks needed for moving from one waypoint to another. These tasks are medium-term strategies like orientating, reaching waypoints, and following a path along the route.
3. *Fine navigation* is the short-term strategy to avoid hazards and obstacles on the path like staircases, busy intersections and holes in the ground.

A person deals with these phases from preliminary planning to fine navigation but not always strictly in this order. If for example a person determines during fine navigation that the path is blocked by road construction, a new route has to be calculated (preliminary planning). Even though this model is based on visually guided behaviour, we use it to derive specific navigation needs and requirements for blind pedestrians in the following scenario.

2.2 Navigation Scenario

The above description of navigation phases illustrates the general tasks we are dealing with in the navigation process. However, these are not detailed enough to derive accurate requirements of a system, which supports navigation. Therefore we analyse in the following the navigation situation of an exemplary blind person: Mr. Cook wants to walk from the railway station across-town to the theatre. In the preliminary planning phase a sighted friend describes the route for him as best as possible, in order to give him a good understanding of the route and its acoustic and physical landmarks. The route is shown as a line on the map in Figure 1: starting point is the railway station on the upper right. The route consists of multiple road sections which are all located between two intersections before it finally ends at the theatre, the route is about two kilometres long.

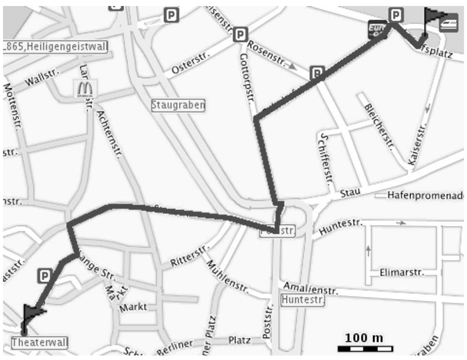

Figure 1: Mr. Cook's route on a map

After leaving the railway station Mr. Cook crosses the square in front of the station to reach the first intersection. Using his long cane he can feel (and additionally hear due to the sound caused by the long cane) the tactile guidance system on the ground which is installed around the railway station. Additional cues are given by surrounding noise caused by other pedestrians and the traffic.

Using this information, he deals with the fine navigation tasks for e.g. avoiding collisions with other pedestrians and obstacles. To reach the next intersection Mr. Cook performs the gross navigation tasks. He adjusts his heading continuously according to the direction in which the intersection is located. In addition he has to adjust his walking speed according to the distance of the intersections. Both gross navigation tasks are greatly eased by the tactile guidance system. After reaching the intersection Mr. Cook remembers, that he needs to turn right as his friend told him. On the following crossing the tactile guidance systems ends and the traffic density is waning. Due to parked cars, a narrower pavement, and obstacles like dustbins standing around, fine navigation becomes more difficult. The lack of acoustic impressions from other pedestrians further aggravates the gross navigation tasks. Following the right direction and preparing for the next intersection becomes laborious. Mr. Cook walks further towards his destination. On his way Mr. Cook has to follow 14 intersections and to change direction eight times. To manage the route Mr. Cook has to remember and estimate the distances between the intersections. In addition, he has to recall the directions he has to choose and to remember special auditory landmarks like fountains as described by his friend.

2.3 A Blind Person's Navigation Tasks

Analysing the situation of a blind pedestrian leads to a set of tasks, which need to be performed to navigate from one point to another. In summary, we identified following six tasks: find a route (Task 1), identify the current position (Task 2), remember and choose the right direction at intersections (Task 3), identify the distance to the next intersection (Task 4), keep a road section's direction (Task 5), avoid hazards and obstacles (Task 6).

In the scenario above, the preliminary planning (Task 1) is done together with Mr. Cook's sighted friend. Tasks 2 to Task 5 are gross navigation tasks: knowing one's own position (Task 2), is necessary in order to manage the other gross navigation tasks. The next task (Task 3) is remembering which direction should be chosen. This closes the gap between preliminary planning and gross navigation. Knowing the distance to the next intersection is necessary in order to prepare for the intersection. Identifying the distance (Task 4) is based on previous knowledge from preliminary planning and cues given by the tactile guidance system and the acoustic perception. Keeping a sections direction (Task 5) is greatly aided by the tactile guidance system. Without this aid a blind person relies on the long cane assisted by his acoustic perception. The last task (Task 6), a fine navigation task, is managed using the long cane assisted by one's acoustic perception.

In the scenario, Mr. Cook is able to deal with all described tasks without guidance. Event though this might be true for some people who are blind, research from Kitchint et al. [11] shows that only very few are actually travelling alone without sighted assistance. In fact, the situation is even worse for unknown environments. Assistance by a navigation aid that makes blind and visually impaired persons more independent and gives them a higher mobility is therefore desirable.

Today preliminary planning is mostly done with the help of sighted people. Additional preliminary planning aids are tactile maps and their computer supported variants [7] [20]. Also gross navigation is mostly done with aid by sighted people. Tools which support gross navigation have also been developed, but are not widely used. Electronic gross navigation aids are discussed in the next section after taking a closer look at additional constraints for blind users in the following paragraphs. The most successful and widely used travel aids for the blind are long canes and guide dogs. Both aids are used for fine navigation. Additional tools for fine navigation are obstacle detection systems [2] [10] [16].

Tools supporting the preliminary planning and the fine navigation are already widely and successfully used. However, tools for gross navigation have not been accepted by blind users, yet. Thus, we focus in this paper on tools for gross navigation only. One reason, that blind persons do not accept already available tools is, that these do not overcome the specific constraints, which arise when supporting a blind person in the navigation process. The system must not confine the user in his freedom of movement. Therefore, it should be lightweight and be well portable. The use of the long cane or the guide dog must not be hampered. Therefore, interaction with the navigation aid should not require the use of both hands. As blind people need all their senses while moving around traffic a navigation aid must not disturb the user's perceptiveness or at least keep these restrictions at a very low level. As hearing is the only sense that allows blind people the perception of distant objects, it is especially important for navigation. Therefore, the system should not require the use of headphones and keep the amount of generated sound at a very low level. In addition, sound should only be used if the user remains stationary. Using the system only very little attention should be needed. Therefore, the user interface has to be as intuitive as possible. Particularly if the user is walking she should have to share only very little attention with the navigation support system.

3 Related Work

Tools that ease gross navigation for blind people have been on the market for many years. They share some features with navigation systems used by sighted people. Existing gross navigation aids for the blind can be divided into two categories according to the modality used for information presentation: The first is based mainly on an acoustic presentation while the other tries to provide information mainly through a somatosensory output. Additional systems have been developed for investigation of presentation techniques. We classify these systems using the gross navigation tasks and the additional constraints described above.

The speech based system MOBIC [15] is a travel aid for blind people and the elderly. Harrasser [9] developed a system which also displays most guidance information by speech. Additional cues are given through two vibrators, but only simple warnings and instructions like "turn left" are given via vibration. Both system's support the user in identifying his position (Task 2), and remembering the right direction at intersections (Task 3). However, they cannot provide the user with information about distance (Task 4) and direction (Task 5) while being between two intersections. Another system was developed by Loomis et al. [13]. The system consists of a component to determine the user's position and orientation, a Geographic Information System (GIS), and the user interface. The user interface displays information by speech output and a virtual auditory display. Loomis' system is furthermore able to help the user determining distances (Task 4) and keeping a section's direction (Task 5). However, major limitation of the systems mentioned so far is that they primarily use sound to present information. Therefore, the user's perception of the environment is hampered especially if headphones are used. This is unsuitable in particularly for blind and visually impaired people.

Besides those systems with an acoustic output attempts have been made with haptic output. Ertan et al. [5] developed an indoor navigation system with 16 motors that vibrate, mounted in the back of a vest. They used the motors to display five different instructions like "turn left", "turn right", and "stop". A navigation aid developed by Ross and Blasch [17] provides navigation information in the form of taps on the back. Both systems support the user in remembering the right direction at intersections (Task 3). They can provide the user with information about the direction (Task 5) but only inexactly and without immediately feedback. They do not support Task 2 and Task 4. Another system that uses haptic output is the commercially available BrailleNote GPS [8] from the Sendero Group. BrailleNote provides the user with instructions, nearby location names, and distances to destinations using Braille. BrailleNote support the user in identifying his position (Task 2) and remembering the right direction at intersections (Task 3). Like the speech based systems BrailleNote fails supporting Task 4 and 5. Even if these systems do not hamper the user's acoustic perception they can not provide exact directional cues and permanent feedback if the user is not located at an intersection.

Besides the above-named aids, systems have been developed for investigation of presentation techniques for pedestrians. ActiveBelt is a system developed by Tsukada and Yasumura [19]. It displays information via a belt equipped with eight motors that vibrate. Directions are given by vibration in the corresponding direction. A similar belt-type system was developed and evaluated by the feelSpace project [6] for the investigation of sensory substitution. Both systems have not been developed as a navigation aid and without blind people in mind. Therefore, these systems can not provide the user with navigation information. Nonetheless they are able to provide exact directional cues and permanent feedback using only somatosensory stimulation.

4 Design of a somatorsensory navigation aid for blind pedestrians

For our somatosensory navigation aid we aim at better support for the gross navigation tasks as we see here the largest need to help blind pedestrians. Due to the limitations of existing gross navigation aids, in the following we examine the specific requirements and present the application design of our somatosensory navigation aid.

4.1 Requirements for a Gross Navigation Aid

The following requirements refine and elaborate the general requirements (Tasks 2-5) for gross navigation derived from the scenario in Section 2. In addition, technical requirements for position and orientation determination are outlined.

Indentifying the Current Position (Task 2) The user has to be able to determine when she has reached an intersection. Aditionally she has to know which intersection she has reached. This information enables her to integrate the intersection into her mental model of the environment. By doing so the user is able to determine or update her position inside the mental model. Knowing her position and the structure of her environment gives the user the possibility to adjust her acting according to possibly existing previous knowledge. To enable the user to identify her own position between intersections, position information should be provided on request.

Choosing the Direction at Intersections (Task 3) After reaching an intersection, the user wants to proceed on the route. Therefore, she has to adjust her orientation according to the next road section. To be able to do this, she has to know the direction of the section. An informal instruction like "turn left" is necessary to give a rough clue about the right direction. Detailed information about the exact direction enables her to proceed accurately. This information has to be given according to the user's actual orientation and not according to the cardinal points.

Distance to the Next Intersection (Task 4) To be able to prepare himself for the next section the user has to be informed about the distance to the next intersection. This information becomes more important the closer he gets to the intersection. Therefore information is not always necessary but rather should be provided periodically and more often when getting nearer to the intersection.

Keeping a Sections Direction (Task 5) After leaving an intersection the user needs to proceed the route by reaching the next intersection. Therefore, he has to walk along the road section till its end. In order to do that, he has to keep his orientation according to the section's direction. Consequently, the user has to be informed if and how his orientation differs from the section direction. If this is the case the system should present the correct orientation to the user immediately.

To be able to provide the user with the above mentioned information the following technical requirements have to be fulfilled.

Position determination To provide the user with information about his environment a navigation aid has to determine the user's position. In the following, we are making some assumptions about how exact the navigation aid has to determine the position. The navigation aid has to be able to safely detect if the user reaches an intersection and which intersection he has reached. The assumption that intersections are at least 20 meters apart from each other and an average speed of 4 km/h (1.11 m/s) leads to the following formula that has to be fulfilled:

$$\frac{20m}{2} \geq \frac{1}{frequency} * 1.11\frac{m}{s} + error \quad (1)$$

Orientation determination To be able to not only display information relative to the user's position, but also to her orientation, the user's heading has to be measured. The work of Loomis et al. [12] indicate that displaying direction information relative to the user's head might show the best results. It can be assumed that if the navigation aid can measure the orientation of the head fast and accurate enough this is also true for the torsos orientation. Nevertheless, the orientation cannot be measured without an error and only with a certain frequency. A measurement error of b degree is leading to an error of f meters in a distance of r meters as shown in Formula 2

$$f = |r| * \sqrt{\sin(b)^2 + (1 - \cos(b))^2} \quad (2)$$

For example, an error of 5 degree and a distance of 10 meters lead to an error of 1.7 meters. In addition to the error resulting from inaccurate measurements a further error results from measurement frequency. Following the assumption that the user will not turn around in less then a second, a measurement frequency of 36 hertz would for example be high enough for an error less than 5 degree. The error resulting from measurement frequency and the measurement error have to be combined. Consequently, both errors has to be taken into account while choosing the device for orientation determination.

4.2 Application Design

Our proposed solution uses vibrational stimulation as primary output modality to meet the requirements presented above. The navigation aid consists of four physical components which are illustrated in Figure 2. To determine the user's orientation an electronic compass is used. The chosen compass device fits the requirements easily if used outdoor and is attached to the users head. The user's position is determined by a Global Positioning System (GPS) receiver as GPS is the only outdoor positioning system which is robust, cheap and globally available. The receiver is attached to the users belt together with a Personal Digital Assistant (PDA) a handheld computer. The compass as well as the GPS receiver are connected to the PDA which is used for data acquisition and processing. In addition, geographic data including route information is stored on the PDA.

The PDA's speaker is used to display two kinds of seldom-needed information. A description of the actual position including street names and instructions like "turn left" are given at intersections and on request. Speech output is used to assure that this information is clear and easy to understand. As this information is seldom presented without using headphones the user's auditory perception is only minimally hampered. Direction and distance are needed more often or permanent. Therefore they are presented with vibration as discussed in the next section.

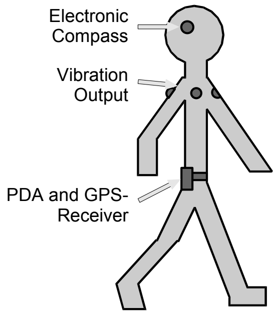

Figure 2: The system's components carried by a pedestrian

4.3 Design of the Somatosensory Display

The somatosensory display is used to provide two kinds of information: Primarily it shows whether and how the user's orientation deviates from the routes actual direction. This enables the user to keep the routes direction. Additionally, the distance to the next intersection is shown to enable the user identifying the next intersection early. The route direction is displayed as long as the user is not correctly orientated and the output is adjusted immediately to the user's movement. Therefore, the output is providing direct feedback and enables the user to adapt his heading immediately.

One objective of our prototype was to build an inexpensive and flexible tactile display. Compared with other existing systems like AcitveBelt and feelSpace (see Section 3), we therefore reduced the number of vibrators to a minimum of three to display the direction. The choice of the body location for the vibrators is also important. As Brewster and Brown said in [3] certain body locations are suitable, others are particularly unsuitable for certain types of vibrotactile display. We decided to attach the vibrators to both of the user's upper arms and to his back, since these provided best perception for our type of vibrators without being annoying.

Each of the three vibrators represents a different direction. If the one on the left arm vibrates the system tells the user that the user has to turn left. The vibrator at the user's back means accordingly to turn around and the one at the right arm to turn right. According to the requirements (see Section 4.1), we need a more accurate output of the direction. To be able to show more than three directions with three vibrators, the motors are vibrating with multiple level of intensity. Figure 3 shows how the intensity of the particular vibrator depends on the presented direction. The direction left-rear is for example expressed by two vibrators, the one on the left and the one on the back, both with medium intensity. The direction ahead-left is only expressed by one vibrator with an intensity corresponding to the respective direction. Ahead, which would mean that the user is correctly orientated, is expressed by the absence of vibration. This means that as long as the user is orientated according to the actual section the system remains "somatosensory silent", impeding unnecessary outputs. By using three vibrators only, on the one hand the costs of the systems are reduced and on the other hand we can easily change the location of the vibrators on the user's body to evaluate different sensory perceptions. Furthermore the low number of vibrators reduces the weight of the system and thus improves the wearing comfort.

The somatosensory output takes not only place on sections but displays directional information during the whole walk. By this means, the user is able to keep the direction on sections and to accurately align her orientation at intersections. Thereby the simple verbal instructions are enriched with exact directional information

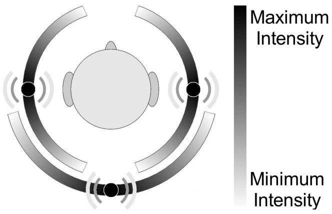

Figure 3: The vibration intensity dependig on the direction

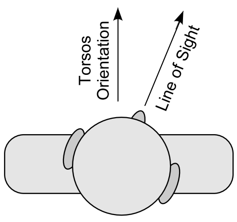

Figure 4: Line of sight compared to the torsos orientation

and feedback.

According to the requirements the direction should be displayed relatively to the user's orientation. As shown in Figure 4 the user's orientation could be interpreted as the line of sight or as the torso's heading. An output according to the user's line of sight corresponds to the perception by the head-centred senses like seeing or hearing. As for seeing, by turning the head the environment could be explored and the user could actively scan the surrounding for the path. Using the torso's heading on the other hand is comparable to the leading by another person. The user is pulled into the section's direction and is not actively exploring the surrounding. Both variants are valid but Loomis et al. [12] evaluations shows that at least for an acoustic output the line of sight leads to better results.

To display the distance the same vibrators as for the direction are used. Using a low count of vibrators keeps the weight low while offering a high level of convenience. Compared to the direction the distance is seldom needed as long as the user is far away from the next intersection. However, this information becomes more important if the user comes nearer to the intersection. Therefore, it is presented more often the closer the user get to the intersection. As long as the user is more than 100 meters away from the next intersection all vibrators vibrate for half a second with maximum intensity every 100 meters. While the user comes closer to the intersection further outputs are generated. 50 meters before the intersection two impulses are generated. While the user approaches the number of impulses rise. 30 meters away three impulses are used, 20 meters away four impulses, and 10 meters away five impulses. Consequently the user has enough time to prepare himself for reaching the intersection.

5 Implementation and Prototype

The described solution has been implemented in hardware and software. Figure 5 shows the overall structure of the system. The software modules are shown on the left and the hardware components on the right. At the top of the software architecture the user interface modules manage the presentation of information. The communication layer below is responsible for the communication between the modules and data processing. The modules at the bottom serve for position and direction determination and the module that accesses the geographic information. On the hardware side, the GPS receiver is connected using Bluetooth while the other hardware components are connected by an Inter-Integrated Circuit (I^2C) bus [18]. An adapter circuit connects the motors that vibrate to this bus. The electronic compass is directly attached to the I^2C bus. An adapter connects the I^2C bus to a RS-232 bus and a power supply provides the necessary current. In the following, we describe the software and hardware components in more detail.

5.1 Software Modules

The software modules are designed according to publisher/subscriber design pattern. All communication between the modules is realized using this pattern. When the system is started the communication module initialises and registers the other modules. The position and direction module determines the user's position and orientation from the GPS receiver and the electronic compass. This information is merged and forwarded to the communication module. Afterwards the communication module asks the GIS for the actual direction of the route. This direction is compared to the user's orientation and an appropriate event is fired to the presentation module. Likewise events are raised if the user comes near to, or reaches, an intersection.

The presentation module is further divided into the somatosensory, the speech and the visual output, although the visual output is only needed for testing purposes. The somatosensory output module implements the somatosensory display as described above. The module receives events if the deviation between the users orientation and the actual direction change. Additional events are received if the distance to the next intersections drops below certain ranges. The module is implemented in a way that enables access to a variable amount and different kinds of vibrators. The speech output receives events if the user reaches an intersection or asks for positional information. Based on the event a corresponding sentence is constructed and spoken using a speech synthesizer.

To assure platform independency the software is implemented in Microsoft's C-Sharp. Access to the hardware components is done using a Bluetooth connection to the GPS receiver and a serial connection to the remaining components. All communication with the hardware components is implemented using the Smart Device Framework [14].

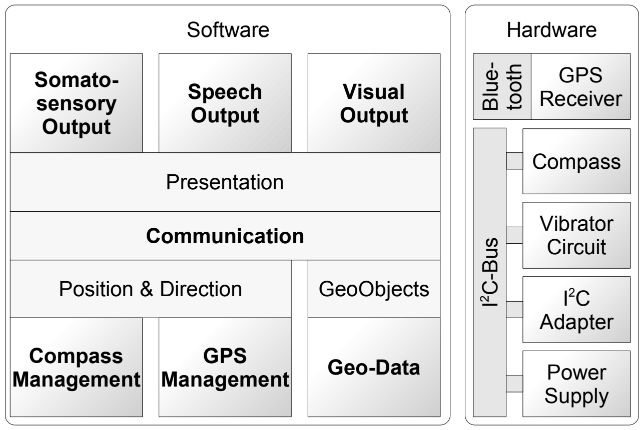

Figure 5: The system's software and hardware architecture

5.2 Hardware Components

The system runs on platforms where Microsoft's .NET framework is available. To ease mobile usage we use a PDA as primary platform. According to the requirements three components has to be accessed. The GPS receiver is connected using a wireless Bluetooth connection. In addition an electronic compass and three vibrators are connected to the PDA using an I^2C bus. We choose a Devantech CMPS03 as compass because it is quite cheap, small, and fits the requirements. Because of it's small size the compass could be attached to the user's head by integrating it into an hat or cap. The compass is equipped with an I^2C bus connector. For the vibrational output we used three motors that vibrate like those used in current game controllers shown in Figure 6. Each vibrator is integrated into a plastic package. The vibrators are controlled by adjusting the input voltage. Therefore, we developed an adapter that connects the vibrators with the I^2C bus. The adapter is build around an digital-to-analogue converter that is connected to an amplifier for each vibrator. Both the compass as well as the vibrator-adapter are wired with an I^2C Bus to serial adapter that connects with the iPAQ's RS-232 serial interface. Thereby the software can communicate with the hardware components.

Figure 6: A motor that vibrates compared to the size of an eurocent (left) vibrator worn on the arm inside a plastic package (right)

6 Conclusion and Future Work

In this paper, we presented a navigation support system for blind and visually impaired pedestrians. Our proposed solution uses somatosensory presentation techniques to convey important information about directions and distances of a route and its waypoints. The system guides the user in a non-intrusive way without disturbing the perception of the environment through somatosensory sensation.

We illustrated the different phases of the navigation process the user has to deal with while moving: preliminary planning, gross navigation, and fine navigation. On basis of a scenario describing a typical navigation procedure of a blind person we identified major tasks that have to be performed during this process. There are already efficient tools available that support the preliminary and fine navigation phases. However, tools for gross navigation are not widely used for several reasons. In order to develop a navigation support system, we analysed the requirements for gross-navigation in detail. In particular, the presentation of the direction to the next waypoint adds up to a challenge for the user interface design: The system has to convey exact direction information continuously and at the same time non-intrusively. To fulfil these requirements our approach utilizes a somatosenory display, consisting of three vibrating motors, which are attached to the user's body. First in-house tests demonstrate that the system supports the most important task of the gross navigation phase and guides the user from one location to another through a non-intrusive interface, without interfering neither the auditory perception of the environment nor the use of other tools like the long cane. By adjusting the intensity of the three attached vibrators, an accurate display of the current direction to the next waypoint is possible.

Although the system supports the user in navigation tasks, some future work is necessary to improve the wearability. Cables need to be replaced by wireless technology. The motors for vibration can be reduced in size and the power consumption can be lowered. Additionally, to the presentation of directions through the somatosensory display, the user interface can be used to present further types of information, such as points of interest (POIs) close to the route or obstacles detected by, e.g., an ultrasonic long cane. Different types of information could then be conveyed via various frequency patterns of the vibration.

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