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Abstract

There are many navigation systems and applications providing help for visually impaired and especially blind users in urban environment. However, none of them provides solution to the problem with insufficient description of the environment and the navigational instructions.

The most sever problem in navigation and orientation without sight are different navigational points and orientation keys. These points and keys cannot be obtained automatically and have to be collected by either limited number of trained navigational instructors or by visually impaired people themselves. Moreover the data from location services based on GPS [1] or similar technology are very inaccurate in urban areas due to high buildings, which cover substantial area of sky and cannot be used for precise (in order of meters) navigation.

To address these issues we proposed collaborative navigation system based on utilization of the knowledge gained by visually impaired pedestrians. At first the approximate location of the visually impaired user is acquired by means of GPS. Thereafter the precise location of the user and navigation instruction are obtained by means of communication and collaboration with other visually impaired persons.

Several studies were conducted to prove the concept of the collaborative navigation system with over hundred blind participants (both qualitative and quantitative studies; some of the subjects participated in more than one study). The results show that the essential conditions for operation of collaborative navigation for visually impaired (the existence of communication among visually impaired users about navigation and ability to share their knowledge, and the sufficient length of regularly walked routes they remember to every detail) are fulfilled and that user base is wide enough to sufficiently cover significant parts of the urban environment.

Keywords

collaboration, communication, visually impaired, navigation.

Contents

1 Introduction

The situations when orientation is lost are mentally demanding especially for the visually impaired users and it is necessary to analyze the ways to help them by means of some navigational aids. The solutions to this problem partly exists in the form of:

- navigation call centers (e.g., Navigation center of Czech Blind United – SONS [2] where navigation instructors and operators directly navigate visually impaired person),
- voice-enabled navigation applications for smart phones [3, 4]
- or custom hardware or wearable computer aids [5, 6, 7].

The last mentioned solution can use many sensors such as camera, headset for communication, GPS [1] or even Microsoft Kinnect [8] to analyze image and provide visually impaired users information about their surroundings.

Although all the mentioned navigation systems are designed for visually impaired, none of them is ideal. Notably the fact that many of the custom hardware or wearable computers aids are in prototype phase of development and that only few of all aids can solve the situation when the visually impaired user gets lost.

The goal of our research is to explore possibilities of utilization of distribute knowledge of environment among visually impaired users and the design of collaborative navigation system based on their communication.

1.1 Use case

Let us imagine that Alice is a visually impaired person who has decided to visit a new art exhibition for visually impaired in the city center on Saturday evening (see Figure 1.1). She knows the address but does not know the destination and the route well. She does not have computer and uses smart phone equipped with GPS module and installed screen reader for all her communication (call, messages, email, web). If she feels unsure about the route or get lost she can use several navigation methods available:

- ask passerby people,
- use voice-enabled navigation application on her smart phone,
- call navigation center for visually impaired,
- get in touch with navigation instructor,
- call visually impaired friend who may know the destination,
- call unknown visually impaired person with useful knowledge of desired destination who walks along the gallery every day from his/her home to the nearby public transport stops to get to the work (there can be possibly more than just one impaired person).

Figure 1.1: Alice is a visually impaired person who has decided to visit a new art exhibition for visually impaired in the city center on Saturday evening but does not know the destination and the route well

The navigation center unfortunately does not have good enough information to describe especially the way to the gallery but they provide at least information about the public transport. It is too late to get help in advance from a navigation instructor (Alice decided to go to the exhibition in last minute) and Alice does not know anyone from her friends who can give her description of the route from public transport to the gallery. Moreover, Alice does not feel comfortable asking foreign people (see section 3.1 Communication in Navigation of Visually Impaired, Figure 3.7). Further more the reception of GSP signal in that area is not accurate enough for precise navigation via smart phone. The last option for Alice is the unknown visually impaired person.

The selection of the visually impaired person who can describe the environment of destination in suitable quality is not a trivial problem. Several parameters need to be taken into account:

- frequency of visits of the destination, date of last visit of the destination, direction of motion, etc.;
- preferences of the helping visually impaired person such as time schedule when he/she is available, maximum incoming requests, etc.;
- and also preferences of the person who is asking for help like duration, category [9], onset (early or late blind) of the impairment or even usage of the guide dog (see section 3.4 Recovery From Loss of Orientation, subsection 3.4.3 Disscussion).

1.2 Problem Description

The common problem of all the existing navigation solutions is lack of environment description especially created for visually impaired users with focus on special navigational points and orientation keys [10, 11, 12] needed for safe and efficient navigation of visually impaired users. This specific description is hard to obtain as only trained navigation instructors can create it in a full extent. Unfortunately, there is typically very limited number of such instructors.

The description with obvious limitations given by the level of the impairment [13, 14, 15] can be partially obtained also by visually impaired persons. The typical navigational points and orientation keys (landmarks) obtained by visually impaired themselves are:

- leading lines created by edges of the pavement, handrails, corners of buildings, best side of street to travel on, etc.,
- sounds from traffic, construction work, water, width of the street from the echo, etc.,
- smells of different types like bakery, drugstore, sewers, etc.,
- direction of heat from sun in certain time of day,
- approximate distances, elevation changes, type of ground material.

For the names of streets, order of turns on the route, navigation through parks and estates, location of specific house in the street, etc. visually impaired people need description from navigation instructor.

The visually impaired people remember special description of their frequent routes provided by navigation instructors and can present them to other people. There are much more visually impaired users with specific knowledge than instructors available. The problem is that their knowledge is limited to only few routes and that they cannot generate new complete navigation descriptions without help of an instructor.

The idea how to overcome the problems mentioned above is to allow and facilitate direct simultaneous help between visually impaired people and sharing of their knowledge (navigational points and orientation keys) about certain places.

2 State of the Art

The main difference between navigation system designed especially for the sighted users and the visually impaired users is in level of detail of the environment description and the representation of the instruction.

Sighted users and drivers are bound to streets and roads and the details contained in description are sufficient for them. On the other hand visually impaired users use different navigation features of the environment description provided by navigation system designed particularly for sighted are not sufficient for them [12].

There are several options for navigation application on smartphones used nowadays by visually impaired despite they were designed for sighted or/and drivers. Most common are Nokia Maps preinstalled on Symbian [16] smartphones, which are in large used by visually impaired users for their hardware keyboard and good screenreader [17]. Other options can be found in navigation applications for Android in higher versions (4.0 and above) [18] with build-in eyes free interaction Explore-by-touch or on iOS devices with VoiceOver [19].

2.1 Navigation of Visually Impaired

Although all the following navigation system are designed especially for visually impaired, they all have their benefits and drawbacks.

2.1.1 Mobile Navigation Applications for Visually Impaired

The first navigation solutions especially created for visually impaired to be mentioned are specialized mobile applications. There is large number of various mobile applications for several platforms helping visually impaired to navigate in outdoor environment.

Comercial Application

Loadstone [3] is navigation application for visually impaired users for Symbian OS [16], which enables visually impaired users to record, store and share GPS recorded tracks and points of interests, and later navigate to them also using GPS location. The Loadstone application contains no map information at the beginning but the user can download the content other users created and shared.

BlindSquare [4] application for iOS uses GPS to locate user and offers him surrounding points of interest from FourSquare [20] and Open Street Map [21]. It enables user to explore his/her surroundings not to exactly navigate but in some cases this information can be helpful.

Research Projects

The first application to mention is the project, which is nearest to our objective [22]. The navigation system is designed for all possible kinds of impairment (mobile, cognitive, visual, etc.) and the route is calculated based on the models of the users with this impairments (e.g.

where there is unsigned pedestrian crossing the route for visually impaired user is directed around this place to safer crossing or for person on wheel chair the stairs are omitted from the route). There is also possibility to reuse the route using Case Based Reasoning [23], which takes into account preferences of the users and their impairments: the path of the user is recorded and offered to the user with the same profile (navigation instruction are derived from standard GIS system).

Naviterier [24] prototype of navigation system for indoor and outdoor based on detailed environment description and well-specified steps to follow. User navigates himself/herself based on the navigation instruction given by the system. The instructions are segmented to logic parts (door to door, corner to corner, etc.) and contains all the information needed for visually impaired user to find and recognize specific location on the route.

Another navigation system in research is TANIA. This navigation system [25] is based on small wearable computer and GPS and movement sensor. The movement sensor helps to better estimate precise position of the user. Navigation instruction are presented on touchscreen display with voice and acoustic output.

The last to mention is navigation system based on RFID grid and reader connected to smartphone [26]. The RFID tags are located on the leading lines used by blind people such as sides of the pavement or corners of building. The position of user is determined from the identification number of the RFID tag.

2.1.2 Navigation Call Centers

Trained navigation instructors and operators in navigation center (e.g. navigation center of Czech Blind United - SONS [2]) create description of complicated parts of the city or use model-centric navigation to guide visually impaired by telephone call or to send him prepared navigation instruction (including public transport) by email. There is an option for visually impaired to carry special device for localization by GPS [27]. Than the operator can see location of the visually impaired person and can help him or guide him in the situation of loss of orientation. Despite the obvious benefits of this type navigation system it lacks 24/7 working hours and the number of operators is limited to currently four operators.

2.1.3 Wearable Navigation Systems

The wearable navigation system uses many sensors such as camera, headset for communication, GPS or even Microsoft Kinect [5, 28], to analyze image and provide visually impaired users information about their surroundings. Some of the navigation systems enable a remote operator to see user's surroundings and help the operator prepare more accurate navigation instruction [29, 7, 30]. There are also systems, which uses speech recognition to avoid the need of the remote operator [6].

The computer vision algorithms can provide useful results for navigation, but there are many constrains for the usage, such as good lightning and capturing the right part of the surrounding area. Mainly the one mentioned later is problematic for visually impaired user. The problem of capturing right part of the surrounding area can be partly removed by mounting capturing device firmly on the user (on the particular part of the body under particular angle [7]), but it still does not remove problem of obstruction of the image by distant object, which the user cannot locate.

Even though the wearable computers represent the highest level of technical equipment they are often expensive to purchase, maintain and uncomfortable to wear.

2.1.4 Tactile Navigation Aids and Displays

The multimodal interaction techniques became very popular in the mobile environment where the common way of interaction (watching large display, typing on physical keyboard) becomes inefficient (small displays) or unusable (small sized full keyboards). The most exploited alternative interaction techniques are voice or touch input and output. However it seems that the voice communication especially in noisy environments is not always as suitable as necessary and the haptic interaction is used in a very simplified way (touching solid surfaces - mostly glassy displays or vibrations). Moreover if we would like to present complex information (with complicated structure - rich semantic relations between information parts and several abstract layers) we will very fast reach the expressivity limit of the voice output as it can present the information in sequential way only.

The haptic interaction as it is presented today (vibrations of solid devices) has very limited expressivity potential. Voice input is also limited as it shows low reliability and long response times. The touch interaction (typically touching glassy surfaces) lacks rich haptic feedback for the user what results in discomfort during interaction.

If we combine the mobile environment with potential user limitations (e.g. user driving a car or visually impaired user) we must conclude that the alternative interaction techniques as they are presented today are inefficient. This is true especially if we take into account that if the limitations of common communication channels last for longer time than the user can learn to use alternative communication channels very efficiently [31], but this potential is not exploited fully.

Expressivity of Haptic Interfaces

There are several haptic features, which can be used for representation of heat map data for visually impaired users. The temperature, shape and gestures are the most common.

Temperature Temperature is a very rarely used interaction technique, although it is naturally embedded in human language as a metaphor for social proximity and feelings (e.g., "They gave him a warm reception" or "She gave him an icy stare."). High temperature comes with metaphors like safety, solidarity or friendship, whereas low temperature comes with metaphors like alienation or solitude [32].

The sensation of cold or hot is given by the difference from the individual neutral zone wide around $6-8\,^{\circ}\mathrm{C}$ [33]. Within this neutral zone no changes of the temperature are distinguishable. The skin can also adapt to the perception of temperature. The sensation of coolness was reported at $28.5-29.5\,^{\circ}\mathrm{C}$ and sensation of warmth at $37.5-38.5\,^{\circ}\mathrm{C}$. The pain thresholds for temperature are $46\,^{\circ}\mathrm{C}$ and $11-13\,^{\circ}\mathrm{C}$ [34].

Gesture Touch interaction technique is commonly used and is very natural. Moreover hand gestures like squeezing or tight grasp also reflect metaphors from the real world. These gestures also appear in human language as metaphors for strong intention (grasp in order to initiate function [35]) or getting something from inside (see Figure 2.1).

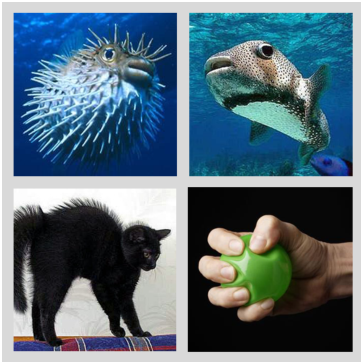


Figure 2.1: Top left - porcupine fish in danger, top right - porcupine fish feeling safe, bottom left - bristling cat, bottom right - squeeze of ball.

Shape Another neglected haptic feature in user interfaces is a shape. There are several user interfaces using shape transformation back and forward from physical to virtual world respectively [36]. They were created to proof a concept of manipulation both virtual and physical world not as user interfaces for everyday use. As mentioned for temperature and gestures also the shape comes with metaphors. The spiky objects resemble something dangerous on the other hand soft object are safe and cannot cause and harm. One example coming from the nature is a porcupine fish (see Figure 2.1), which changes its shape depending on the feeling of safety. Another example is domestic cat, which is soft if safe, but when it is scared it bristles. The shape also supports affordability of an object. It can express the purpose of an object but also its usage and interaction e.g. handle of the door.

Tactile Displays

There are experimental UI designs introducing tangible interfaces (typically combined with large wall or table touchscreens) [37], which confirm that enriching the haptic interaction increases the efficiency of user interaction, however the real application of some designs is not clear, e.g. Kinetic Tiles [38].

Some of the interfaces go from the side of providing spatial information to people with low ability to explore environment e.g. visually impaired people. Espinosa et al. [39] conducted an experiment where visually impaired people were learnt new complex routes through city using direct experience with usage of tactile maps. The results show that new routes can be learned with navigation expert in direct experience or with help of tactile map or by tactile maps itself if the direct experience is not available.

Electro mechanical equivalents to the prefabricated tactile maps (e.g. made from wood) can be found in tactile displays. First to mention is 3D tactile display created by Shinohara et al. [40]. This display consists from array of 64×64 tactor pins and creates hexagonal matrix. By means of changing the height of the tactor pins a 3D image can be shown. Xu et al. [41] used hand TeslaTouch [42] electro vibration display (with no mechanical parts) to conducted an experiment with visually impaired participants and their ability to distinguish different types of rendering styles on TeslaTouch.

Another research has been made in the field of exploring virtual environments. Schneider et al. [43] created a method called constructive exploration to enable visually impaired people to explore virtual tactile map. This system uses force feedback device based device – Phantom [44]. Another attempt to use virtual reality and Phantom was research by Simonnet et al. [45]. They proposed a system helping visually impaired sailors to explore naval maps.

The last mentioned systems are based on usage of Phantom devices. Lécuyer et al. [46] on the other hand use modified white cane to interact with virtual environment. Their system uses multimodal interaction by means of force feedback equipped white cane, simulation of the heat from sun (by circle of infrared light lamps around user) and auditory simulation of the virtual environment (such as footsteps of virtual guide or ambient noise).

Mobile Tactile Devices

The systems used for exploration of the virtual environments based on force feedback are rather complicated and not mobile enough for user to carry around. This problem try to solve Yatani et al. [47] by adding tactile pad to touch screen smart phone, which can be used by visually impaired people. They use 3×3 vibration motors to simulate direction of the destination selected of the user.

Another system using touch and tactile feedback are tactile displays mounted on the chest. Bourbakis et al. [48] use 2D tactile pad mounted on user's chest together with image recognizing software and project obstacles in front of the user to the tactile pad. On the other hand van Erp et al. [49] conducted experiments with 1D tactile belt around user's chest to simulate obstacles in 3D virtual environment around the visually impaired user.

The last to mention is the navigation system based on ultrasound handle, which conveys information to the user through different types of vibrations based on the orientation and the distance from the obstacles [50]. The vibro-tactile actuators are located under each finger (4 per finger) and information is coded by intensity levels and pulse duration.

2.2 Research in Cognitive Psychology

An extensive research in cognitive psychology has been already done, especially research in cognitive mapping, way finding and coding strategies of visually impaired [10, 11, 51, 52]. This knowledge is essential for designing every navigation system for visually impaired, which is based on navigation instructions and speech output. As the visually impaired (particularly blind) people use diametral different navigational points and orientation keys than sighted people. Following sections covers elemental works from the field.

According to Downs [53]: "*Cognitive mapping* is a construct which encompasses those cognitive processes which enable people to acquire, code, store, recall, manipulate information about the nature of their spatial environment, and is an essential component in the adaptive process of spatial decision making. Similarly, a *cognitive map* is an abstraction, which refers to a cross-section, at one point in time, of the environment as people believe to be."

2.2.1 Cognitive Mapping of Visually Impaired

There is clear distinction among people who have visual memory (e.g. lost their sight during the life) and people who are congenitally blind. The former later blind people have some visuo-spatial memories and tent to navigate similarly to sighted people. On the other the latter mentioned people without visuo-spatial memories had to developed different strategies to cope with navigation.

Another important aspect in navigation and orientation of visually impaired people is the difference between near and fare space in which they perform particular task. The near space – haptic space – relates to small-scale or manipulatory space e.g. areas that can be explored without changing position of the body. The far space – locomotion space – relates to medium- or large-scale space e.g. areas in which locomotion is required for exploration [10].

The strategies for cognitive mapping have also impact on the efficiency of the navigation. For instance the research made by Bradley and Dunlop [54], who stated that visually impaired people are more efficient and have less workload if they are given navigational instruction by other visually impaired people more than by untrained (in the navigation of visually impaired) sighted. However this work does not cover the communication among visually impaired and their habits and subjective preferences in the search for the help.

2.2.2 Coding Strategies in Haptic Space

There are two options of coding the location of an object in haptic space: either by reference to our own body and movements or to some external network. People with little or none visually experience tend to code spatial relations by reference to their own body. On the other hand for sighted people is more natural to code the position to an object relative to other objects (external network) [10].

Coding strategies based on the reference to a body are more reliable in haptic space and are equivalently efficient as strategies used by sighted people [55].

2.2.3 Way finding and Cognitive Maps in Locomotor Space

From the various methods used to investigate cognitive maps of blind people the most common is direct reproduction of the route.

It was found that blind children were less accurate in reproducing familiar environment (school campus) than sighted one, however there were some individual differences where blind participants were more accurate than sighted [56]. It was later proven that the congenitally blind participants had a tendency to linearize curved paths, that the maps were segmented and the features of the routes were more accrued on familiar routes.

Some of the studies of locomotor space were focused on the problem of exploration of the unknown space [57, 58]. They have identified several strategies from the behavior of the blind participants:

- *Perimeter* – Explored the boundaries of an area to identify the area's shape, size and key features around its perimeter, by walking along the edge of the layout.
- *Grid* – Investigated the internal elements of an area to learn their spatial relationships, by taking straight-line paths from one side of the layout to the other.
- *Object to object* – Moving repeatedly from one object to another, or feeling the relationship between objects using hand or cane.
- *Perimeter to object* – Moving repeatedly between an object and the perimeter.

- *Home base to object* – Moving repeatedly between the home base (origin point for exploration) and all the others in turn.
- *Cyclic* – Each of the four objects visited in turn, and then returning to the first object.
- *Back-and-forth* – Moving repeatedly between two objects.

It was found that perimeter and gridline strategies used in isolation gave good knowledge of object location, however in a test of integrated spatial knowledge had these strategies poorer results. The most successful participants tended to use object to object, perimeter to object or home-base to object strategies, and also often used a wider range of different strategies.

It was also found that the cyclic patterns were used mainly by early blind participants (individuals who were born blind or lost sight before the age of 3 when visuospatial concepts were not fully developed), whereas late blind and blindfolded sighted participants tended to use the back-and-forth strategy, which was associated with good performance. Conversely, cyclic exploration was associated with a poorer performance.

Generally the experiments with blind participants show that the lack of visual experience does not prevent them from acquisition of spatial representation and creation of cognitive maps. Also it was proven that totally blind participants perform at the level of sighted participants on spatial tasks. Spatially relevant information is available through senses other than vision, like through hearing, touch and movement, and this information can form the basis for spatial coding. And important is that the processing of spatial information by congenitally blind people is not necessarily less efficient than by sighted people.

2.3 Usability Testing in Collaborative Environment

The problem of user communication in a collaborative environment is similar to the problem of agent systems in terms of multiple entities (agents or users) communicating and collaborating together. This problem is solved in tasks dealing with simulation of pedestrians using agent systems [59]. However in that case whole visualization runs over rectangular grid (principle of work of pedestrian agents multi-agent cellular automata system) and terrain is represented by a custom-made 3D street model [60] or by the rectangular grid itself. On the other hand there are systems based on Google Earth [61] maps [62], which are close to our proposed system by means of map usage.

From the field of visualization of usability testing with visually impaired users an interactive analytical tool for usability analysis of mobile indoor navigation application [24] exists but does not solve the test supervision. The other system which solves the observation of usability testing are Morae [63] and similar products.

2.4 Discussion

The common problem of state-of-the-art navigation solutions for visually impaired people is lack of environment description created with respect to their cognitive mapping and orientation strategies, and rich multimodal interface capable of delivering complex information without visual cues (see section 1.2 Problem Description). As a solution to these issues we propose navigation system based on collaboration of visually impaired users (see chapter 3 Proposed Solution).

3 Proposed Solution

The principal problem is how to gather the specific description of the environment where the visually impaired users will navigate. As a solution to the situation described on Figure 3.1 a navigation system based on collaboration between visually impaired users was proposed.

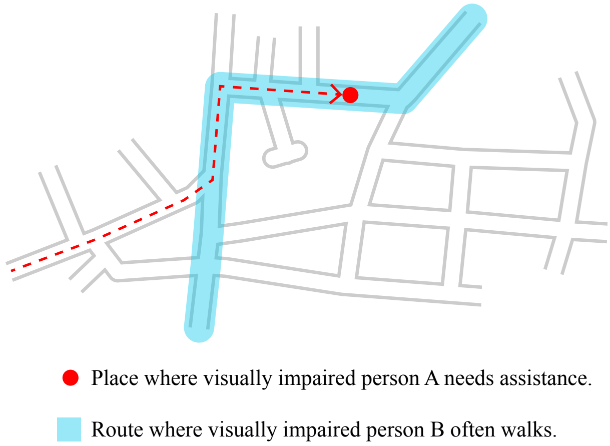


Figure 3.1: Scheme illustrates the use case (see section 1.1 Use Case) and shows environment description shared between visually impaired persons. The blue area marks the part of the urban environment known by visually impaired user B. The visually impaired user A got lost in the area known to the user B. The goal of collaborative navigation system is to identify user B and to connect user A to user B in order to get description of the area and solve navigational problem.

The collaboration among the users can be generalized as cognitive information communication in which communication takes place at cognitive level in intra-cognitive sensor sharing (i.e. members of communication share what they perceive via several sensory channels one visually impaired person describes what he/she hears, smells, touches, etc. to the other one) [64].

The essential conditions for such navigation system are:

- the existence of communication among visually impaired users about navigation and ability to share their knowledge (needed for helping other visually impaired users with navigation),
- and the sufficient length of regularly walked routes they remember to every detail.

The problem of selecting suitable visually impaired person who will give the lost user useful description of the environment is not trivial as it is shown in the previous chapters (see section 1.1 Use Case) and the complexity of this problem leads to the problem of reality (data) mining [65].

The proposed collaborative navigation system for visually impaired is based on the two main principles:

- the first is the knowledge gained from cognitive psychology of visually impaired people (the mental models of the environment) and
- the second one is derived from their natural behavior (segmenting of the route rich in navigational points and orientation keys recognized by visually impaired).

The main difference from the existing state-of-the-art navigation systems (see chapter 2 State of the Art) which are based on the environment description limited both in coverage of the city and in number of the navigational instructors, is *the utilization of the knowledge distributed among high number of visually impaired users in suitable quality* (see Figure 3.2) (common mental models, navigational points and orientation keys).

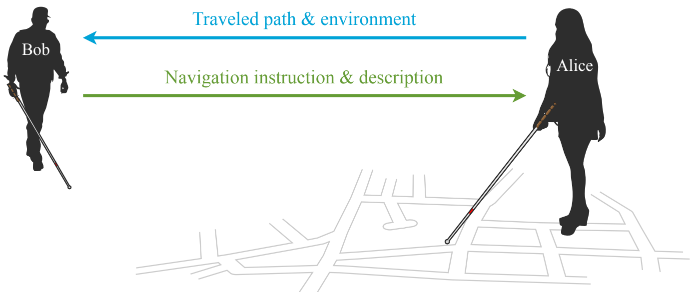


Figure 3.2: Resuming from loss of orientation and getting navigation instructions: user A (Alice) shares her traveled path and description of her surroundings with user B (Bob), than she receives navigation instruction with description of navigational points and orientation keys and further route instructions.

To explore the possibilities of creation and utilization of the collaborative navigation system of visually impaired we have conducted three studies. To help visually impaired users to get feeling of confidence and safety while independent traveling we have proposed the prototype of tangible heat map. The visualization tool was developed to help test supervision and later evaluation of usability testing of proposed collaborative navigation system.

The first study was conducted to clarify attitudes and habits of visually impaired users in communication with navigation instructors, friends, family and unknown persons in situation of the loss of orientation or need of help with navigation. The existence of communication among visually impaired people is the key condition for successful function of the navigation system.

The goal of the second study was to get insight into the structure and the length of the regular routes visually impaired people walk in the urban environment and estimate the average coverage of the city by their mental map and their ability to navigate others along the routes. It is obvious that there are individual differences in the distance and the quality of the environment description (level of detail of the environment they walk in) the visually impaired people remember (store in mental maps). This information is important for estimation of minimal number of users needed for successful operation of the proposed navigation system based on collaboration of visually impaired users.

The main aim of the third study was to identify general structure and patterns in communication between visually impaired person who lost orientation and some other person who try to help him via phone.

The target group for all studies comprised of visually impaired people of different age, duration of disability and technical skills. The target group consisted of persons with blindness of category 4 and 5 of the ICD-10 WHO classification [9] – blindness with light perception and no light perception - e.g. complete blindness.

3.1 Communication in Navigation of Visually Impaired

To gain initial insight into the problem of the communication in navigation of visually impaired users a user study has been made. The study comprised of qualitative and quantitative part [66].

- The qualitative study consisted of five semi-structured interviews and has been conducted to gain insight into the problem and to form basic hypotheses for the consequent quantitative study.
- The quantitative study has been conducted via e-mail based questionnaire, and the aim was to get statistically valid data and to validate the hypotheses formulated during the qualitative study.

The recruitment of visually impaired people who will agree with personal participation in a study is rather problematic. Therefore, for the quantitative study we have selected participants from a group of visually impaired people already collaborating with our department for longer time.

The quantitative study was conducted via email through mailing list of the navigational and educational center for visually impaired people Czech Blind United – SONS [2].

3.1.1 Qualitative Study

The qualitative study consisted of five one-hour semi-structured interviews with visually impaired participants. The goal of the qualitative study was to gain in- depth information about participants' favorite means of communication with other people, their openness to communicate with unknown people and willingness to help them with navigation, and the privacy problem of tracking and storing location of their movement.

The topics for the interviews were: frequency in which participants seek help from unknown people, their feelings in stress situations, their favorite narrative style for route description and their willingness to help other unknown visually impaired people in navigation and participate in program for collaborative navigation. In the evaluation of qualitative research results potential bias has to be considered due to the sensitive questions covering topics about participants' feelings and stress.

The following topics were discussed with five participants between 25 and 64 years (4 males, 1 female) during the semi-structured interviews:

- community of visually impaired,
- collaboration in navigation,

- experiences with location services,
- privacy issues of location tracking,
- behavior in situations of orientation loss.

Table 3.1 contains key factoids collected during the qualitative study with visually impaired participants. The majority of participants has experience with navigation of other visually impaired and/or were themselves navigated by another visually impaired person (No. 1). The majority of participants assesses instructions given by visually impaired person as better than instruction given by sighted (No. 2). The majority of participants finds asking unknown people for direction as natural part of the navigational process (No. 3). More than half of the participants expressed negative concerns about sharing their location for the purpose of helping other visually impaired (No. 4).

Table 3.1: Key factoids collected during qualitative study.

No.	Factoid	Occurrence
1	Participant has experience with navigating other visually impaired and was navigated by other visually impaired by mobile phone, ICQ, etc.	5
2	Navigational instructions given by visually impaired on known place are better than instruction from sighted.	4
3	Asking unknown people on the street for direction is natural part of the navigation process.	4
4	Negative concerns about collection participant's location.	3

One of the participants also mentioned that there is a problem with finding someone suitable to ask for help – some of the passerby people do not want to help him/her or do not speak Czech – and this is the reason he/she do not like to ask people on the street.

Hypotheses

Based on the qualitative study we have formulated following hypotheses:

- **H1**: Visually impaired user can navigate another visually impaired user via mobile phone.
- **H2**: Visually impaired user will prefer navigational instruction provided by the visually impaired person than by sighted one.
- **H3**: Visually impaired user will not hesitate to ask unknown people on the street to get right direction.
- **H4**: Visually impaired user will allow collecting information about his/her location to help with navigation of other visually impaired people.

3.1.2 Quantitative Study

The quantitative study was conducted based on a questionnaire compiled from the findings obtained in qualitative studies. The goal was to validate the hypotheses formulated based on qualitative study (see section above). The questions were focused on the following topics:

- behavior during obtaining navigation information from unknown people in the streets,
- preferences in contact selection when seeking for navigational instruction,
- navigating friends and family members via phone, email, instant messaging, etc.,
- requesting help with navigation from friends or family members,
- willingness to help unknown visually impaired person with navigation,
- privacy problem of position tracking.

In the quantitative study, 54 visually impaired respondents from 20 to 80 years took part. The respondents were 36 males and 18 females with average age 47 years, 17 of respondents were congenitally blind.

The questionnaires were sent by email to the mailing list of the navigational and educational center Czech Blind United – SONS [2]. Not all of the questions were correctly filled in due to the respondents' type of impairment (the exact number is mentioned in the results if only the part of the participants were able to correctly fill the answer) and only the correctly filled in questions were taken into the account.

Figure 3.3 shows the preferences in selection of the contact, which will help the visually impaired person with navigation in unknown place. Higher bar represents higher score calculated from the ordering of following four variants: blind person who does not know the place of navigation; sighted person with experience with navigation of visually impaired; blind person who knows the place of navigation; and sighted person with no experience with navigation of visually impaired.

Figure 3.3: Preferences in selecting contact for help with navigation.

Majority of respondents selected sighted person with experience with navigation of visually impaired as the best option to get good navigational information (navigation instructor). The important fact is that as the second best option for getting good navigation information respondents selected other visually impaired person rather than sighted with no experience in navigation of visually impaired.

Due to complicated instruction how to answer the question from which emerges Figure 3.3 – ordering of four variants – the complete responses were collected only from 31 respondents.

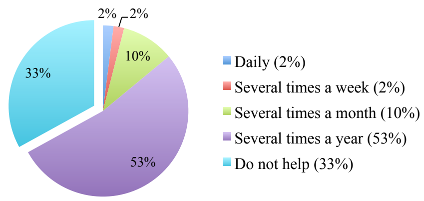


Figure 3.4: Amount of respondents helping friends or family members in navigation.

Figure 3.4 and 3.5 show the behavior in the situation when the visually impaired user helps or is guided by other visually impaired friend or family member. The major part (67% – daily 2%, weekly 2%, monthly 10%, yearly 53%) of respondents has experience with navigation friends or family members by phone, email or instant messaging or was guided themselves (51% – daily 2%, weekly 0%, monthly 8%, yearly 41%).

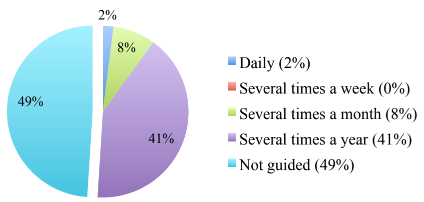


Figure 3.5: Amount of respondents being guided by friends or family members.

Almost half (51% – do not like asking 47%, do not ask 4%) of respondents does not like to ask unknown people for help or do not ask them at all. On the other hand, the rest of participants finds asking unknown people on the street as the natural part of the navigation process (see Figure 3.6).

Figure 3.7 shows that 68% of all respondents have no concerns about location tracking to help choosing right contact for visually impaired user in need of help. Minority of (12% – mind 4%, rather mind 8%) of participants will have problems with location tracking.

3.1.3 Discussion

It seems that the hypothesis H1 is proven as the visually impaired users reported the ability to navigate or to be navigated by other visually impaired users. Figure 3.4 and 3.5 show that visually impaired users already collaborate on navigation in the small groups of users – family

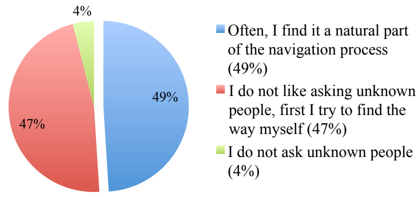


Figure 3.6: Asking unknown people on the street for direction.

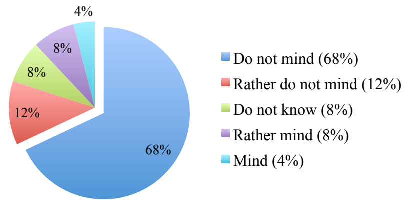


Figure 3.7: Amount of respondents concerned about position tracking.

or groups of friends. We believe that appropriate tools and aids could further enhance the collaboration of these groups. These tools and aids should help to connect unknown visually impaired users who can collaborate on their navigation.

The hypothesis H2 is valid only if we take into account inexperienced sighted people. For expert sighted people the H2 is not valid. From the Figure 3.3 it is obvious that visually impaired people overestimate quality of description from sighted expert in comparison to visually impaired who know the description of the area.

Respondents seem to expect that the description provided by the sighted expert will be more customized to their needs as the expert has more information sources available.

Contrary to the hypothesis H3 51% of participants hesitate to ask unknown people for instructions for navigation (see Figure 3.6). However, the size of this group of participants can be attributed to the fact mentioned by one of the participant of the qualitative study - the problem with finding suitable and willing person who will help. We believe that this problem can be solved by means of usage of our future system, where all of the users suggested by the system for providing help will have the valuable information for navigation and will be willing to help.

For accurate selection of the proper person who will give the lost visually impaired person the right information, the location of all users has to be stored and analyzed. As the Figure 3.7 shows 68%, of all respondents have no problem with location tracking and storing. If the part of participants who rather do not mind (12%) the location tracking is added, 80% of participants have proven the hypothesis H4.

3.2 Regular Routes of Visually Impaired

We have conducted a second study [67] which goal was to get insight into the routes visually impaired people often walk in urban environment and to measure average length per participant to estimate minimal user base for our proposed navigation system based on collaboration of visually impaired.

The regular route is the route, which visually impaired person, walks very often (e.g. weekly) and knows the description to every detail with leading lines, navigational points and orientation keys recognizable by visually impaired. These routes can typically lead from home to nearest public transport stop, shop, school, work, etc.

The recruitment of visually impaired people was done via mailing list of the navigational and educational center for visually impaired people Czech Blind United – SONS [2].

3.2.1 Method

As the method for collecting regular routes of visually impaired people, we first considered long term GPS tracking as a best solution. As the regularly traveled routes are in our focus, the tracking of one person should have been approximately 4 weeks long. Subsequently an interview should have been performed to verify the quality of the environment description visually impaired participants remember.

On one hand the long-term field study would bring more data for the measured regular routes and for instance enable us to observe possible time needed to learn new routes. On the other hand it would require additional interviews to find out the level of detail of the environment description stored (and additionally prove learning of the new routes), and long time for observation which would disproportionately prolong the time of the experiment considering number of participants needed. There would also be a problem with cleaning the data from the routes measured in public transport (we are only interested in routes visually impaired people walk and therefore create mental model of the environment) and to cope with bad accuracy (possible errors in tens of meters) of GPS in urban environment. Above that, the participants would have to be trained in operation of the tracking device such as charging batteries and basic maintenance.

Considering all pros and cons of the previously discussed method we have chosen the qualitative approach which enabled us to explore regular routes to more detail (such as on which side of the street participant walks). We have invited 20 visually impaired participants with blindness of category 4 and 5 of the ICD-10 WHO classification [9] (blindness with light perception and no light perception) to discuss regularly traveled routes in the urban environment.

Table 3.2: List of participants of the study and their location and age.

Number of participants	**Male / Female**	**Category 4 / 5 [9]**	**Mean age**	**Mean duration of disability**	**Congenitally / late blind**
20	10 / 10	8 / 12	42.3	26.3	9 / 11

There were 10 male and 10 female, average age 42.3, average duration of disability 26.3 years, 8 of 20 participants with category 4 blindness and 12 with category 5 [9], 9 participants congenitally and 11 participants late blind and 2 participants who use guide dog; 16 participants of the study live in Prague, 4 others in other larger cities (See Table 3.2).

The main objective of the interviews were to:

- identify regular routes of visually impaired,

- measure approximate length of the walked routes,
- estimate contribution to present network of public transport,
- and estimate number of participants for successful operation of collaborative navigation system.

The participants were asked to describe their weekly walked routes e.g. for work, shopping, library, nearest public transport stop, etc. as detailed as possible as if they were navigating another visually impaired person. Later we reconstructed the routes from the recorded description into the map, measured the length for every participant, and created heat map coverage of the city (see Figure 3.11, 3.12). We have included both direction of some routes (e.g. from home to bus stop and back) as the description of the route can significantly differ in leading lines, slope of the surface and other navigational points and orientation keys.

3.2.2 Qualitative Study

Twenty visually impaired participants who were interviewed regularly walk (i.e. remember the description of the environment) 93.3 km of regular routes in total (see Table 3.3). This sum represents the length of unique regular routes for all participants (e.g. route to the shop twice a week counts as one unique regular route). Mean length of the routes per participant is 4.6 km. Participants of the study visits 4.2 destinations on average (e.g. restaurant, work, school, hobby, shopping, etc.). Public transport stops are not counted as destination if they are on the way to other places i.e. nearest tram stop from home.

Table 3.3: Results of the study on the regularly walked routes.

Number of participants	**Mean length of the routes**	**Total length of the routes**	**Mean number of destinations**
20	4.6 km / participant	93.3 km	4.2 / participant

Figure 3.8 shows the effect of the congenital blindness and late blindness on the length of the regularly walked routes. There is significant difference in the mean length of the routes in late blind group, which is 1 709 m longer than in congenitally blind group. Partly we thing this is due to inertia from the time when the participants were sighted and they lived more actively and traveled more around the city. On the other hand, the group of congenitally blind tends to optimize from the birth to use the best (safest) route and tend to use public transport as much as possible. However, this assumption needs further investigation and research mainly on different cognitive mapping strategies between congenitally and late blind people.

Figure 3.9 shows the relation between different categories of visually impairment and length of the regularly walked routes. The participants with blindness with light perception (category 4) have in average 982 m longer regular routes than participants without light perception. This may be due to the fact that visually impaired participants with category 4 blindness use the remains of sight (light perception) as the navigation aid or to the fact that they have deteriorating impairment and have many visually oriented memories of the environment.

Figure 3.10 shows data for all participants and their age. As it was expected there are significant differences among all participants. Some of the participants walk long routes to the

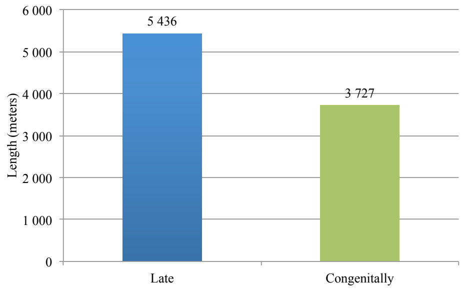


Figure 3.8: The effect of duration of blindness (congenital or late) on mean length of the regularly walked routers.

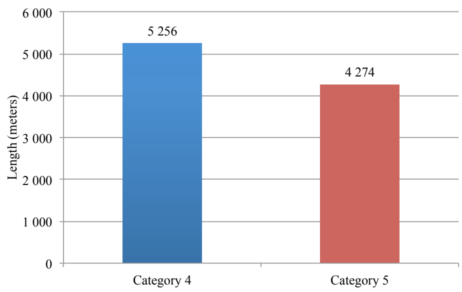


Figure 3.9: The effect of category [9] of blindness on mean length of the regularly walked routes.

nearest public transport or just for a walk. On the other hands some participants avoid walking and use public transport as much as possible or use a guide for unknown or complicated places.

Figure 3.11 shows a heat map where number of routes in certain place is mapped from blue to red values. Red areas indicate the place where exists larger number of regularly walked routes from one or more participants. Similarly, Figure 3.12 shows the same heat map for whole city of Prague.

3.2.3 Discussion

Many of the regular routes of the participants start or end at public transport stops that are usually easily accessible by visually impaired people. The total length of the public transport network in Prague is 1029.8 km (subway 59.4 km, tram 142.4 km and bus 828 km) [68]. The regular routes of 20 visually impaired people, who participated in the study, are 93.3 km long in total. In such way, they extend the current public transport network by 9% and make accessible surrounding area around public transport stops.

To cover the area accessible nowadays by public transport the proposed collaboration navigation system for visually impaired would require approximately 200 active users for Prague (considering non of them share the same route). The Blind United Union (SONS [2]) has over 10 000 members in whole Czech Republic. Considering that 1/10 of the population lives in Prague there is at least one thousand visually impaired. This number corresponds with the estimated number of visually impaired (blind) in Czech Republic which is 10 000 – 20 000. These results fulfill the essential condition about the existence of the sufficient length regular

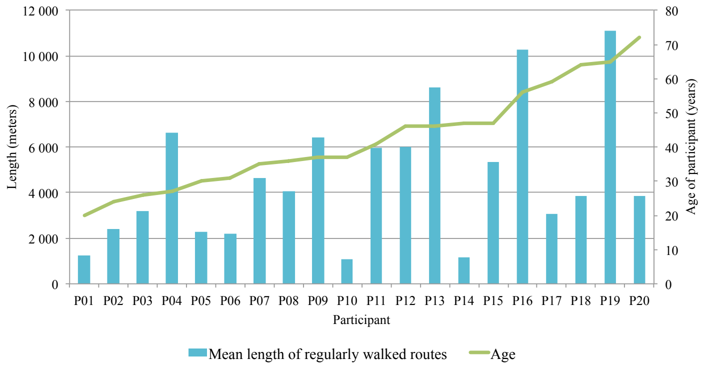


Figure 3.10: The relation between the age of the participant and the mean length of the regularly walked routes.

routes and make the collaborative navigation system feasible.

3.3 Tangible Heat Maps for Navigation of Visually Impaired

Our experimental collaborative navigation system for visually impaired people is based on the idea, that the best navigation help can be provided (besides specially trained navigators) by other visually impaired users that know well the area where the navigation help is needed. This presumption was confirmed by the user research performed with 54 visually impaired users [69].

In our scenario the visually impaired user visits unknown area where the probability of getting lost increases and the stress level is rising. The user is equipped with our navigation system that can provide navigation help when needed. When the user gets lost he/she can request help from another visually impaired user who knows well current area (see Figure 3.1).

3.3.1 Use Case

Our idea how to reduce the stress level is to inform the user about the probability of getting proper help. The probability increases with the number of visually impaired people that visited this unknown area. If it is high the self confidence (due to drop of the stress level) and the feeling of safety (due to feeling of social proximity) of the user can increase significantly. The number of other visually impaired users who visited certain area can be typically presented by means of color heat maps (see Figure 3.12 in section 3.2 Regular Routes of Visually Impaired) which are unusable for our user group.

In this part we focus on maximal exploitation of the haptic modality for visually impaired users. Our approach is inspired by the concept of ”super abilities” which are developed by impaired people to manage their limitations [31]. For example visually impaired people can listen to faster speech and their tactile sensitivity is more accurate.

Based on the analysis of expressivity of haptic interfaces (see section 2.1.4 Expressivity of Haptic Interfaces) we present a tangible heat map prototype which allows rich haptic interaction with the heat map. With this prototype the user is able to instantly check the value of the heat map given by his/her actual position in the unknown area.

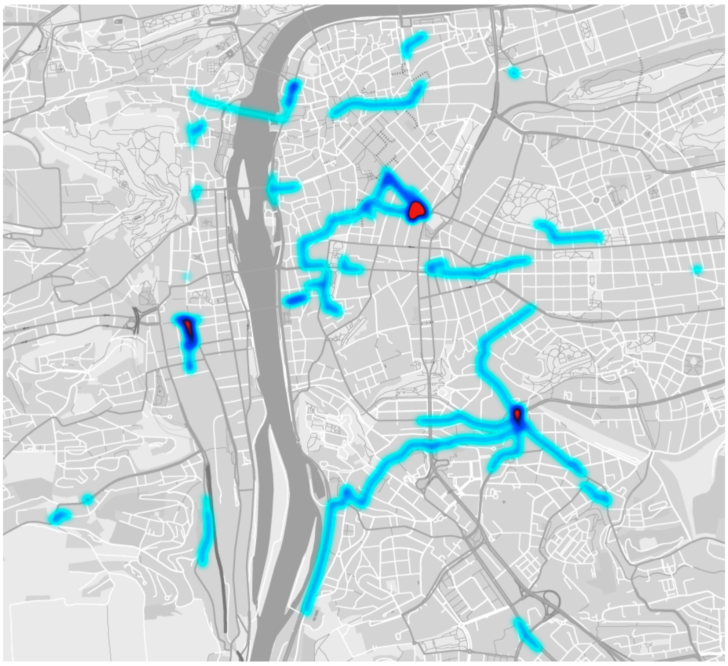


Figure 3.11: Heat map of the routes in city center of Prague.

As mentioned above we would like to present a heat map by means of haptic interaction technique instead of visual one. This is demonstrated by so called tangible heat map prototype which exploits several metaphors: density (low is cold, high is warm); language expressions for social proximity (warm welcome, icy stare); animal behavior (bristling of skin in danger).

Following haptic interaction techniques (see section 2.1.4 Expressivity of Haptic Interfaces) are used to follow described metaphors:

- *Real heat* – metaphor for heat map value and social proximity.
- *Surface shape* – with spikes or smooth as metaphor for safety.
- *Squeeze gesture* – metaphor for getting precise value of heat map.
- *Shape of the device* – affords grasping by hand.

There were several issues influencing the form design of the prototype. The device should afford touching and grasping. As visually impaired people use one hand for holding white cane (or dog leash) while walking the prototype should be handled by one hand only.

Another issue was the placement of the prototype. There were several proposals where to attach the prototype. One approach was to attach the prototype to an object of daily use such as mobile phone or white cane. Another approach was to attach the prototype directly to the users body. We considered glove, sleeve or bracelet as forms of the prototype which were rejected due to possible limitation of the wrist and finger movements which are essential for visually impaired people.

The final form of the prototype is an oval with a hole inside ergonomically shaped so it can be easily grasped by the hand (see Figure 3.13) and put into the pocket. The values from the heat map can be obtained by gripping a palm. They are literally squeezed out of the prototype.

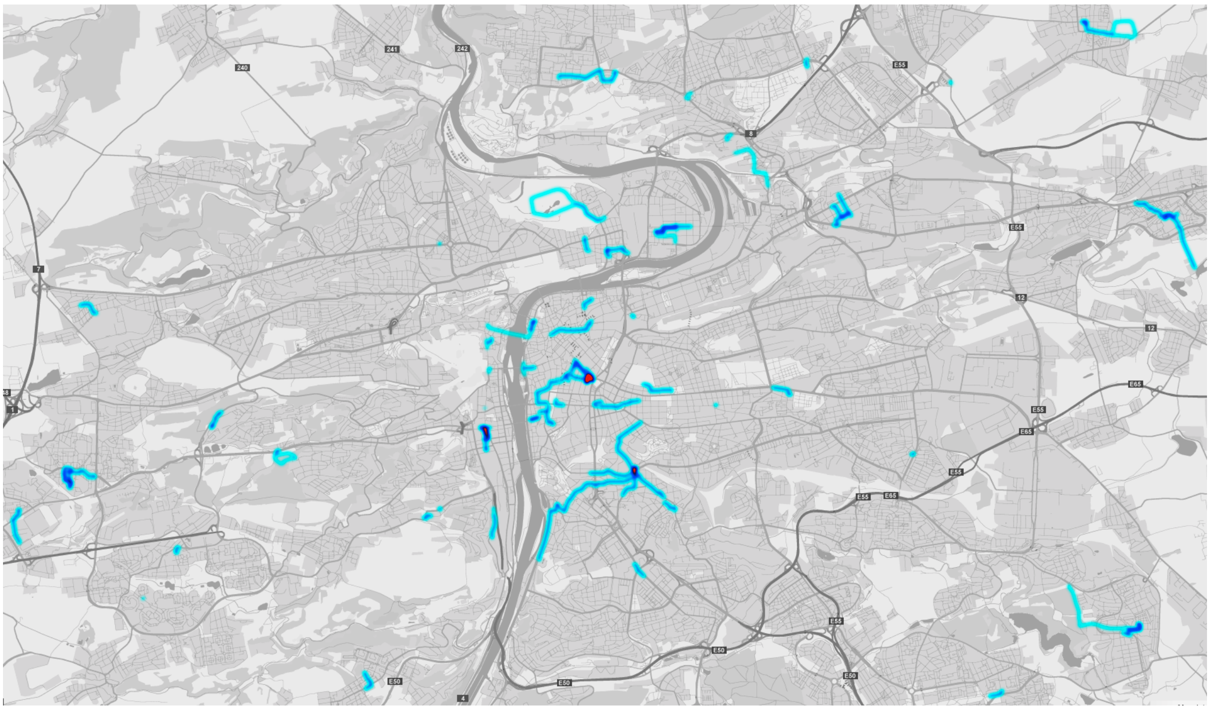


Figure 3.12: Heat map of the routes in whole city of Prague.

The prototype is made of silicon which is pleasant for touch and is a good conductor of heat. The surface is made of small protrusions, which change their height based on the number of potential guides (see Figure 3.14).

3.3.2 Mapping values to haptic interface

The following table (see Table 3.4) contains mapping of values from color heat map to haptic interface. For each of three haptic interaction methods there is defined behavior for two different value ranges of the heat map - low and high.

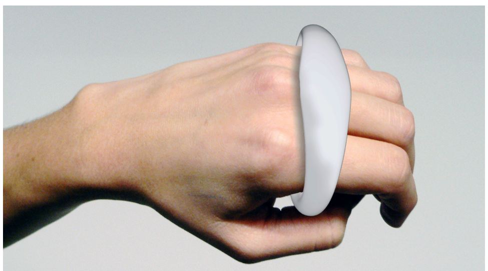


Figure 3.13: Tangible heat map prototype on the hand.

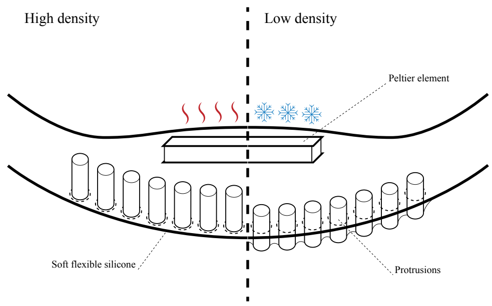


Figure 3.14: Protrusions on the surface change their height according to the heat map density.

Table 3.4: Mapping of heat map values to haptic interaction methods (see Figure 3.15a and 3.15b).

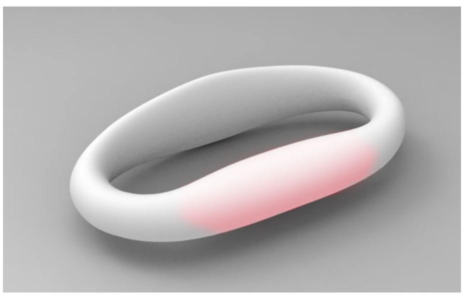
Haptic interaction	**High value**	**Low value**
Temperature	Warm	Cold
Shape	Plain	Spiky
Gesture (grasp)	Voice (precise value)	

3.3.3 Discussion

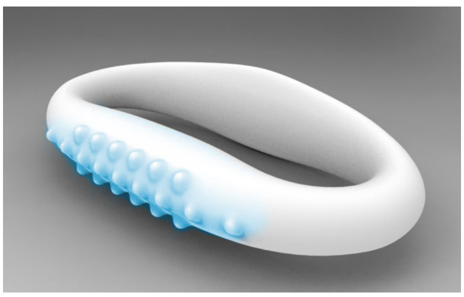
We have designed an prototype of a tangible heat map for visually impaired users, which can instantly provide the visually impaired user with number of potential guides (other visually impaired users familiar with current area) while walking through unknown area [70].

The following user study with visually impaired users should clarify proper selection of metaphors for haptic interactions and analyze emotional feedback. The selected shape and the from of the prototype should be also verified during this study.

We will also examine possible combinations of haptic interactions e.g. use shape of the material as more precise indicator of heat/cold level and abilities of visually impaired users distinguish heat and shape.



(a) Warm plain shape in the area with *high* number of potential guides.



(b) Cold spiky shape in the area with *low* number of potential guides.

Figure 3.15: Prototype shape and temperature based on the number of potential guides in the area.

3.4 Recovery From Loss of Orientation

The aim of the following study is to get insight into the process and structure of the dialogues among visually impaired people and a hypothetical assistance center in the situation when they lose orientation [71]. The results were used to design dialogue model which can be used by both assistance centers for visually impaired and for purpose of collaborative navigation system. The structure of the dialogues is important for fluent and fast communication and mutual understanding among the users.

There are many elements and factors that must be considered, such as context of a whole dialog, relationships between actors and their current state of mind, but also individual dispositions and characteristics of particular persons or disruptive effects for example.

Also communication skills and abilities of particular persons are mutually very different as well as their approaches to the communication. Therefore, it is practically impossible to identify some general communication patterns that would be applied to all people. But it is possible to reach this on some specific and exactly defined domain and this is precisely the case of this thesis. Therefore, the main aim of this part of work is to identify general structure and patterns in communication between visually impaired person who lost orientation and some other person who try to help him via phone.

3.4.1 Qualitative Study

The qualitative study comprised from two parts (described later) in which 16 blind people participated (see Table 3.5). The aim of the study was to find out how blind people behave in a situation when they lose orientation. Both of the parts were performed via interviews.

Table 3.5: List of participants of the qualitative study.

Part	Number of participants	Mean age	Male / Female
A	4	47.5	3 / 1
B	12	39.6	4 / 8
Total	16	41.6	7 / 9

Part A

The main objective of this phase of the study was to get initial insight into an issue of navigation of visually impaired and determine how visual impaired people are behaving in a situation when they lose orientation. What do they feel in such a situation, how they exactly react to it and how it would be possible to help them in such a situation. The topics of the first part of the interview were:

- Movement in an outdoor environment.
- Orientation aids.
- Experience with a loss of an orientation.

- Ideal form of help in situations when orientation is lost.

Part B

The main objective of this phase of the study was to extend and more specify findings from the first phase of the qualitative study. Especially those findings that relate to situation when visual impaired people lost their orientation and try recover by phone in cooperation with an assistant center. At the beginning the participants were introduced to imaginary situation on which they were asked questions:

> *"Imagine that you are going by the bus. Reporting of stations is turned off, and you have miscalculated passed stations, so you get off at a different station than you think. But neighborhood of the station is very similar to a place where you originally wanted to get off. Therefore, you will proceed by a way which you think that you know. You will go for a while and then you find out that a route does not continue as it should. But you are not sure why that is - if you mistook a station, or made a mistake somewhere along the route."*

A semistructured interview was chosen as a method to give participants space to express themselves about particular issues. This approach enabled us to find out much more information about particular issues than only simple answers to direct questions.

Hypotheses

Following five hypotheses were defined from findings collected during interviews conducted in the qualitative research with 16 visually impaired participants:

- **H1:** There is the crucial difference between navigation of visually impaired persons who use a cane for blind and who use an assistance dog.
- **H2:** When orientation is lost, visually impaired people are able to describe their situation to a phone sufficiently precise to enable to a called person to identify their position.
- **H3:** It is possible to navigate a visually impaired person who lost an orientation through a phone.
- **H4:** The most important navigational points and orientation keys for a remote navigation of visually impaired persons are possible to detect by a cane.
- **H5:** When visually impaired people who lost orientation receive the help from a phone, they tend to verify in some way the given information.

3.4.2 Quantitative Study

The basic hypotheses were formulated from the previous qualitative studies. For the purpose of practical verification of these hypotheses the quantitative ethnographic field study has been realized with total 21 participants. To ensure validity and correctness of results this study was divided into two parts, both parts have been realized in a different environment.

Test A was performed with 5 participants and Test B was performed with 16 participants. The dialogs were recorded during all sessions. The group of participants consisted of 12 males and 10 females in age from 21 to 60 years with the average age 34.5 years, 14 participants were totally blind and 14 participants were congenitally blind (see Table 3.6). Two participants regularly used an assistance dog.

Table 3.6: List of participants of the quantitative study.

Number of participants	**Mean age**	**Male / Female**
21	34.5	12 / 9

The main objective of the qualitative study was to confirm or refute hypotheses (see section 3.4.1 Hypotheses) and identify behavior patterns of visually impaired people in the situation when they lose orientation and try to recover through phone. Important behavior patterns of visually impaired people in the situation, when they lose orientation, were successfully identified and dialogs recoded from communication among participants and our prepared assistance center.

For the purpose of this study two test scenarios were prepared. To ensure the correctness and accuracy of results both tests had a form of the ethnographic study, it means that they were performed directly in a natural environment of the defined target group - in the streets of Prague. Moreover, tests were performed on different places - this approach enables to analyze behavior of visually impaired people in different conditions and increase the accuracy and credibility of final results.

Test A

Participants were brought to a prepared route in the streets of Prague (see Figure 3.16) and were asked for testing our outdoor version of Naviterier [72] mobile navigation application there. The description of the route was divided into six sections along which participants were navigated.

There was an intentional mistake in the description of route and therefore a participant was navigated to the dead-end street and cannot continue. This situation the participant could not solve himself/herself so he/she was forced to ask for a help. For this situation, the application contained a special button that connect participant with the assistance center. The participant was connected with an operator who navigated him/her to the right way. The call between the operator and the participant was recorded and the dialogs were used in a next phases of this study.

Test B

Scenario for this study was inspired by the imaginary situation that was used in the second phase of the qualitative research and that was proven as realistic for all participants. Therefore, participants were given following task:

> *"You have an appointment with your friends in front of the restaurant Lemon Leaf. Go by bus from the station Karlovo náměstí over stations chrám sv. Cyrila a Metoděje and Na Zderaze to the station Dittrichova. From the station*

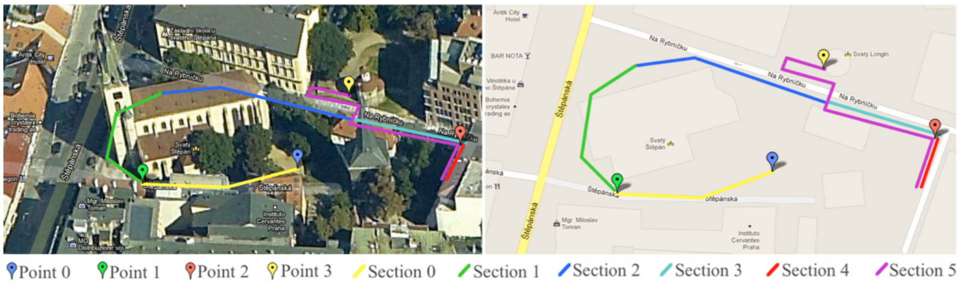


Figure 3.16: The map of the route prepared for Test A.

> *continue according to the route description in navigation NaviTerier that will lead you to the restaurant."*

The bus ride was simulated by the assistant who guided the participant, announced particular stations and informed him/her where he/she should get off (see Figure 3.17). For the navigation of the participant from the station Dittrichova to the restaurant Lemon Leaf was used mobile navigation application [72] that was installed on Nokia 6120.

However, reporting of stations in the bus were shifted, so the participant did not get off at the station Dittrichova, but already at the station Na Zderaze. Therefore, navigation application navigated the participant into wall and he/she had to use prepared helpline - the participant was notified about the possibility to use the helpline before the test itself.

The operator of the assistance center, who has very detailed knowledge about the place where the participant moved, helped him/her and navigate him/her to the right way. The call between the operator and the participant was recorded again and thus obtained dialogs were used in a next phases of this study.

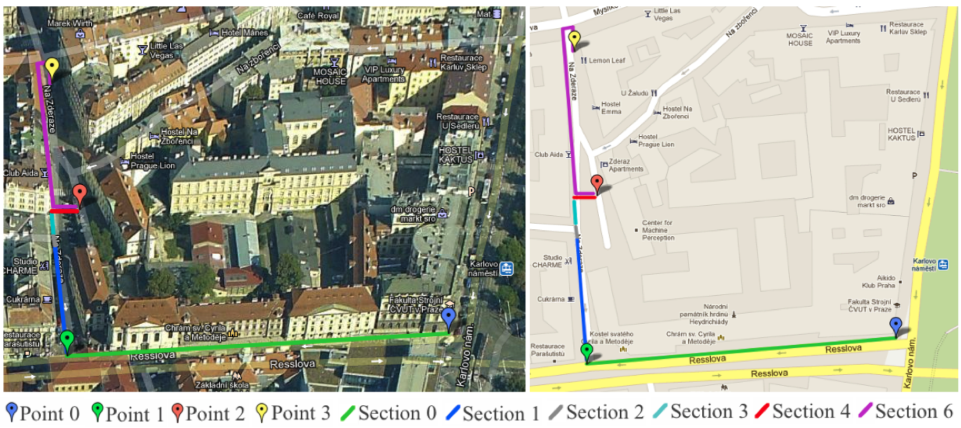


Figure 3.17: The map of the route prepared for Test B.

3.4.3 Disscussion

The following section contains discussion of the results of both qualitative and quantitative studies on recovery from the loss of orientation.

Qualitative Study

All participants agreed that they have been several times in the situation when they lost orientation. Participants agreed that this situation is unpleasant and relatively common. Participants also agreed that the easiest solution in such situation is the help from passerby people. In case when such help would not be available, the participants had different personal preferences. For example, participant P3, who can be termed as a technical type, would use GPS in such case. Conversely, participant P2 rejected the use of the GPS. All participants also agreed on the possibility of help through the phone.

It was difficult to say how would they solve this situation in a case of absence of passerby people for all participants. Some participants themselves mentioned uses of a mobile phone in that situation. Rest of participants was directly asked if they would use a mobile phone to call someone in such situation. Some of them answered that they would use it, rest of participants rejected this option.

The participants who rejected a use of mobile phone simultaneously said that if they knew someone who knew a place where they got lost orientation, they would probably call him. At first, visually impaired people must believe that person, who they should call, will be able to navigate them. It means that called person would be able to identify their exact position from their utterances, help them to find some unambiguous point in their nearby and describe them a route from this point to a place which they would already know.

Some of the participants prefered direct leading by a phone and if they lost an orientation and call to the center, they would hold a called person on a phone until they orientate themselves again. Contrary, the others prefer only one-shot information that would enable them to find a correct route and after obtaining of this information they would end the call and thenceforth continue individually.

Quantitative Study

All the hypotheses defined from the findings obtained during the qualitative study has been proven (see section 3.4.1 Hypotheses).

It has been proved that there is a crucial difference between the orientation of visually impaired people who use a cane for the blind and those who use an assistance dog (H1). In the group of participants there were two people who regularly use an assistance dog – both these people did not successfully reach the target of the route. It was shown that people with an assistance dog are typically not accustomed to perceive as many details from the route as people with a cane.

In the situation when visually impaired people lose orientation, they are able to describe their situation on a phone precisely enough to enable the called person to identify their position (H2). The operator on the prepared helpline successfully identified the position of 18 participants from the total of 21.

It is possible to successfully navigate a visually impaired person who lost orientation via phone (H3). The operator on the prepared helpline successfully navigated 17 participants out of the total 21 participants to the target of the route.

Most important orientation points which visually impaired people used when communicating via phone, are those points that are possible to be identified by a cane (H4). These points were used during the calls with our helpline by all 21 participants.

Visually impaired people who lost an orientation tend to verify the information that they receive by a phone (H5). Practically all participant were moving while they were receiving information by the phone and tried to find the points that the called person was talking about. Eleven participants either required a repeat of the received information or repeated the information themselves and asked for their confirmation. Seven participants held the called person on the phone to very end of the route and constantly checked the accuracy of their course.

General Dialog Structure

A generalization of the structure of human dialogs is a very complex problem. To deal with this problem it is necessary to obtain sufficient corpus of relevant dialogs from the target domain that enables to identify and describe general dialog patterns.

In the case of this part of the work, the corpus was obtained during the qualitative research - 21 dialogs in which lost participants called the prepared helpline and tried to find the way to the target of the route in cooperation with the operator were collected in total. On the base of these dialogs, that is possible to find in the attached files, was identified the general dialog structure which is shown in the Figure 3.18.

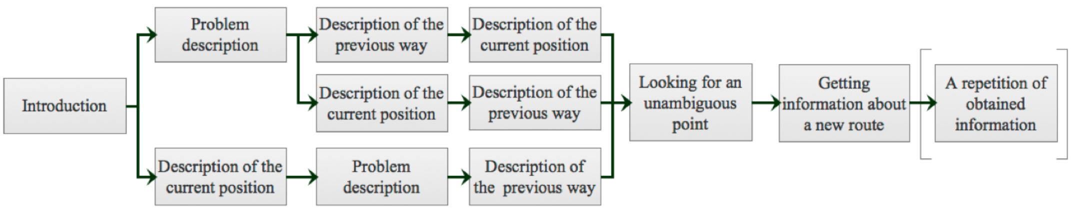


Figure 3.18: The general structure of the obtained dialogs.

Collected dialogs confirmed that very important aspect of communication between lost visually impaired person and some other person who tries to help him via phone are individual abilities of particular people. Some people were able to precise and understandable describe their situation and exact position, but for others was the passing of such information very difficult. It was also unveiled that the most important part of the dialog is the identification of the exact place, where the calling person currently is. Without successful identification of this point the called person is not able to navigate the calling person correctly.

It was also revealed that for exact identification of position of calling person is necessary to find some unambiguous point on which both sides would agree. The identification of such point enables to the called person to recognize the precise position of calling person and consequently also navigate him from this point.

3.5 Usability Testing of Collaborative Tasks

Every navigation system developed needs to be tested with its user group. The same applies for to the collaborative navigation system. The problem of testing the collaborative tasks is a relatively high number of participants - more than 10. Organization of such a test is very complicated, as all the participants should act in parallel and the timing of the tasks becomes a very complicated issue. Other problem is safety of participants and supervision of the test.

The usability testing of collaborative tasks with visually impaired users in urban environment needs specific approach to meet test observer's needs for the test supervision and the later evaluation of measured data. The test supervision is essential for participants' safety and smooth course of the test as the problematic evaluation of large number of variables that change in time and space. Visualization can help to solve these problems. Current visualization solution does not support test supervision so the test observer does not have an overview about the test progress.

3.5.1 Use Case

Let us imagine that more than 10 visually impaired persons are participating in a usability test and an observer is supervising one of them. Other participants have also assigned personal supervisor. Every participant travels along his/her route by different means of transport (mainly by foot) to a predetermined destination. Participants are intentionally put in a situation when they do not know how to continue to the destination and have to communicate with other predetermined participants to solve the navigational problem [73].

3.5.2 Supervision and Evaluation

The supervision of the usability test of navigation in real urban environment is essential for the visually impaired participants' safety and smooth course of the test. The problems with loss of orientation, stress, accident or problems with tested system could cause premature termination of the test or could lead to a severe trauma for the participant.

Besides the participant's safety also the ecological validity of the test should be taken into consideration. Thus so-called shadowing method [74] of research is used in which participants are told they are left alone and observer follows them from a save distance providing safety supervision.

In parallel with the supervision, an evaluation of executed usability test has to be performed. The evaluation is problematic due to large number of variables that can change in time and space. These are participant's location, speed, requests for contacts to other participants (a place where a problem with navigation occurred), communication realized between participants, and their mutual position.

These issues should be addressed to help test observer to reach efficiency in supervision and evaluation of the usability tests of navigation with large number of visually impaired users in collaborative urban environment (see section 2.3 Usability testing in Collaborative Environment). The main idea is to give the observer powerful visualization and communication tool, which will enable fast and efficient evaluation of the test progress and communication with the group of supervisors.

3.5.3 Visualization system

The main objectives of the visualization system for usability testing of collaborative tasks are:

- the supervision of the test - observer supervises position, motion, speed and collaboration of participants, and accomplishment of the test tasks,

- the evaluation of the executed tests - after the end of the test observer evaluates mutual position and communication of participants in time and the problems occurred during the test,
- storing and loading of an executed test - the executed tests are stored according to the date of the testing and can be loaded for further evaluation.

System Architecture

The proposed visualization system consists of three parts: a participant's application for mobile phone, which collects data and sends them to the server, a server, which stores all measured data (location, problems, communication and participant id) and a visualization application for supervision and evaluation which is used by the test observer (see Figure 3.19).

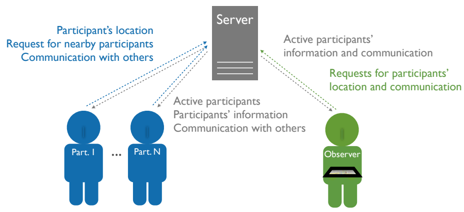


Figure 3.19: Proposed system architecture.

The participant's application is deployed on a smart mobile phone and authenticates participant to the server, sends GPS positions, speed and participant's communication. The participant's position is tracked only while he/she is walking. Thus the analysis of the accelerometer data in the mobile phone is done to identify the situations when the participant is walking. The travel speed from GPS is also checked to eliminate false detection of walking (e.g. bumpy road surface while traveling by public transport).

The server provides stored data from participants' applications about the ongoing test or about the executed tests. Than the data are visualized on observer's device. Platform used for the visualization with sufficient map resources and performance is Android OS 2.2.3 with Google Maps running on Samsung Galaxy Tab 10.1 tablet. This gives test the organizer bigger screen while maintaining mobility during the test supervision. The visualization should support displaying of user's location, speed, communication and requests for contacts. The test organizer should also be able to analyze the executed usability tests.

For the test supervision observer uses the Live mode ("Live" button) in which position of participants is automatically updated and visualized. After the test finishes the observer evaluates the results in the History mode ("History" button). The history mode enables the observer to evaluate the previous test and to see the mutual position and the communication of participants in time (see Figure 3.20).

For this purpose a time slider was added. In the respective sides of the time slider there are start and end time indicators. In the middle above the time slider there is indicator of the current time slider position in the time. The movement of the time slider changes participant's marker position to the position in the time of the current time indicator. For more detailed manipulation the time slider has the ability to change its precision. As the observer moves

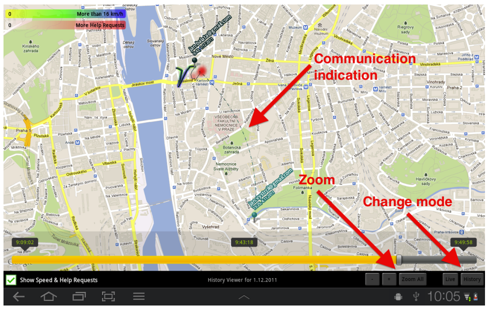


Figure 3.20: The visualization of the executed test on the application display.

finger up and down from the slider the speed of the time elapsed by the time slider is lowered by a fraction of the distance from finger to the slider itself.

Visualization

Each participant is visualized by a marker (pin), which displays his/her position, on the map. This marker is labeled with name and time (see Figure 3.21d) and participants are visually distinguished by different color of the marker and walked path. Participant's walked path from past to the position of the time slider (or current time in the test supervision – the Live mode) is displayed as bold a line, the path walked after the position of the time slider is displayed as a thin line. As there is a lot of GPS locations stored for detailed visualization in high zoom levels the level of detail based on the zoom of the map is introduced to increase the application's performance.

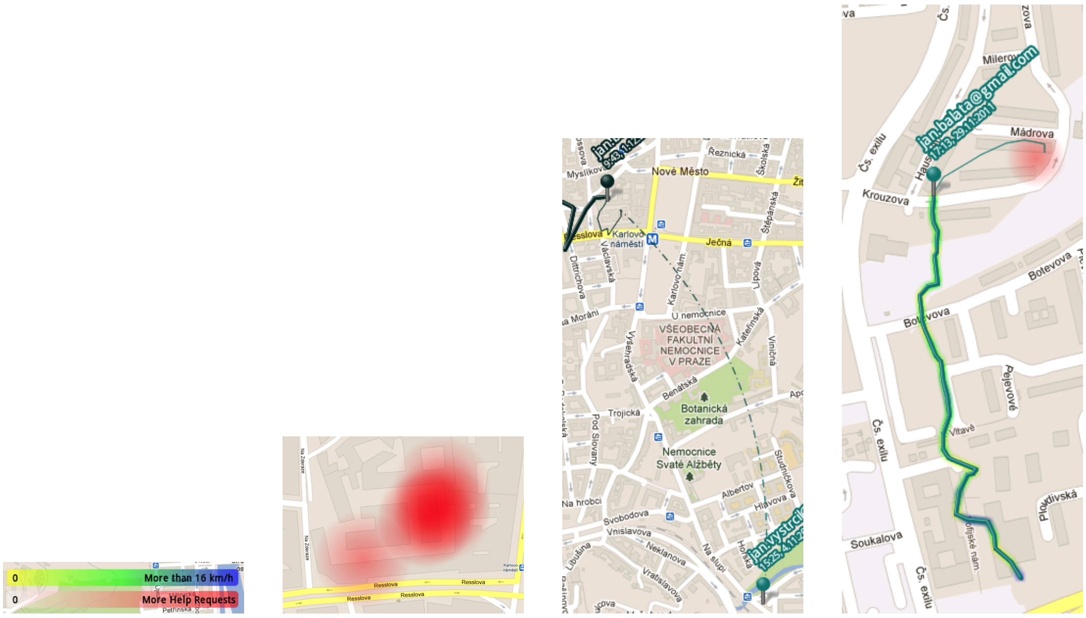
As well as the participant's position and travelled path, the observer can see participant's speed and communication with other participants. From the communication the test observer can assume what are participant's preferred contacts in problematic situations. Dash-dotted line visualizes the communication with other participant from a certain place and time (see Figure 3.21a). The color of the ends of the line corresponds to the color of the participant's marker, which should help recognizing communication among many participants. The curved shape of the communication line simulates position above the terrain by 2.5D projection.

The speed is used to evaluate places, where participant slowed down to solve a problem (difficult crossing, insufficient environment description, etc.) and continued without asking for help. Participant's traveling speed is mapped from yellow to blue glow along his/her walked path (see Figure 3.21b and Figure 3.21c). The speed is mapped only from 0 km/h to 16 km/h because the data are measured only while the participant is walking.

From the data about participant's requests for the list of participants available for help, problematic areas in environment can be identified (e.g. the loss of orientation). The density of the color distinguishes the number of problems occurred on a certain location. The places where problems occurred are displayed as red heat map (see Figure 3.21b and Figure 3.21d).

The usage of Google Maps also allows the interaction with created overlay on the default street map such as zooming and panning. The "Zoom All" function has been added to zoom and pan to all the test participants (see Figure 3.20).

The pilot test of the proposed system was executed with two participants in the urban environment in the center of Prague, Czech Republic. The participants traveled to prepared



(a) (b) (c) (d)

Figure 3.21: The final visualization used in application: mapping of heat maps (3.21a), problems heat map (3.21b), user communication (3.21c) and recorder route (3.21d).

destinations, simulated communication and reported problems with navigation and orientation. Data of position, communication and speed were measured and different means of transport were used during the test.

After the pilot test the evaluation of the measured data was performed by the test observer and inspected by the heuristic evaluation.

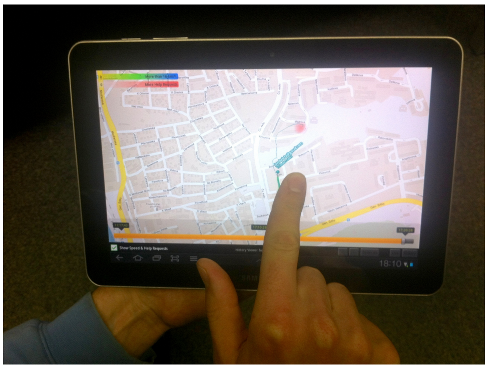


Figure 3.22: Visualization deployed on the Android Samsung Galaxy Tab 10.1 (tablet).

3.5.4 Discussion

The results of the pilot test have revealed overall usability of the tool for the visualization of the usability tests of the collaborative tasks and understandable visualization of mutual position of the participants. More over, it showed a good identification of problematic places for navigation and orientation based on the participants' requests for list of the available contacts and identification of the place and the time of the participants' communication (see Figure 3.22).

For the future development the usability test with the organizers and a large number of visually impaired participants have to be done to properly check the usability and test organizer's orientation in multi-user environment and an annotation tool will be developed to share and store notes and details about usability test and to support communication with the group of supervisors.

4 Conclusions

The goal of the dissertation thesis is to research the area of the user communication in collaborative environment. The results of this research are applicable for modeling and design of various systems, which use distributed knowledge.

One of the use cases selected for the purpose of the thesis is the simultaneous collaborative navigation among visually impaired users where distributed knowledge of the environment can be utilized. To explore this use case we have conducted three studies (see sections 3.1 Communication in Navigation of Visually Impaired, 3.2 Regular Routes of Visually Impaired and 3.4 Recovery From Loss of Orientation). The results of the studies confirmed the essential conditions (see chapter 3 Proposed Solution) for the operation of the collaborative navigation system and brought insights into the communication of the visually impaired during navigation, recovery from loss of orientation and to the length of the regular routes they often travel.

To help visually impaired users to get feeling of confidence and safety while independent traveling we have proposed the prototype of tangible heat map (see section 3.3 Tangible Heat Maps for Navigation of Visually Impaired) which demonstrates rich haptic interaction in real application. The values of heat map obtained from the places often visited by other visually impaired users are mapped to several haptic features such as real temperature and surface shape of the prototype.

The visualization tool was developed (see section 3.5 Usability Testing of Collaborative Tasks) to help test supervision and later evaluation of usability testing of proposed collaborative navigation system.

4.1 Future work

The future work will be focused on several topics. At first the technical solution for data collection (mobile platform, deployment, maintenance by users, etc.) which is essential for both operation of the system and for the longterm field studies on behavior of visually impaired need to be prepared. Later the matching and routing algorithms to connect visually impaired users (user models, ontologies, technical solution etc.) need to be developed and a research on dynamic aspects of the quality and the allocation of the distributed knowledge such as the learning and the forgetting curves [75] of the new routes and the routes walked in past (longterm field study) should be performed. At last the implementation and evaluation of the tangible heat map prototype (technical solution, user study, etc.) has to be realized.

5 Dissertation Thesis

Title User Communication in Collaborative Environment

Abstract There are many navigation systems and applications providing help for visually impaired and especially blind users in urban environment. However, none of them provides solution to the problem with insufficient description of the environment and the navigational instructions.

The most sever problem in navigation and orientation without sight are different navigational points and orientation keys. These points and keys cannot be obtained automatically and have to be collected by either limited number of trained navigational instructors or by visually impaired people themselves. Moreover the data from location services based on GPS [1] or similar technology are very inaccurate in urban areas due to high buildings which cover substantial area of sky and cannot be used for precise (in order of meters) navigation.

To address these issues we proposed collaborative navigation system based on utilization of the knowledge gained by visually impaired pedestrians. At first the approximate location of the visually impaired user is acquired by means of GPS. Thereafter the precise location of the user and navigation instruction are obtained by means of communication and collaboration with other visually impaired persons.

Several studies were conducted to prove the concept of the collaborative navigation system with over hundred blind participants (both qualitative and quantitative studies; some of the subjects participated in more than one study). The results show that the essential conditions for operation of collaborative navigation for visually impaired (the existence of communication among visually impaired users about navigation and ability to share their knowledge, and the sufficient length of regularly walked routes they remember to every detail) are fulfilled and that user base is wide enough to sufficiently cover significant parts of the urban environment.

The future work will be focused on several topics. At first the technical solution for data collection (mobile platform, deployment, maintenance by users, etc.) which is essential for both operation of the system and for the longterm field studies on behavior of visually impaired need to be prepared. Later the matching and routing algorithms to connect visually impaired users (user models, ontologies, technical solution etc.) need to be developed and a research on dynamic aspects of the quality and the allocation of the distributed knowledge such as the learning and the forgetting curves [75] of the new routes and the routes walked in past (longterm field study) should be performed. At last the implementation and evaluation of the tangible heat map prototype (technical solution, user study, etc.) has to be realized.

Keywords: collaboration, communication, visually impaired, navigation.

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