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Verbal Route Descriptions in Navigation of People with Visual Impairments

Doctoral Thesis

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Declaration

I hereby declare I have written this doctoral thesis independently and quoted all the sources of information used in accordance with methodological instructions on ethical principles for writing an academic thesis. Moreover, I state that this thesis has neither been submitted nor accepted for any other degree.

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Abstract

English This thesis focuses on the problem of navigation of people with visual impairments. There are many research directions in this field from sensory substitution, obstacle detection aids to different kind of navigation systems based on various input and output modalities. However, currently available navigation systems do not support navigation and orientation skills of people with visual impairments in the sense of supporting the creation of proper route knowledge.

This thesis aims to explore the role of verbal descriptions in navigation from the perspective of human-computer interaction. In a series of experiments, we provide insights into verbal description sharing habits and tele-assistance navigation strategies. Based on those insights, we design three navigation systems prototypes { a collaborative navigation system, a landmark-based navigation system, and a conversational navigation agent. This thesis contributes both on a theoretical level providing in-depth observations of the navigation process and also on a pragmatic level providing prototypes and guidelines for designers of the future navigation system for people with visual impairments.

Keywords Human-computer interaction, accessibility, navigation, visual impairment, verbal route description, spatial language, conversational user interface.

Cesky Dizertacn prace se zameruje na problem navigace osob se zrakovym postizenm. Existuje mnoho vyzkumnych smeru od senzoricke substituce, pres systemy vyhyban se prekazkam, po navigacn systemy s ruznymi vstupnmi a vystupnmi modalitami. Soucasne dostupne navigacn systemy vsak nepodporuj prirozene navigacn a orientacn schopnosti osob se zrakovym postizenm ve smyslu podpory vytvaren spravneho mentalnho modelu trasy.

Tato prace se zameruje na vyzkum role slovnho propisu tras na navigaci z pohledu oboru styku cloveka s pocitacem (human-computer interaction). V serii experimentu poskytujeme vhled do problematiky sdlen slovnch popisu a strategi tele-asistivn navigace. Na zaklade techto vhledu jsme navrhli tri prototypy navigacnch systemu { kolaborativn navigaci, navigaci na zaklade vyznamnych bodu a konverzacnho navigacnho agenta. Prnos teto prace je jak na teoreticke urovni poskytnutm detailnch pozorovan navigacnho procesu ale i na pragmaticke urovni poskytnutm prototypu a doporucen pro navrhare budoucch navigacnch systemu pro osoby se zrakovym postizenm.

Klcova slova Interakce cloveka a pocitace, prstupnost, zrakove postizen, slovn popis trasy, prostorovy jazyk, konverzacn uzivatelske rozhran.

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Chapter 1

Introduction

Abstract. The mobility of a person is largely limited by visual impairment. This leads to a decrease in travel-related activities and less involvement in social life. People with visual impairment have different strategies regarding orientation in space, some of them are trained by orientation and mobility specialist, some of them are gained through time. While the construction of cognitive maps of the route is required for efficient navigation, without sight other strategies have to be employed. One of them is a verbal description of a route, which was showed to have a similar effect on the creation of cognitive maps as visual and direct experience.

1.1 Motivation

Even with the huge leap of technologies in past years, there are still few commercially available navigation aids for people with visual impairments. In their daily travel-related activities, they end up relying on their trained skills, white cane, a smartphone with car navigation application, and the help of someone else (either directly on the street or via phone, see Subsection 3.2.1).

The ability to travel independently is required for the satisfactory level of quality of life and self-confidence. Visual impairment limits mainly a person's mobility and reduces travel-related activities [46]. Even though visually impaired people undergo special training of navigation and orientation skills, 30 % of them never leave home alone without a sighted guide [28], [112] and this number remains stable for the past twenty-five years despite the advances in information and geolocation technologies.

People with visual impairments experience a high level of stress whenever they try to travel independently [119], and only a fraction of blind people travel independently to unknown places [47]. Restricted mobility typically results in loss of leisure time activities (38 % of visually impaired people reported at least some interference with their leisure activities [101]), loss of career and work opportunities, and loss of social contacts [24]. The independent movement also plays an important role in the process of adjustment to blindness. According to the model defined by Tuttle and Tuttle [103], the adjustment process consists of seven phases: trauma, shock and denial, mourning and withdrawal, succumbing and depression, reassessment, and reaffirmation, coping and mobilization, self-acceptance, and self-esteem. Independent movement and the ability to navigate in known and unknown spaces is important for the sixth phase, coping and mobilization, where it can help to develop key competencies, such as the ability to work, to create social relations, or to act independently.

In general, the mobility of a person is mainly influenced by the efficiency of the wayfinding process. This process consists of three stages: planning of the route, execution of the planned route, and processing the information about the environment [62]. All parts of the wayfinding process can be supported by navigation aids, which assist the visually impaired pedestrian.

1.2 User Group Definition

The World Health Organization classifies the visual impairments according to severity on the range from mild or no visual impairment, thought moderate visual impairment and severe visual impairment (or low vision) to blindness (light perception) and total blindness (no light perception) [113]. Further, we may refer to people based on the onset of the disability as congenitally blind (born with the disability), early blind (acquired the disability in early childhood) and late blind (in higher age, i.e., after puberty).

There are 253 million people with visual impairments. Thirty-six million of them are blind, and 217 million have moderate to severe vision impairment. Around 81 % of people who are blind or have moderate or severe vision impairment are aged over 50 years [19].

First, it is important to get insights into the different aspects playing a role in the orientation and mobility skills of people with visual impairment. The key resource is research conducted in past decades in the field of cognitive psychology.

1.2.1 Orientation and Navigation

There are three levels of spatial knowledge: landmark knowledge which is the simplest level of the spatial knowledge, holds information about the existence of important places and objects and ability to recognize them [52]; survey knowledge which captures relations between landmarks represented by angles or distances [111]; and route knowledge which consists of series of procedural descriptions about origin, destination and landmarks along the route [42].

In large spaces where body movement is necessary, visually impaired people use different cognitive strategies from those used by sighted people for navigation and orientation. These strategies are mostly based on egocentric frames [68], [69]. Typically, they have to memorize a large amount of information [102] in the form of sequential representation [69] based on routes. Route knowledge has to be acquired on a declarative level [47] which means, that the route knowledge can also be used when the person is not on the route itself; on the other hand, procedural level route knowledge denotes the route knowledge which is in a form of a fixed automated reaction to stimuli on the route.

Fortunately, it seems that visually impaired people acquire superior serial memory skills. A study by Raz et al. [84] discovered that congenitally blind people are better than sighted people in both item memory and serial memory and that their serial memory skills are outstanding, especially for long sequences. In a study by Bradley and Dunlop [20], it was revealed that in a situation of pre-recorded verbal navigation, the blind navigator navigated the blind traveler significantly faster than a sighted navigator.

1.2.2 Cognitive Mapping

According to Downs [35]: "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."

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 late blind people have some visuospatial memories and tend to navigate similarly to sighted people for a certain period of time. On the other hand, the congenitally blind people without visuospatial 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 far space in which they perform a particular task. The near space — haptic space — relates to small-scale or manipulatory space i.e., areas that can be explored without changing a position of the body. The far space — locomotor space — relates to medium- or large-scale space e.g., areas in which locomotion is required for exploration [105].

1.2.3 Coding Strategies

Various coding strategies are important for exploring space around a person in the nearest vicinity. They are also employed in exploring tactile maps, which are proved to be useful in training of new routes and exploring unknown environments [38] sometimes enhanced with multimodal (vibration or sound) information [21].

There are two options for coding the location of an object in haptic space: either by reference to our own body and movements or some external network. People with little or none visually experience (usually congenitally blind and early blind people) tend to code spatial relations by reference to their own body. On the other hand, for sighted people it is more natural to code the position to an object relative to other objects (external network) [105].

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 [43].

1.2.4 Wayfinding and Cognitive Maps in Locomotor Space

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

It was found that blind children were less accurate in reproducing familiar environment (school campus) than sighted ones, however, there were some individual differences when blind participants were more accurate than sighted [25]. 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 accurate on familiar routes.

Some of the studies of locomotor space were focused on the problem of exploration of the unknown space [44], [54]. They have identified several strategies observing 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.

Perimeter and grid strategies used in isolation gave good knowledge of object location, however, in a test of integrated spatial knowledge, these strategies had worse results. The most successful participants tended to use an object to object, perimeter to object or home-base to object strategies, and also often used a wider range of different strategies. 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 the 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. An important fact is that the processing of spatial information by congenitally blind people is not necessarily less efficient than by sighted people [105].

1.2.5 Verbal Descriptions

Denis and Zimmer [33] showed that verbal description of a route can be adequately converted into mental representations and that it creates similar results to the visual experience. Moreover, the mental representations created in both ways show similar metric properties [31].

Similarly, Striuksma [98] discovered that even congenitally blind people can perform tasks traditionally associated with spatial imagery, showed that the connection between different modalities is used to form an abstract mental representation, and suggested that spatial images are supramodal. On the other hand, Loomis et al. [64] later argues that spatial images are amodal and that their functional characteristics are not tied to a source modality, i.e., their functional properties are equivalent. Verbal descriptions of a route are tightly connected to spatial language, which is defined as "a means of representing objects and locations through verbal description with respect to multiple coordinate systems or frames of reference." [18]. Spatial language has an important role in wayfinding process: it is used first, to form a mental representation of space; second, to plan a route; third, to formulate an action to reach the goal [32] (which corresponds to stages of wayfinding process [78] in context of the visually impaired population). Namely, Denis [32] observed the usage of spatial language in the context of referring to action, referring to a landmark, referring to an action together with a landmark, description of a landmark, and commentaries.

Similarly, Golledge et al. [47] claim that one of the basic strategies for independent and efficient navigation is navigation from landmark to landmark. Landmarks are defined as conceptually and perceptually distinct locations, build or naturally occurring (e.g., a church on a square, or specific smell of nearby bakery). Landmark may not be only one feature but also a combination of several features creates a landmark [47]. Not surprisingly, landmarks are also the most prevalent information in the verbal description of routes used by humans and were also proved to increase the confidence and trust of the traveler when incorporated to the route description [67]. The choice of landmarks is subject to individual capabilities of the traveler { in case of visually impaired travelers, a suitable landmark can be a leading line (natural or artificial), corner of a building with a specific shape, a location of the busy street, or specific material or slope of a sidewalk. Further, Ross et al. [88] have shown that inclusion of landmarks within pedestrian route itinerary increased user confidence and reduced navigation errors. Findings of Ross et al. [88] also extend to voice-only navigation [85], where participants preferred inclusion of landmarks. There are also some experimental designs of navigation systems, which rely primarily on landmarks to navigate users from origin A to destination B, e.g., Millonig and Schechtner [70].

For the successful learning of new routes and new environment, the survey knowledge has to be formed [94]. Noordzij [75] showed that verbal description positively supports the creation of survey knowledge.

1.3 Research Problem and Research Questions

As we can see, there are many differences between orientation and mobility of people with visual impairment and the general population. The approach we take in this work should follow and respect their navigation skills and strategies. Thus, we choose a User Centered Design (ISO 9241-210:2010) [58] methodology as a center point of the work to be able to reflect the specific needs of our user group. Although a lot of work was done in this field, not many influenced development of commercially available navigation aids (see Related Work in Chapter 6).

> Research problem: We identified a problem in how the current navigation systems support the specific needs of visually impaired pedestrians. Particularly in the way that they do not provide a verbal description that would support them in gaining sufficient route and survey knowledge or the new route.

This thesis aims the provide answers to following research questions which are tightly connected to our approach of solving the research problem:

- RQ1 How do people with visual impairments share spatial knowledge in a form of verbal route description?

- RQ2 How much and how well do people with visual impairments remember their regular routes?
- RQ3 How do people with visual impairments perform while sharing the verbal route description over the phone?
- RQ4 How can be tele-assistance navigation for people with visual impairments improved in general?
- RQ5 How will people with visual impairments perform with automatically generated verbal description during navigation?

1.4 Organization of the Thesis

The thesis is organized into seven chapters. First three chapters provide a reader with theoretical framework and setting in which the following four chapters introduce conducted research providing answers to defined research questions.

- Chapter 1 describes the motivation and general related work.
- Chapter 2 summarizes the methodology and methods used in this thesis.
- Chapter 3 reports on the user studies focused on sharing of route verbal description in the community of people with visual impairments.
- Chapter 4 reports on the experiment where visually impaired people navigated each other over the phone (tele-assistance).
- Chapter 5 presents a concept of collaborative navigation for visually impaired people.
- Chapter 6 builds upon the third and fourth chapter. It presents an approach to automatically generate verbal route description with similar properties to human-made ones.
- Chapter 7 describes the design and prototyping process of a conversational agent using outcomes of third and sixth chapter along with a description of methods to use to enable global and local personalization for the users.
- Chapter 8 concludes the thesis.

Research questions RQ1, RQ2 are answered in Chapter 3, RQ3, RQ4 in Chapter 4 and RQ5 in Chapter 6. Chapters 5 and 7 introduce concepts and prototypes implied by the research questions.

Chapter 2

Methodology and Methods

Abstract. In this chapter, we summarize the research methodologies and methods used to provide answers to the research questions defined in the previous chapter. Besides the focus on answering the research questions, our research also focuses on providing practically applicable outcomes to directly benefit the user group.

2.1 Methodology

This thesis is placed within the pragmatic research paradigm [66]. Both qualitative, quantitative, and mixed methods of data collection, analysis and reporting are used to best fit the research problem. The focus is on understanding and answering the research questions, solving emerging problems, and delivering practically applicable results. We employ User-Centered Design methodology, and we strongly focus our aim around the users.

We set this thesis around two key frameworks: First, Ability-based design [118] mainly the principle of Ability { leveraging all the abilities of a user { and the principle of Commodity { creating a low-cost solution using readily available hardware (and software) solution. We focus on building systems, which support natural orientation skills and strategies of visually impaired and use current technologies without the need for buying or using additional hardware.

Second, the quantitative difference theory [40] where we assume the normal range of spatio-cognitive behavior of visually impaired people, even though some [68], [99] argue there is a thin border between deficiency theory and inefficiency theory [96] depending on the particular task and its context.

2.2 Methods

We use different types of research methods to answer the research questions. We often use a combination of the methods, e.g., experimental accompanied by a correlational method. For research questions RQ1, RQ3, RQ4, and RQ5 we use observational methods. For RQ1, RQ2, RQ5 correlational method. For RQ5 we use experimental methods.

RQ1 (How do people with visual impairments share spatial knowledge in a form of verbal route description?) is approached first by semi-structured interview from which we formulated hypotheses, which were then assessed using a survey. We selected an interview instead of a focus group as we wanted to get deeper into the problem field. Furthermore, interview enabled us to invest more time into individual participants and obtain deeper insights.

RQ2 (How much and how well do people with visual impairments remember their regular routes?) is approached by means of a quantitative structured interview. We selected this method as we aimed to collect highly complicated structured data, for which a in-person presence of a researcher was required (given the user group and accessibility issues connected with for example remote survey) { we asked the participants to name routes they take every week and then let them describe each of the routes in as much detail as possible.

RQ3 (How do people with visual impairments perform while sharing the verbal route description over the phone?) and RQ4 (How can be tele-assistance navigation for people with visual impairments improved in general?) are handled together using a field study method to observe the behavior of the participants in the natural environment and reach higher ecological validity of the research results.

RQ5 (How will people with visual impairments perform with automatically generated verbal description during navigation?) was approached in three separate experiments. In the first experiment, a mixed method was used: an empirical study when we systematically changed an independent variable combined with a questionnaire (Likert scale). Next, a field study was performed, and qualitative data were collected using contextual inquiry when interacting with a prototype. Last, a diary study method was applied to observe a long term interaction with a prototype.

Chapter 3

Verbal Route Description Sharing

Abstract. A navigation system for visually impaired users may be much more efficient if it is based on collaboration among visually impaired persons and on utilizing distributed knowledge about the environment in which the navigation task takes place. To design a new system of this kind, it is necessary to make a study of communication among visually impaired users while navigating in a given environment and on their regularly walked routes. A qualitative study was conducted to gain insight into the issue of communication among visually impaired persons while they are navigating in an unknown environment, and our hypotheses were validated by a quantitative study with a sample of 54 visually impaired respondents. A qualitative study was conducted with 20 visually impaired participants aimed at investigating regularly walked routes used by visually impaired persons. The results show that most visually impaired users already collaborate on navigation, and consider an environment description from other visually impaired persons to be adequate for safe and efficient navigation. The results also suggest that the proposed collaborative navigation system is based on the natural behavior of visually impaired persons. In addition, it has been shown that a network of regularly walked routes can greatly expand the urban area in which visually impaired persons are able to navigate safely and efficiently.

Note. This chapter is based on published journal paper Collaborative Navigation of Visually Impaired [8].

3.1 Introduction

The main difference between navigation systems specially designed for sighted users and visually impaired users lies in the level of detail of the environment description, and in the representation of the instructions.

Sighted users and drivers are bound to streets and roads, and the details contained in a description of these elements are sufficient for them. However, visually impaired users make use of different navigation features in the environment, and the description provided by a navigation system specially designed for sighted persons is not adequate for them [108].

Several navigation applications on smartphones are nowadays used by visually impaired persons, although they were originally designed for sighted pedestrians or drivers. The most common is the Nokia Maps application, pre-installed on Symbian[1] smartphones, which is widely used by visually impaired users because of their hardware keyboard and their good screenreader[2] Other options are built-in navigation applications either in Android [3] smartphones (version 4.0 and above) with Explore-by-Touch support for eyes-free interaction, or in iOS[4] devices with VoiceOver[5].

Situations in which orientation is lost are mentally demanding, especially for visually impaired users, and it is necessary to analyze ways to help them by means of navigational aids. Some partial solutions to this problem are available in the form of:

- navigation call centers (e.g., Navigation Center of Czech Blind United organization [30] where orientation and mobility specialists and trained operators directly navigate visually impaired persons),
- voice-enabled navigation applications for smart phones (i.e., Loadstone GPS[6] or BlindSquare[7]),
- custom hardware or wearable computer aids [56], [83], [123].

The last of these three solutions can involve a wide range of sensors, e.g., cameras, headsets for communication, GPS, or even Microsoft Kinect, to analyze images and provide information for visually impaired users about their surroundings.

Although all these navigation systems are designed for visually impaired persons, none of them is ideal. Important considerations are that many custom hardware or wearable computer aids are in the prototype phase of development, and only a small proportion of all aids can resolve situations in which a visually impaired user gets lost.

3.1.1 Use Case

Let us imagine that Alice is a visually impaired person who has decided to visit a new art exhibition for the visually impaired in the city center on a Saturday evening (see Figure 3.1). She knows the address, but she does not know the destination area or the route well. She does not have a computer, and she uses a smartphone equipped with a GPS module and the installed screen reader for all her communication (calls, messages, emails, web). If she feels unsure about the route, or if she gets lost, she might be able to use several available navigation methods:

- ask strangers passing by,
- use the voice-enabled navigation application on her smartphone,
- call the navigation center for the visually impaired and get instructed remotely,
- get in touch with an orientation and mobility specialist,

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[1] Symbian OS { https://en.wikipedia.org/wiki/Symbian
[2] Mobile Speak { http://codefactoryglobal.com/app-store/mobile-speak/
[3] Android OS { https://www.android.com/
[4] iOS { https://www.apple.com/lae/ios/ios-11/
[5] VoiceOver { https://www.apple.com/lae/accessibility/iphone/vision/
[6] Loadstone GPS { https://www.loadstone-gps.com/
[7] BlindSquare { http://www.blindsquare.com/

Figure 3.1: Alice is a visually impaired person who has decided to visit a new art exhibition for the visually impaired in the city center on a Saturday evening but does not know the destination or the route well.

- call visually impaired friend who may know the destination area and who will instruct her remotely,
- call an unknown visually impaired person with useful knowledge of the desired destination are, who walks past the gallery (where art exhibition takes part, see Use Case) every day on the route from his/her home to a nearby public transport stop to get to work (there may be more than one visually impaired person able to help in this way).

3.1.2 Problem Description

A common problem for all the existing navigation solutions is the lack of an environment description especially created for visually impaired users, focusing on specific navigation points (e.g., leading lines) and orientation cues (e.g., sounds, slopes), i.e., landmarks [46], [105], [108], which visually impaired users need for safe and efficient navigation. The mental representation of the route can be formed from direct experience or a verbal description [32]. The verbal description of this kind is hard to obtain, as only trained orientation and mobility specialist can provide it in a fully satisfactory form and it requires good knowledge of the area and necessity to perform on-site reconnaissance. Unfortunately, there is typically only a very limited number of such specialist.

A useful description can also be provided by visually impaired persons who are familiar with a particular area. Typical landmarks provided by visually impaired people based on their own experience and observation are:

- leading lines formed by edges of the pavement, handrails, corners of buildings, the better side of the street to travel on, etc.,
- sounds from traffic, construction work, water, width of the street from the echo, etc.,
- smells of various types, e.g., bakeries, drugstores, sewers, etc.,
- the direction of heat from the sun at certain times of day,

- approximate distances, changes in elevation, type of ground material.

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

People with visual impairments remember the verbal description of frequent routes provided by orientation and mobility specialist and can pass these descriptions to other people. There are much more visually impaired people with specific route knowledge than orientation and mobility specialists available. The problem is that the knowledge is fragmented to a number of rather short routes.

An idea for overcoming these problems is to support and facilitate direct simultaneous help between visually impaired people, and sharing of their knowledge about certain places (navigation points and orientation cues).

In this chapter, we present a set of experiments focused on exploring how people with visual impairments share a verbal description of their regular routes and how much of the regular routes they remember and can efficiently share.

3.2 Related Work

The related work sections summarizes part of related work focused on collaboration in navigation of visually impaired.

3.2.1 Collaboration in Navigation

The collaboration with and among visually impaired people has been explored and evaluated in several system and prototypes. One of the most used was VizWiz [17], an object recognition system where sighted volunteers and crowdworkers [87] helped visually impaired people recognize the object. Similarly, Be My Eyes[8], which connects visually impaired people with sighted volunteers, is commonly used in situations where image recognition or OCR does not work [6].

More into the area of navigation, Hara et al. [50] used sighted volunteers to describe public transport stations location or entrances to buildings [122] to visually impaired people, or barriers on sidewalks and crosswalks [51] to hint wheelchair users about accessibility.

The collaboration also exists among visually impaired people themselves. Visually impaired people create a detailed mental map of their regular routes [79]. The regular routes are those learned by orientation and mobility specialist, self-learned or shared by friends or acquaintances [16], [82]. Landmarks are naturally occurring or build features of the environment that stand-out in the vicinity. They are often used when visually impaired people describe their regular routes to another person.

There are clear reasons for the statement that being navigated by another visually impaired person is perceived better. Williams et al. [116] observed the situation when sighted persons helped visually impaired person with navigation and strategies, language, and understanding differed largely. This is also supported by Bradley and Dunlop [20], who showed that visually

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[8] Be My Eyes – https://www.bemyeyes.com/

Participant	P1	P2	P3	P4	P5
Age	57	63	30	25	34
Gender	M	F	M	M	M
Category	5	5	5	5	5
Onset	L	L	C	C	L

Table 3.1: List of participants, their age, gender, the category of impairment (5 { no light perception [113]), and the onset of impairment (C { congenitally blind, L { late blind).

impaired people navigate with less workload with a verbal description of route formed by another visually impaired person than by sighted person.

Based on the difference between the mental representation of the routes between sighted and blind people we draw an inspiration for navigation based on collaboration among visually impaired people themselves by means of sharing their regular routes on the fly via a phone call, i.e., tele-assistance navigation.

3.3 Ways of verbal description sharing

First, we aim to gain in-depth insights into the way visually impaired people share their regular routes, how they are willing to help others and how much information they are able to share in sufficient quality.

3.3.1 Qualitative study

The goal of the qualitative user study was to obtain in-depth information about participants favorite means of communication with other people, their openness to communicating with strangers, their willingness to help them with navigation, and the privacy problem of the location sharing and storing.

Participants

Five visually impaired participants (1 female, 4 males) were recruited via an e-mail leaflet sent to a group of Czech Blind United organization [30] clients (see Table 3.1). The participants in the user study were aged from 25 to 64 years (mean = 41:80, SD = 17:05). All of the participants had Category 5 vision impairment (no light perception) [113]. Two participants were congenitally blind, and three participants were late blind.

Procedure

We conducted five semi-structured interviews (all of them were conducted in person). The interviews lasted 60 minutes and were performed in a usability lab dedicated for execution of user studies. We asked the participants about the community of visually impaired persons, communication in navigation, experiences with locations services, privacy issues of location sharing, and behavior in situations of loss of orientation. After the interview, the participants were debriefed and received their payment.

No.	Factoid	Occurrence
1	Participant has experience of navigating other visually impaired persons, and has been navigated by other visually impaired persons by mobile phone, ICQ, etc.	5
2	Navigational instructions given by a visually impaired person about a place that he/she knows are better than instructions from a sighted person.	4
3	Asking strangers in the street for directions is a natural part of the navigation process.	4
4	Participants have concerns about location sharing.	3

Table 3.2: Key factoids extracted from the semi-structured interviews.

Findings

We extracted 4 key factoids from the semi-structured interviews (see Table 3.2). Further we report overall findings.

Community of visually impaired persons. More than half of the participants meet with their friends regularly, and the majority of the participants know where their family members and good friends live. Some of the participants regularly visit places connected with their hobbies. For example, P1 stated: \I used to ski, but it was a long time ago. Later I went to yoga class. Now I visit rehabilitation exercises every Tuesday."

Communication in navigation. Majority of the participants had experience with navigation other visually impaired persons remotely and had themselves been navigated by another visually impaired person or by a sighted passerby (No. 1). Some of the participants requested navigation by a phone call and some by an e-mail or SMS. For example P1 said\We advise over the phone each other. For example, I know that this person knows the route to a place where I want to go. So I ask him to describe to me the route because he knows all the important landmarks."Most of the participant agreed that navigation instructions given by a visually impaired person are better than the instructions given by sighted persons (No. 2).

Experience with location services. More than half of the participants had some experience with GPS navigation applications in smartphones. Some of them use the navigation application regularly (either on known and unknown routes), despite the low GPS accuracy [71] in city centers.

Privacy issues of location sharing. More than half of the participants expressed concerns about sharing their location even for the purposes of helping other visually impaired persons (No. 4). For example, P1 stated: \I don't like the idea that someone would know where I go regularly." or \If there was an agreement about the data usage, I wouldn't mind if some other visually impaired person contacted me with a request for navigation on the route I know."

Behavior in situation of going astray. Most of the participants consider asking a passerby for directions to be a natural part of the navigational process (No. 3). However, there was a case where a participant (P1) hesitated to ask a passerby: "When I get lost, I have to ask a passerby. However, I try to postpone it as far as it goes. First I try to back-track to find the right way." and "Once, when there was a big snowfall, I shouted outside for a help. I didn't try the phone, because I didn't know where I was at all."

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

Hypotheses

From the key factoids described in Table 3.2 we define following hypotheses, which we evaluated in a survey 3.3.2 described in the next subsection within this chapter.

- H1 A visually impaired person can navigate another visually impaired user via mobile phone.
- H2 A visually impaired person will prefer navigation instructions provided by another visually impaired person to instructions from a sighted person.
- H3 A visually impaired person will not hesitate to ask strangers in the street in order to get reliable directions.
- H4 A visually impaired person will allow information to be collected about his/her location in order to help in navigating other visually impaired people.

3.3.2 Quantitative Survey

The quantitative study was conducted on the basis of a questionnaire compiled from the findings obtained in the qualitative studies. The goal was to validate the hypotheses formulated on the basis of the qualitative user study.

Participants

Fifty-four visually impaired respondents (18 females, 36 males) were recruited via an e-mail leaflet sent to a group of Czech Blind United organization [30] clients. The respondents were aged from 20 to 80 years ($mean = 47.06$, $SD = 15.89$). The respondents had Category 4 vision impairment (light perception) and Category 5 vision impairment (no light perception) [113]. Seventeen respondents were congenitally blind, and thirty-seven respondents were late blind.

Procedure

We conducted a survey using questionnaire with 12 closed-ended questions. The questions were administered via e-mail. The respondents filled-in the responses in a reply to the original e-mail. The general topics of the questionnaire were demographic information, behavior while obtaining navigation information from passerby in the street, preferences in selecting contacts when seeking for navigation instruction, navigating friends and family members via phone, email, instant messaging, etc., requesting help with navigation from friends or family members, willingness to help an unknown visually impaired person with navigation, and privacy problem of location sharing.

Findings

Fifty-four e-mails returned with a filled-in questionnaire. Due to the nature of the impairment of the participants' not all answers were filled-in correctly. The exact number of respondents taken into account in each finding is reported in the results, only correctly filled-in are taken into account.

Do you ask passersby on the street for navigation instructions (n = 47)? The percentage of the respondents who selected particular answer follows: 49 % { often, I find it a natural part of the navigation process; 47 % { I do not like asking passerby, first i try to find the way myself; 4 % { I do not ask passerby.

How often do you call your friends or family members for help with navigation (n = 49)? The percentage of the respondents who selected particular answer follows: 49 % { never; 41 % { several times a year; 8 % { several times a month; 2 % { daily.

How often do you help your friends or family members with navigation (via phone call, ICQ, e-mail, etc.) (n = 49)? The percentage of the respondents who selected particular answer follows: 53 % { several times a year; 33 % { never; 10 % { several times a month; 2 % { several times a week; 2 % { daily.

If an unknown visually impaired person calls you for help with navigation at the location you walk daily, will you help him/her (n = 49)? The percentage of the respondents who selected particular answer follows: 82% { yes; 12 % { probably yes; 4 % { I do not know; 2 % { no.

Would you mind automated recording (e.g., using GPS) of your regularly travelled routes in order to help other visually impaired in navigation (n = 50)? The percentage of the respondents who selected particular answer follows: 68 % { do not mind; 12 % { rather do not mind; 8 % { do not know; 8 % { rather mind; 4 % { mind.

Do you use electronic navigation (i.e., smartphone application) (n = 50)? The percentage of the respondents who selected particular answer follows: 68 % { do not use; 18 % { several times a month; 12 % { several times a year; 2 % { daily.

Preferences in selection of the person who will help the visually impaired person to navigate in an unknown place (n = 31). The score calculated from the ordering of the following four variants: 3.52 { sighted person with experience of navigating visually impaired persons; 3.26 { blind person who knows the place of navigation; 2.19 { sighted person with no

Figure 3.2: The preference for selecting a contact for help in navigation (n = 31).

experience of navigating visually impaired persons; 1.03 { blind person who does not know the place of navigation (minimum = 1, maximum = 4).

3.3.3 Discussion

It seems that hypothesis H1 has been proven, as the visually impaired users reported that they can navigate or be navigated by other visually impaired users. The results show that visually impaired users already collaborate on navigating in small groups of users { family 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 visually impaired users who do not know each other but can collaborate in navigating.

Hypothesis H2 is valid if we only take into consideration untrained sighted persons. H2 is not valid for expert sighted persons. Figure 3.2 shows that visually impaired people rate the quality of the description provided by a sighted expert more highly than the description provided by a visually impaired person who knows the area. Respondents seem to expect that the description provided by a sighted expert will be more customized to their needs, as the expert has more information sources available.

The validity of hypothesis H3 is not proved. 51 % of the participants hesitate to ask strangers for instructions for navigation. However, the size of this group of participants can be attributed to a fact mentioned by one of the participants in the qualitative study { the problem of finding a suitable person who is willing to help. We believe that this problem can be solved by implementing our future system, where all of the users proposed by the system to provide help will have valuable information for navigation and will be willing to help.

In order to select accurately a suitable person to provide the right information for a visually impaired person who is lost, the location of all users needs to be stored and analyzed. The results shows that 68 % of all respondents have no problem with location sharing and location storing. If we add in those participants who do not mind only to some extent (12 %), a total of 80 % of the participants provide support for hypothesis H4.

ID	Age	Gender	Category	Onset	ID	Age	Gender	Category	Onset
P01	36	M	5	L	P11	46	M	5	L
P02	64	M	5	L	P12	47	M	5	C
P03	65	F	5	L	P13	24	F	5	C
P04	37	F	4	L	P14	35	M	4	L
P05	31	M	5	C	P15	27	M	4	C
P06	37	F	4	L	P16	56	F	4	C
P07	59	M	5	L	P17	26	F	4	C
P08	47	F	5	C	P18	72	M	4	L
P09	30	M	5	L	P19	41	F	5	L
P10	46	F	4	L	P20	20	F	5	C

Table 3.3: List of participants, their age, gender, the category of impairment (4 { light perception, 5 { no light perception [113]), and the onset of impairment (C { congenitally blind, L { late blind).

3.4 Length of the Regular Routes

A regular route is typically the route to work, to the local shopping area, to the nearest public transport stop, or a route that a visually impaired person uses for taking a walk. In our definition, it is a route which is walked at least once a week. Usually, the person knows every detail of the regular route, e.g., the optimal leading lines, cracks in the pavement, smell and sounds (echoes), strategies for crossing a street, etc.

These routes can be collected by tracking the person or can be collected via an interview and plotted into a geographical database. These two methods can be used to produce a map showing the density of regular routes of multiple people, which can be then rendered as a heat map. Areas with a greater density of regular routes have a greater number of visually impaired people regularly walking through that area so that higher-quality verbal descriptions of the routes are available for navigation.

3.4.1 Quantitative Structured Interview

The aim of the quantitative user study was to identify regular routes walked by the visually impaired participants, measure the approximate length of the regular routes, estimate the contribution of the regular routes walked by the visually impaired persons to the current network of public transport.

Participants

Twenty visually impaired participants (10 females, 10 males) were recruited via an e-mail leaflet sent to a group of Czech Blind United organization [30] clients (see Table 3.3). The participants were aged from 20 to 72 years (mean = 42:30, SD = 14:81). Eight participants had Category 4 vision impairment(light perception) and twelve participants had Category 5 vision impairment (no light perception) [113]. Nine participants were congenitally blind, and eleven respondents were late blind. Two participants used a guide dog. Sixteen participants lived in Prague, and four participants lived in other large cities. All of the respondents were native Czech speakers.

Procedure

We conducted a 20 semi-structured interviews (all of them were conducted in person). The interviews lasted for approximately 40 minutes and were performed in a usability lab dedicated for execution of user studies. We asked the participants to describe their regular routes walked at least once a week in as much detail as possible, as if they were describing the route to another visually impaired person. After the interview, the participants were debriefed and received their payment.

Results

After the interviews we reconstructed all the collected regular routes from the description into a map, we measured the length of the routes for each participant and created a heat-map (see Figure 3.4).

The twenty visually impaired participants who were interviewed walk a total of 93.33 km of regular routes, and were able to describe the environment of these regular routes. This sum represents the length of unique regular routes for all participants (e.g., the route to the shop twice a week counts as one unique regular route). The mean length of the routes per participant is 4.67 km. The participants in the study visit 4.25 destinations, on an average (e.g., restaurants, workplaces, schools, hobbies, shops, etc.). The nearest public transport stops from home are not counted as destinations if they lie on the way to other places.

Regarding the level of detail of the verbal descriptions, the participants described common landmarks such as slopes, leading lines, auditory and olfactory landmarks, names of streets, cracks in sidewalks, walls, the position of buildings, or directions. All descriptions were in such detail we were able to reconstruct all the routes and draw them into a map. However, quantitative analysis of landmark usage was not performed.

The data suggests that there is no effect of congenital blindness and late blindness on the length of the regularly walked routes. There is a difference in the mean length of the routes for the late blind group, whose members walk 1 709 m further than the congenitally blind group. We think this may be partly due to inertia from the time when the participants were sighted, and when they had greater mobility and traveled more around the city. On the other hand, the group of congenitally blind persons tends to optimize from birth and to use the best (safest) route. They also tended to use public transport as much as possible. However, this assumption needs to be further investigated in a study of the different cognitive mapping strategies employed by congenitally blind and late blind persons.

Figure 3.3 shows the mean length of the regular routes for each participant. As expected, there are differences among the participants. Some of the participants walk long routes to the nearest public transport, or just for recreational walking. On the other hand, other participants avoid walking and use public transport as much as possible or use a guide for unknown or complicated places. It seems, there is no effect of age on the length of regular routes.

Figure 3.4 shows a heat map, which maps a number of routes in a certain place from blue to red values. Red areas indicate places where there are larger numbers of regularly walked routes involving one participant or more.

Figure 3.3: The relation between the age of the participant (orange line) and the length of the regularly walked routes (blue column) (n = 20). Participants are ordered by age in an ascending manner.

3.4.2 Discussion

Many of the regular routes of the participants start or end at public transport stops, which are usually easily accessible for 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, bus 828 km) [36]. The regular walking routes taken by the 20 visually impaired persons who participated in the study have a combined total length of 93.3 km. These walking routes extend the current public transport network by 9 % and create access to areas around public transport stops.

To cover the area accessible nowadays by public transport by regular routes, we would require approximately 200 active users for Prague (with none of them sharing the same route). The Czech Blind United organization [30] provides an estimated number of 100 000 people with visual impairments living in the whole Czech Republic. Considering that one-tenth of the population lives in Prague, there will be at least one thousand visually impaired persons in the city.

3.5 Conclusion

The results from the first study have revealed that most of the hypotheses about communication among visually impaired people during navigation were correct and provided important insights into the problems (see Section 3.2.1).

The data collected from the second study on regularly walked routes showed that visually impaired persons remember quite long route descriptions (in cognitive maps) and that they are able to describe them to other people with all important navigation points and orientation cues (see Section 3.4).

In summary, our studies have shown that both communication in navigation and regular routes of visually impaired people exist. They communicate about navigation on a regular basis and the regular routes have potential cover large areas of the city. These were the essential conditions for attempting to set up a navigation system based on collaboration among visually impaired persons. Both essential conditions have been fulfilled, and it has been shown that successful operation of the system is feasible.

Figure 3.4: Heat map of routes in the whole city of Prague (ranging from blue { a low number of regular routes { to red { a high number of regular routes) (n = 20).

3.6 Implications

In this chapter, we showed how the verbal descriptions are shared among visually impaired people and that the amount of the information shared is remarkable. This fact suggests that there are an opportunity and meaning to support even unknown people in sharing their regular routes. Furthermore, in the results, we provide answers to RQ1 (How do people with visual impairments share spatial knowledge in a form of verbal route description?) and RQ2 (How much and how well do they remember their regular routes?) as defined in Chapter 1. Detailed answers to the research questions are summarized in the chapter Conclusion 8.

In the next chapter, we look at how exactly the sharing process proceeds when it is done in real time over the phone (tele-assistance). The motivation is to understand and gain in-depth insights into the strategies people with visual impairments take and to provide guidance for both professional tele-assistance centers but more importantly to individuals who wish to share their regular routes with other people with visual impairments.

Chapter 4

Blind-to-Blind Tele-Assistance

Abstract. We raise a question whether it is possible to build a large-scale navigation system for blind pedestrians where a blind person navigates another blind person remotely by mobile phone. We have conducted an experiment, in which we observed blind people navigating each other in a city center in 19 sessions. We focused on problems in the navigator's attempts to lead the traveler to the destination. We observed 96 problems in total, classified them on the basis of the type of navigator or traveler activity and according to the location in which the problem occurred. Most of the problems occurred during the activities performed by the navigator. We extracted a set of guidelines based on analysis of navigation problems and successful navigation strategies. We have partially mapped the problem of tele-assistance navigation to POMDP based dialogue system.

Note. This chapter is based on published conference paper Navigation Problems in Blind-to-Blind Pedestrians Tele-Assistance Navigation [9].

4.1 Introduction

Several approaches how to support independent traveling of visually impaired people exist. However, as mentioned in the previous chapter (Chapter 3) existing solutions are suffering from a lack of suitable data for route description. Further, in Chapter 3, we have shown that visually impaired people often navigate each other remotely by means of a phone call (tele-assistance) or emails and that this form of navigation is preferred over navigation by an untrained sighted person.

One already existing navigation solution is also based on a tele-assistance. It is a tele-assistance navigation center with professional navigators (see subsection 4.2.2). The main problem of this solution is its scalability as the gathering of the suitable set of landmarks for the particular area often requires the physical presence of the professional navigator on the spot. According to a study by Balata et al. [8], visually impaired people memorize relatively long routes at a very high level of detail. It was also shown that 67 % of visually impaired people have experience with sharing their route with friends/family via email, phone, messaging [10] and that they prefer navigation provided by a blind person to sighted person (also supported by [20], [60]). This opens the possibility to base a tele-assistance navigation service on visually impaired volunteers and to build up an efficient large-scale system where one visually impaired person navigates another. In this situation, the blind navigator (navigator) forms a natural source of suitable landmarks with their descriptions and with routing strategies optimized for blind travelers (traveler).

According to the functional model of a general navigation system for the blind defined by Loomis et al. [63], the navigator in such tele-assistance navigation service fully covers components providing a description of the environment (typically some kind of geographic information system), route planning, auditory display and speech input. The only component that cannot be covered independently by the navigator is the component responsible for determining the traveler's position and orientation. Here, collaboration with the traveler is needed. The traveler serves as a sensor gathering necessary data for the navigator, and can determine the position and orientation on her/his own.

The key feature of such tele-assistance navigation service is its non-stop availability. Here an automated dialogue-based navigation can be employed. There are several approaches to dialogue management: finite state machine, information state, grammar-based, plan-based and data-driven approach. Our case is highly complex, and thus data-driven approach like POMDP based dialogue managers is a suitable soulution [95].

Based on [62], [63], we identified the following five activities (three for navigator and two for traveler) that we wanted to observe in our experiment: The navigator describes the environment, plans the route (gives navigation instructions), and determines the blind traveler's position [63]. The traveler travels to a remote destination (executes navigation instructions), and senses the environment (identifies landmarks) [62].

Our main goal is to define a set of guidelines for efficient blind-to-blind tele-assistance navigation. We will investigate the process of tele-assistance-based navigation by blind people, with special reference to navigation problems that occur during this activity. Based on the analysis of the navigation problems we will develop recommendations for improving the training procedures in order to increase the efficiency of wayfinding in situations where tele-assistance takes place. Further, we will map the problem of tele-assistance-based navigation to POMDP based dialogue system in order to replace navigator with the computer system in the future.

4.2 Related Work

The related work section in this chapter follows the related work of previous chapters namely Chapter 1 and 3, and extends it with knowledge about pedestrian navigation.

4.2.1 Pedestrian Navigation

It has been shown that landmarks (representing landmark knowledge) are by far the most frequently-used category of navigation cues for pedestrians [67] (unlike junctions, distance, road type and street names or numbers). A study conducted by Ross et al. [88] states that the inclusion of landmarks within the pedestrian navigation instructions increased user confidence, and reduced or eliminated navigation errors. Rehrl et al. [85] showed that voice-only guidance in an unfamiliar environment is feasible and that participants preferred landmark-enhanced instructions.

The fact that humans rely primarily on landmarks to navigate from point A to B is reflected in many experimental designs of navigation systems, e.g., the system of Millonig and Schechtner [70]. The system designed by Hile et al. [53] presents a set of heuristics for selecting appropriate landmarks along the navigation path.

In our experiment, where the navigator instructs the traveler remotely without being physically present on the route and without any visual feedback, a declarative level of route knowledge is needed. The navigators were therefore thoroughly trained in compliance with official training methodology in the region where the tests were conducted [114]. The navigators were also introduced to objects that were not located on the test route. Finally, they checked a tactile map of the route and its environment to gain overview knowledge. In the training procedures for our experiment, we paid special attention to introducing all important landmarks and describing them to the navigators in order to support the creation of landmark knowledge (see Apparatus in section 4.3).

4.2.2 Orientation and Navigation of the Blind

In large spaces where body movement is necessary, visually impaired pedestrians use different cognitive strategies from those used by sighted pedestrians for navigation and orientation, based on egocentric frames [68], [69]. Typically, they have to memorize a large amount of information [102] in the form of sequential representation [69] based on routes. Route knowledge has to be acquired on a declarative level [47]. Fortunately, it seems that visually impaired people acquire superior serial memory skills. A study by Raz et al. [84] discovered that congenitally blind people are better than sighted people in both item memory and serial memory and that their serial memory skills are outstanding, especially for long sequences. In a study by Bradley and Dunlop [20], it was revealed that in a situation of pre-recorded verbal navigation, the blind navigator navigated the blind traveler significantly faster than a sighted navigator.

There are numerous navigation aids for visually impaired pedestrians. Some use special sensors to identify objects on the route, e.g., cameras [23], or an RFID based electronic cane [39]. Others are based on a concept described in [80] and rely on some kind of positioning system (e.g., GPS) in combination with the GIS system to identify objects and navigate the pedestrian, e.g., Ariadne GPS, BlindSquare. There have also been attempts to develop special interaction techniques for presenting navigation instructions, e.g., an auditory display [62] or a tactile compass [81].

The navigation aids based on major GIS systems (Google Maps, Apple Maps, OSM Maps, Nokia HERE Maps) suffer from an inappropriate description of the environment for visually impaired pedestrians. The available description may be imprecise (e.g., missing sidewalks or missing handrails), or may be ambiguous (e.g., an inadequate description of pedestrian crossing, meaning that it cannot be localized and identified without visual feedback) or it may ignore specific navigation cues (e.g., the surface structure of the sidewalk, acoustic landmarks such as the specific sound of a passage, the traffic noise of a busy street, or other sensory landmarks, such as the smell of a bakery). In addition, routing algorithms can encounter problems with non-trivial adjustments to the preferences and abilities of visually impaired people, e.g., their inability to cross open spaces (e.g., large squares).

Both inappropriate descriptions and unsuitable routing algorithms can be avoided by introducing navigation systems based on tele-assistance with a trained human agent. Various approaches have been proposed on the basis of various ways to identify the position and the environment of the pedestrian, like transmission of chest-mounted camera view to the navigator [23], a verbal description from the pedestrian optionally combined with GPS location and GIS [30], [100], or purely based on a verbal description and knowledge of the environment [109]. Namely Navigational Centre for the Blind [30], operating since 2007, proved to be helpful tele-assistance navigation service widely used (6650 cases in years 2008-2013 [29]) by the community of visually impaired people.

4.3 Experiment

In our experiment, we observed the process of navigation by a navigator navigating traveler by means of tele-assistance. The purpose of the experiment was to get insights into the process and to provide guidance for improvements (RQ4, Chapter 1). The navigation was performed in a way similar to that used in [20], [109]. The goal was to identify navigation problems in the following activities:

- Navigator describing the environment,
- Navigator giving navigation instructions,
- Navigator determining traveler's position,
- Traveler executing navigation instructions,
- Traveler identifying landmarks.

The experiment consisted of 19 sessions. There were two participants in each session, one in the traveler role and the other in the navigator role. Each session lasted around 100 minutes.

4.3.1 Participants

25 visually impaired participants (12 females, 13 males) were recruited via three methods: an e-mail leaflet sent to a group of Czech Blind United [30] clients, direct recruiting of our long term collaborators, and snowball technique. The participants in the experiment were aged from 25 years to 66 years (mean = 43:44, SD = 13:27). Fourteen participants had Category 4 vision impairment (light perception); 11 participants had Category 5 vision impairment (no light perception) [113]; 12 participants were congenitally blind, 13 participants were late blind. All of the participants were native Czech speakers. None of the participants in the traveler role knew the route before the experiment, though the character of environment was familiar to them. During recruitment, the participants were asked whether they are willing to participate in both roles, as the traveler in the first session, and then as the navigator in the following session. Table 4.1 contains details about the participants. Table 4.2 contains details about the sessions and about the roles that the participants took (the session IDs do not necessarily correspond to their real order). We tried to balance onset of impairment, category of impairment and gender of the participants in the sessions as much as possible. All of the participants (except P23) were

Part. No.	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25
Onset	C	L	C	C	C	L	C	C	C	C	L	L	L	C	C	L	L	L	L	L	C	L	C	L	L
Category	5	5	4	5	5	4	5	4	5	4	4	5	4	4	5	4	5	4	4	5	5	4	5	5	5
Gender	F	M	F	F	M	M	M	F	M	F	M	M	M	F	M	F	M	F	M	F	F	F	F	M	M
Age	38	60	37	42	29	61	43	27	32	29	36	37	50	38	43	38	60	50	62	66	25	65	29	31	58

Table 4.1: List of participants, including onset of the impairment (congenital { C, late { L), category of visual impairment [113], gender (male { M, female { F), and age.

Session	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}	S_{18}	S_{19}
Traveler	P1	P3	P5	P6	P4	P8	P10	P11	P13	P14	P16	P17	P18	P19	P22	P21	P23	P24	P25
Navigator	P2	P4	P6	P3	P7	P9	P11	P12	P12	P15	P17	P18	P14	P20	P19	P22	P2	P23	P24
Duration	11:23	5:17	7:06	{	{	{	{	4:20	4:15	8:41	{	9:32	6:01	8:51	4:32	{	{	{	4:52
Success	Yes	Yes	Yes	No	No	No	{	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	No	Yes
Problems	1	1	4	8	11	7	4	0	1	3	11	4	4	7	3	4	3	12	8

Table 4.2: List of sessions, including participants' role in the experiment, duration of navigation (minutes), success of session, and the number of navigation problems.

active and regularly traveled alone. Several researchers have noted that it is quite difficult to acquire blind pedestrians as a target user group for a usability study [20], [23]. However, we had established a relationship with blind communities (namely Czech Blind United organization [30]) during our previous studies, and this made it comparatively easy to recruit a considerable number of blind participants for our experiment.

4.3.2 Apparatus

Training methodology

The goal of the training was to learn the navigators the route for regular independent walking, i.e., to form a declarative level of the route knowledge. We arranged several meetings with the chief methodologist from the Czech Blind United [30]. One of the chief methodologist's fields of expertise is in the training visually impaired people in spatial orientation and in preparing itineraries for their regular routes (i.e., routes to work, to a shop, to a public transport station/stop, etc.) in accordance with their navigation strategies. In order to conform with the official training methodology [114] used by the chief methodologist, we proceeded as follows: 1) We selected the route, identified important landmarks, and consulted possible dangers on the route together with the chief methodologist. 2) Together, we prepared a tactile map of the route and printed it on a paper using foil fuser technology (swell paper). 3) The experimenter observed the chief methodologist training the navigator in the first pilot session. 4) The experimenter trained the navigator according to the observed methodology under the supervision of the chief methodologist in the second pilot session. 5) The trained experimenter trained the navigators in all subsequent sessions of the experiment.

Description of the route

For our experiment, we selected a city center outdoor environment. Environments for this type of experiment are usually real environments [20], [85] rather than artificial (lab) environments,