ZADÁNÍ DIPLOMOVÉ PRÁCE

I. OSOBNÍ A STUDIJNÍ ÚDAJE

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II. ÚDAJE K DIPLOMOVÉ PRÁCI

Název diplomové práce:

Navigace nevidomých osob v městské zástavbě s využitím hromadné dopravy

Název diplomové práce anglicky:

Navigation of Visually Impaired People in Urban Areas with Environment Transitions and Use of Public Transportation

Pokyny pro vypracování:

Analyzujte literaturu zabývající se orientací a pohybem osob se zrakovým postižením a navigačních systémů založených na textovém popisu tras pro outdoor i indoor. Dále se zaměřte na situace nastávající při pohybu nevidomých osob s využitím městské hromadné dopravy v městské zástavbě. Navrhněte způsob popisu tras na příkladech identifikovaných situací. Provede 2 iterace experimentu s nevidomými uživateli na prototypech nízké úrovně. Analyzujte možnosti použití technologie Bluetooth majáčků a implementuje prototyp navigační aplikace, který je využívá. Proveďte testování použitelnosti prototypu navigační aplikace.

Seznam doporučené literatury:

[1] Ungar, S. (2000). Cognitive mapping without visual experience. In Kitchin, R. & Freundschuh, S. (eds) Cognitive Mapping: Past Present and Future.London: Routledge.

[2] Golledge, R.G., 1999. Human wayfinding and cognitive maps. Wayfinding behavior: Cognitive mapping and other spatial processes, pp.5-45.

[3] Vystrčil, J., Míkovec, Z., & Slavik, P. (2012). Naviterier-indoor navigation system for visually impaired.

[4] Guo, Yao & Wang, Wenjun & Chen, Xiangqun. (2017). FreeNavi: Landmark-Based Mapless Indoor Navigation Based on WiFi Fingerprints. 1-5.

[5] Limin Zeng and Gerhard Weber. 2015. A Pilot Study of Collaborative Accessibility: How Blind People Find an Entrance. In Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '15). ACM, New York, NY, USA, 347-356.

[6] Guentert, M. (2011). Improving public transit accessibility for blind riders: a train station navigation assistant. In The proceedings of the 13th international ACM SIGACCESS conference on Computers and accessibility (ASSETS '11). ACM, New York, NY, USA, 317-318.

[7] J Balata, Z Mikovec, P Bures, and E Mulickova. 2016. Automatically generated landmark-enhanced navigation instructions for blind pedestrians. In FedCSIS. IEEE, 1605?1612.

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master's thesis

Navigation of Visually Impaired People in Urban Areas with Environment Transitions and Use of Public Transportation

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May 2018

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Declaration

I declare that I worked out the presented thesis independently and I quoted all used sources of information in accord with Methodical instructions about ethical principles for writing academic thesis.

Prague, May 23, 2018 ....

Abstract

This thesis focuses on the problem of navigation of visually impaired people in urban areas. The main objective of this thesis is to enable seamless connection of indoor and outdoor navigation including the usage of the public transportation. Set of navigation instructions designed for sidewalk-based navigation systems focused mainly on environment transitions and use of public transport is presented. To that purpose we conducted two experiments with visually impaired people and evaluated our method on low-fidelity prototypes. Furthermore, we investigated the use of Bluetooth beacons as synchronization at route decision points, to overcome the possible lose of orientation and to provide error recovery for the users. To evaluate proposed solution, the high-fidelity prototype of navigation application was created for another qualitative study with visually impaired people. The outcome of the user experiments are the recommendations for the future design of the navigation system for visually impaired.

Keywords

Visually Impaired; Navigation; Public Transport; Urban Areas

Abstract

Tato práce se zaměřuje na problematiku navigace osob se zrakovým postižením v městském prostředí. Hlavním cílem této práce je umožnit bezproblémové propojení vnitřní a venkovní navigace včetně využití veřejné dopravy. Je představen soubor navigačních instrukcí určených pro navigační systémy založené na chodníkové síti zaměřených především na přechody mezi prostředími a využití veřejné dopravy. Za tímto účelem byly provedeny dva experimenty se zrakově postiženými a naši metodu jsme vyhodnotili na low-fidelity prototypech. Dále jsme zkoumali využití Bluetooth majáků jako synchronizaci na rozhodovacích bodech trasy, za účelem překonání možné ztráty orientace a umožnení zotavení se z chyb během navigace. Pro vyhodnocení navrhovaného řešení byl vytvořen high-fidelity prototyp navigační aplikace, který byl následně kvalitativně otestován s uživateli. Výsledky experimentů s uživateli jsou doporučení pro budoucí vývoj navigačního systému pro zrakově postižené.

Klíčová slova

Navigace; Nevidomí, Městské prostředí, Hromadná doprava

Contents

Abbreviations

List of abbreviations used in this thesis:

GPS	Global Positioning System
GIS	Geographic Information System
BLE	Bluetooth Low Energy
POI	Point of Interest
HTML	HyperText Markup Language
CSS	Cascading Style Sheets
JSON	JavaScript Object Notation
SDK	Software Development Kit
API	Application Programming Interface
RSSI	Received Signal Strength Indicator
UUID	Universally Unique Identifier
RFID	Radio Frequency Identification
WHO	World Health Organization

1 Introduction

For the visually impaired people, it is vitally important to be able to independently and freely navigate. The limitation of this activity has an impact on their quality of life. The daily events require the ability to move from one place to another independently and efficiently, this ability can free visually impaired from being passive in such activities, they should be able to do this activity with grace, comfort and safety [1]. The international study shows [2] that 36% of blind individuals need sighted companions while travelling outdoors.

Although many helping aids, devices and navigational systems for visually impaired people exist nowadays, majority covers only part of daily navigational issues that visually impaired can encounter with, i.e. outdoor only or indoor only navigation systems. The navigation between outdoor and indoor is not solved in a satisfactory way.

This thesis proposes a method which should enable the seamless connection of these different environments also with the connection on the public transportation. This work builds on the research of the navigation of pedestrians with limited orientation and movement abilities, this research covers mentioned parts of the navigation – outdoor [3] and indoor [4].

1.1 Main objectives

The main objective of this thesis is to propose the way how to connect the outdoor and indoor parts of the navigation into the complex navigation system with environment transitions and use of public transportation.

Apart from the analysis of existing systems and studies, various situations in city navigation have to be identified and methodology for describing these situations proposed as well.

There are challenging situations for blind pedestrians in urban environment e.g. finding entrances to buildings, tram stations or navigating through open spaces as we call semi-outdoor environments (e.g. courtyards). An international study shows [2] that over 64.9% of visually impaired people struggle to find entrances to buildings, 82.4% lacks audio information about public transport stops and 43.3% have problems crossing complex pedestrian crossings. The GPS based systems for outdoor navigation (Blind Square, Ariadne GPS, Kapten Mobility) has limited usage in urban areas and indoors, the positional error in a medium city is about 28 meters for 95% of the time [5]. Indoor navigation systems build on various technologies which are able to localize persons in an environment, such as RFID readers [6], use of cameras [7] or other sensors. The Bluetooth Low Energy beacons can be used to help in these situations, compared to the state-of-art beacon-based navigation systems in lower amount thanks to existing landmark-enhanced navigation instructions. Specifically placing the beacons at selected decision points with the combination of landmark-based navigation instructions.

Further, we will extensively evaluate our proposed solutions with blind pedestrians in the laboratory and in real-environment using qualitative studies.

Summary of thesis main objectives:

- Analyse literature concerning navigation of blind pedestrians and existing navigation systems
- Identify the situations in city type of navigation for blind pedestrians
- Create the methodology for describing the identified situations
- Suggest implementation of the Bluetooth beacons into the navigation system for blind pedestrians
- Conduct more iterations of user testing

2 Analysis

This chapter analyses the literature concerning about orientation and navigation of visually impaired people and literature about navigation systems based on the text description of routes and beacons-based systems for outdoor and indoor navigation. Furthermore, analysis of the situations in the urban environment is presented in this chapter.

2.1 Related Work

2.1.1 Navigation and orientation of visually impaired

Since the vision provides reliable and rich information about the elements and landmarks that do not necessarily need to be in the immediate surrounding of the user, the objects which are in sighted distance can be reliably and without much effort identified and this information used for effective navigation. Therefore visually impaired people are limited in independent and free movement, but they are able to develop and use successful strategies and methods for orienting and navigating.

2.1.1.1 History and theories

The scientist in the past wanted to answer their questions about spatial understanding of blind people. It became a topic of study already in the late of the 17th century by English empiricist Locke.

In the late of 20th three theories were created to answer following question (Andrew, 1983; Fletcher 1980): **If one perceptual modality (i.e. vision) is missing, what (if any) effect does this have on our knowledge of the world?**

- **"Deficiency theory"**: The lack of visual experience may result in a total lack of spatial understanding.

- **"Inefficiency theory"**: It may result in spatial abilities which are similar to, but necessarily less efficient than, those of sighted people.

- **"Difference theory"**: It may result in abilities which are qualitatively different from, but functionally equivalent to, those of sighted people. [8]

It is more difficult to distinguish between the inefficiency and difference theories, although many studies were conducted, most of them focused on participant's current spatial abilities rather than on potential abilities, i.e. they looked at the gross performance of spatial task instead of focusing on the strategies used to solve the spatial task. Later authors (Millar 1994, Ungar et al. 1995) shown that *"... blind people potentially have access to a* ***range of strategies****, some supporting excellent performance, then this would favor an explanation in terms of difference."* [8]

2.1.1.2 Wayfinding

The definition of the term Wayfinding defines R.G. Golledge in [9] as: *"Wayfinding is the process of determining and following a **path** or **route** between origin and a destination. It is purposive, directed, and motivated activity. It may be observed as a trace of sensorimotor actions through an environment. The trace is called the route. The route results from implementing a **travel plan**, which is an a priori activity that defines the **sequence of segments** and turn angles that comprise the path to be followed..."*

The difference between terms *Navigation* and *Wayfinding* is that Wayfinding covers also the process of selecting between various paths in structured space, whereas Navigation means orientation and movement in free space since this term was originally and formally defined, to steer and direct ship or aircraft.

Before the journey users usually create a preliminary plan of the route leading to the destination. The space imagination plays a significant role in process of arranging and understanding spatial relationships and also allows, based on environment knowledge, to find a subjectively optimal way how to judge the difference between start and endpoint of the route. When travelling unknown environment users gain knowledge about the route and its surrounding from a map (sighted) or from **verbal description** of the route from someone who knows the route. If users know the environment and the route, they utilize their memories and memory projections.

Individual route elements are referenced by reference frames, which allow coding and decoding of space knowledge. This knowledge is stored in more complex structures that are called **cognitive maps**. [10]

2.1.1.3 Cognitive mapping and strategies

*"**Cognitive map**, a concept coined by Tolman (1948) and now used widely in many human sciences, is used to specify the internal representation of spatial information."* [9]

Many methods have been used to investigate how blind people construct cognitive maps, these methods were similar as methods used with sighted people. The navigation system for blind should support the creation of cognitive maps and strategies for environment reproduction and exploration.

Following **strategies for indoor exploration** of blind people were identified in studies by Hill, Gaunet, Thinus-Blanc, Swobodzinski and others [8], [10]:

- **Perimeter** strategy: moving along peripheral walls
- **Gri**d strategy: movement on imagined Euclidean grid
- **Object to object** strategy: movement between objects
- **Perimeter to object** strategy: repeated movement between object and perimeter
- **Star** strategy: after identify each object return to reference object
- **Cyclic** strategy: gradually identifying objects in spaces and afterwards return to first object
- **Back and forth**: repeated movement between two objects in space

It was found that object to object, perimeter to object and star strategy had resulted in a good performance of users and also those good performers used a wider range of strategies.

2.1.1.4 Landmarks

There are three levels of environment knowledge applied for navigation in cities [10]:

- **Knowledge of landmarks**
- Knowledge of route
- Overview knowledge of environment

Landmarks can be defined in various ways as says Golledge in [9], the landmark is something capable of attracting attention, i.e. it has dominance visible form and stands out from the surrounding environment, it can be recognizable and remembered by many people. Landmarks are used as anchor or reference points to organize spatial information and help in wayfinding process.

Landmarks are widely used also by blind pedestrians only they chose different types of landmarks. *"Empirical studies confirm that landmarks are in the urban environment the most commonly used and most requested guideline for sighted pedestrians (May, Ross, Bayer & Tarkiainen, 2003). Blind pedestrians use landmarks to the same degree as sighted do. But they chose different elements from the environment as landmarks (Golledge, 1991; Passini and Proulx, 1988). Landmarks can be detected by different senses, haptically – the presence of the tree before the junction detected by hand touching or white cane, hearing – street noise, . . . "* [10]

For navigating visually impaired people outdoors the suitable landmarks can be e.g. street corners and their different shape, pedestrian crossings, steps, etc.

For indoor navigation, visually impaired people still use the landmarks because the three levels of environment knowledge are valid indoors as well. So it is convenient to offer them landmark-based instructions for indoor, only the category of the landmarks changes, as the indoor environment is different compared to outdoor.

5 main guides in buildings, serving as landmarks [10]:

- Passed through the door
- Number of doors passed
- Purpose of rooms (it is useful when the user knows the building, otherwise not)
- Ending of floors - Users expect the same configuration of floors, but often a not excepted difference can lead to going off the route
- Types of rooms (corridor, foyer, etc.)

2.1.2 Navigation systems

There is quite a number of projects, studies and works involved in the topic of creating a navigation system for visually impaired people, both indoor and outdoor type of navigation or navigation systems using various sensors for user's localization.

This theme covers an extensive issue, which has not been solved in a complex way yet. In this section, we look at existing solutions to these problems.

2.1.2.1 Outdoor

There are many navigation systems available these days on the market (Google Maps, BlindSquare, Ariadne GPS), but the main disadvantage is that they rely on the GIS which is designed for a car-like type of navigation, i.e. these systems do not support the natural pedestrian way-finding principles. These navigation systems do not utilize the landmarks instead their navigation instructions are metric-based, e.g. *"After 100 meters turn right"*.

Balata et al. [3] developed the navigation system for an outdoor environment which uses **automatically generated landmark-enhanced navigation instructions** for blind pedestrians. He uses sidewalk-based GIS and also modifies it with new features:

- Geometric representation of sidewalks and their properties – slope, surface
- Landmarks – crossings entry points, corner
- Area features – traffic noise, type of public transport

These features are carefully selected in order to be convenient for visually impaired users and serve as a basis for the generation of navigation instructions, where each instruction is composed of environment description followed by action that should be performed by the user. The descriptions of environments are generated e.g. from street names, addresses, corner's shapes and pedestrian crossings. The action is generated from data about the geometry of the path, street names, corners of the streets, slopes, etc.

Mobility Aid for Blind People (MoBIC) was proposed by Strothotte et al. [11]. MoBIC Travel Aid is dialogue system for blind people. It is intended to be complementary to primary mobility aids (white cane or guide dog). It consists of two components: pre-journey system for planning the journey and exploring the new area before visiting it and outdoor system for executing the prepared plan. This system tries to prepare and present information normally accessible only by sighted people to different user groups, e.g. blind or elderly travellers. The system provides a digital map with the information required by these user groups e.g. type of surface, access routes without many steps, entrances useable by wheelchairs.

This system employs user model and a knowledge base with respect to relevant criteria, e.g. degree and kind of disability of the person, use of other mobility aids.

Dialogue system has two categories of commands, primary and secondary. Primary are e.g. "Where I am" or "How do I have to proceed to reach my destination", secondary commands provide additional features. The system provides a verbal description of user's position and selected features of the environment. These descriptions given to user are inspired in first adventure text games, where players also created some mental representation of the described environment.

The outdoor system uses GPS signal to derive user position and then give information from GIS which is stored in the device.

2.1.2.2 Indoor

In indoor environments compared to outdoor the GIS is designed to be used only by the pedestrians, so that the landmarks are present (doors, elevators, stairs). Indoor Navigation System for Visually Impaired called Naviterier was proposed by Vystrcil et al. [4] and uses offline navigation principle, i.e. position of the user inside the building is not tracked by any technology. Users follow the verbal description of the environment to navigate in unknown areas.

Well-structured instructions and descriptions of important landmarks are provided to users by a special application installed on a smartphone. Where the route itself is split into several parts called segments, see Fig 1. Each segment starts and ends at places which can be easily recognized by users (e.g. junctions of corridors, corridor turns). Segment information is provided to the user in two parts at once, at first keyword "DESCRIPTION" is followed by information about the surrounding environment and then after the "ACTION" keyword follows information what user should do.

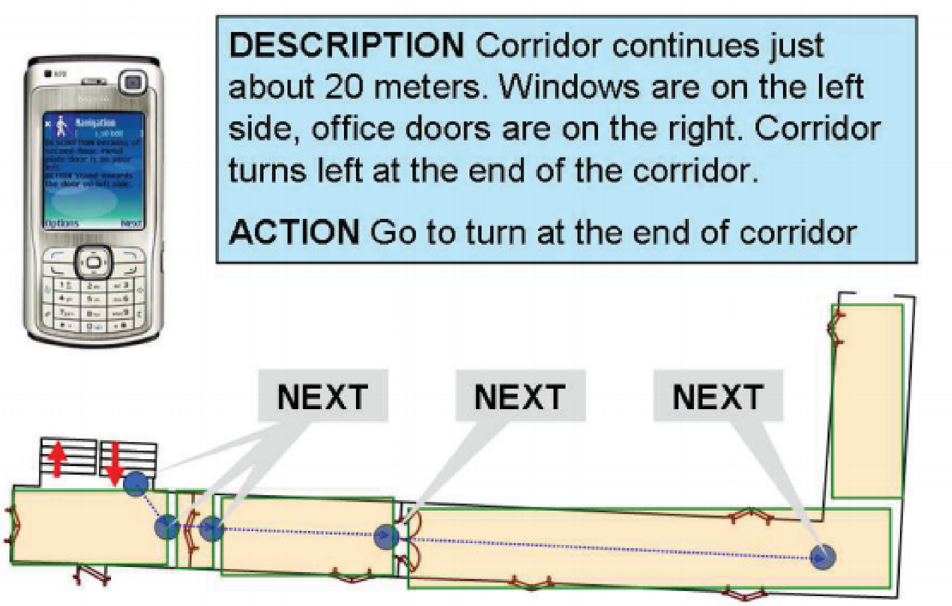

Figure 1 Part of corridor with marked segments. Taken from [4].

This solution has a potential problem in the possibility of lost user's expected position in the indoor environment. Solution to this problem is proposed as QR synchronization codes, which will users scan using the camera of mobile device.

This work also concerns about dangerous obstacles, which are dangerous for all people, but there are also objects, mainly objects hanging in the air, which are very dangerous for blind.

A similar principle of navigation system which uses landmarks in an indoor environment is proposed by Fellner et al. [12]. His work is a category-based method to generate landmark-based route instructions for complex buildings (e.g. hospitals, university buildings).

Landmark category-based navigation model was also proposed by Duckham et al., but it is designed for outdoor navigation. New challenges appear for landmark navigation in the indoor environment (changes of floor levels, different landmark categories and characteristics).

Indoor Landmark Navigation Model proposed in work of Fellner consists of three steps:

1. **identify categories of indoor spatial object, that may serve as landmarks** (classification and expert rating (weighting), it will be done once for each area),

2. **select landmarks from set of landmark candidates** (done automatically),

3. **integration of the selected landmark** to generate route instructions (done automatically)

See Fig 2 for the overview of this landmark navigation model.

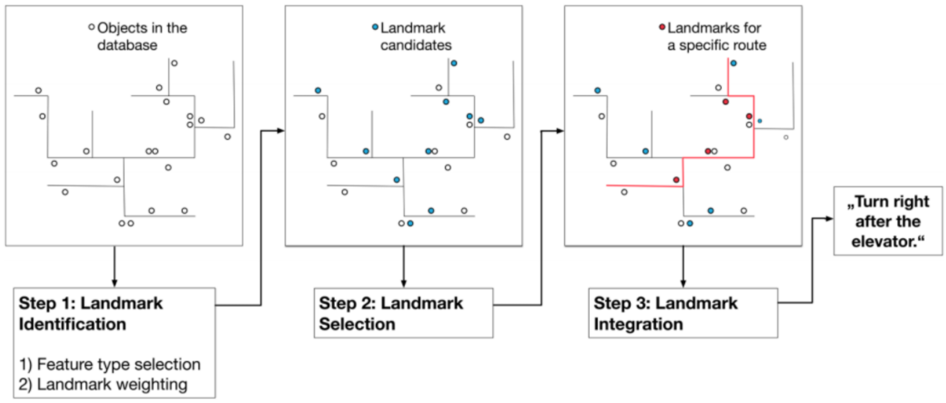

Figure 2 Overview of landmark navigation model. Taken from [12].

Follows the list of how selected landmarks for decision points should be integrated into the landmark-based instruction [12]:

- **Usage of path types instead of street names** - “go along path”, “go along the corridor”, path types: “ramp, elevator, stair”

- **Consideration of routes through open spaces** - lounges, study areas, “pass through the study area”

- **Handling of in-leg landmarks as point objects only and consideration of paths through landmarks** - “continue pass” - point-like landmarks, “continue along” - landmarks with spatial extents (outdoor), not this differentiation for indoor landmarks

- **Adaptation of route instructions for pedestrians and indoor scenarios. Outdoor scenario** - “<Perform action> onto <Street Name> at <Selected landmark>”. **Indoor scenario** - “Turn <Direction> <Spatial preposition> <Number> <Selected landmark>” to create instructions like “Turn right after the second toilet”.

- **Consideration of changes of floor levels.** “Use the <Path type> to go to the <Destination floor number> floor”

- **Consideration of landmark location at decision point** - differentiating between "before", "at" and "after" in the turn instructions.

- **Decision points without selected landmarks** - outdoor model uses street names to create turn instructions. Indoor model - "Turn <Direction> after <Distance>" for decision points without selected landmarks.

Guo et al. [13] developed Landmark-based **Mapless** Indoor Navigation called **FreeNavi** (designed for sighted users) that requires only WiFi fingerprints collected on the device. This system applies knowledge of humans being able to navigate through and identify the environment by landmarks. Therefore, FreeNavi constructs a virtual map only by landmarks descriptions and their connectivity relations.

Virtual map construction algorithm is based on WiFi signal strength data and also landmark fingerprints and the user traces, this data is crowdsourced and then the map created. The generated map does not contain information of turning directions (left or right), i.e. users have to find out by themselves at the junctions in which direction s/he has to continue to next landmark.

This system uses WiFi signal strength to localize users in the indoor environment. The algorithm is based on the similarity of two WiFi fingerprints. This principle is also used for virtual map creation.

2.1.2.3 Finding entrances

When connecting the indoor and the outdoor environments in the navigation system for visually impaired people the crucial moment in the way-finding process is to find the correct entrance to the building.

Finding entrances to the desired building was subject of researchers focused on crowdsourcing [2]. This study says that almost 65% of blind and visually impaired people suffered the mobility hindrance of hard to find entrances in the international survey by Zeng L.(2013). The primary identified reasons for such big number are: the complexity of environment next to entrances, not precise route planners for blind and limited GPS signal which can be blocked by high buildings.

To solve this issue authors used collaborative method for collecting information about entrances and buildings and they also created reference point for each entrance, their concept does not use GPS data but it is expected to use some GPS-base tool to navigate to reference point, i.e. reference point should on place with reliable GPS signal and should be placed on intersection of a main pedestrian road and service path led to the target entrance. When the user arrives at this reference point s/he can get structured and also unstructured data collected by other users.

Structured data contains following data:

- With automatic door (yes/no)

- Floors of entrances (the grounded floor, the first floor, . . .)

- With attached stairs (yes/no)

- Service paths with tactile paving (yes/no)

Unstructured data are text or recorded audio describing more detailed accessibility information or some experiences from other users.

2.1.2.4 Public transport

To develop a navigation system that allows visually impaired to be fully independent in everyday navigation habits it is necessary to include the use of public transportation, as the visually impaired people are used to optimize their routes via public transport [14] and of course, sometimes it is impossible to avoid travelling by public transport on longer distances.

The work of Guentert M. [15] concerns with the orientation of blind persons inside tram stations. Author of this work created a prototype of train station navigation assistant designed for Apple iPhone. This tool should provide user enough and well-structured information about tram station that can be used to develop mental model of the station. As the tram stations are often complicated indoor environments and it is stressful and time-consuming for blind people exploring it and they often need assistance. The prototype was created after the interview with mobility trainer, the station description is provided in tree data-structure, where each level represents one category: overview, floors, platforms and points of interest. Users can navigate through this data-structure with swipe gestures on their smartphone.

2.1.2.5 Use of beacons

In this section, we focus on methods that use Bluetooth Low Energy (BLE) beacons for navigation or proximity estimation.

Many electronic devices, navigation aids and navigation systems using various sensors are now widely available for visually impaired pedestrians, based on various principles of positioning, e.g. GPS based systems - for outdoor navigation (Blind Square, Ariadne GPS, Kapten Mobility), but it has limited usage in urban areas and indoors, the positional error in medium city is about 28 meters for 95% of the time [5]. Indoor navigation systems build on various technologies which are able to localize persons in an environment, such as RFID readers [6], use of cameras [7] or other sensors. These systems often require high deployment costs and are not suitable to use in other environments than indoors, there is no global standard for indoor navigation systems yet.

Work of Gorovyi et al. [16] shows the application of beacons for real-time users positioning based on trilateration calculation using RSSI values from three or more beacons. Performed accuracy test showed that beacon calibration improves system efficiency (1-2 meters in their case).

The Bluetooth technology used for indoor localization is often combined with utilization of other sensors to improve the accuracy of the navigation in an indoor environment (Accelerometer, Barometric sensor). Czogalla et al. [17] developed indoor navigation for $8000m^2$ public indoor environment with 35 beacons installed. The route is presented to users by visual map and directions by vocal instructions.

Commercial solutions for indoor localization or positioning based on the beacons often use a triangulation/trilateration approach such as Indoo.rs[1]. The difficulty of these solutions is mainly in a large number of beacons required. To achieve their proposed accuracy 1-3 meters it is necessary to install beacon every 7-10 meters, e.g. Infsoft[2].

[1] Indoo.rs – https://indoo.rs/
[2] infsoft – https://www.infsoft.com/

Work of Ahmetovic et al. [18] resulted in *NavCog* system, this navigation system relies on BLE beacons installed in an environment which provides sub-meter precise localization with a minimum of 1 beacon every 6 meters (see Fig. 3) and navigation assistance for visually impaired.

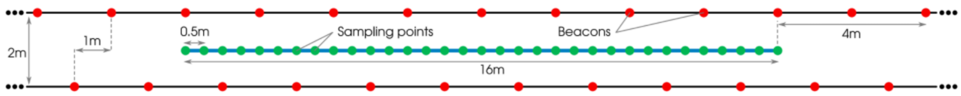

Figure 3 The experimental setting edge used for localization accuracy evaluation.. Taken from [18].

They achieve it by **representing the environment in the one-dimensional graph** which results in lower number of beacons to be used and further, they use multi-modal probabilistic state estimation algorithm and Particle Filtering framework to more precisely estimate user's position. *NavCog* system gives to user the "turn-by-turn" metric navigation instructions, distance announcements inform the user about the distance to next action (e.g. "18 meters"), action instructions give information about turning direction or transit information (e.g. move between floors). It also provides accessibility instruction (e.g. if there is a curb that is easy to trail with a cane) or surrounding information (e.g. building description) on request.

To help visually impaired children in school to move and play independently Freeman et al. [19] used **Audible Beacons as wearable bracelets** that support wireless communication and audio output and also placed beacons in the school environment, see Fig 4.

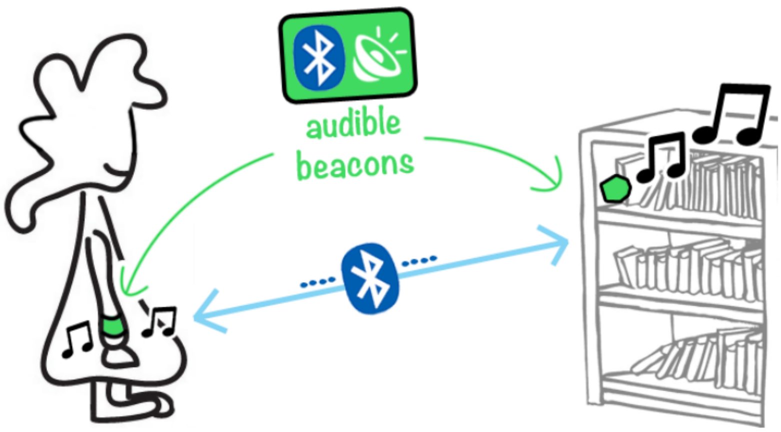

Figure 4 Example usage of the audiable beacons on the environment. Taken from [19].

They presented various scenarios with their solution, beacon bracelets can motivate and tell children about their nearby point of interest, by the specific sound of this POI getting louder the children know they are getting closer. It can help to find her sighted friends, who are wearing bracelets as well. Bracelets and beacons placed in the environment can help to learn the layout of the school and for example, help to find entrances too.

2.2 Environment situations

In order to create navigation with environment transitions and use of public transportation, it is necessary to identify various situations which can blind pedestrians encounter with in the urban environment and afterwards create methodology how to describe environments and situations. To do that the templates for describing these situations were designed in the section 3.1.2.

In this section, the various situations in pedestrian navigation within multiple modes of transport are identified. Different types of environment are also classified.

2.2.1 Environment classification

Change of the environment can mean to go from exterior inside some building or vice versa. But the problem of changing environments is not only within classical indoor and outdoor. There are also semi-outdoor and semi-indoor environments.

Whenever the user changes the environment, the system should give the user information about this environment. This information should contain structured description about space characteristics, to help the user to create a mental map of this space, followed by information about next action.

2.2.1.1 Indoor

Buildings

The diversity of buildings is large, the user should be at least informed of the basic characteristics of the building, for example, where is a reception or information stand, whether the building has a lift or not if the building is accessible for users.

Railway station buildings

Railway station buildings especially the main stations in cities are very complicated indoor environments, so we consider it as the typical indoor environment.

The user can typically enter/exit the building from more entrances/exits, he should get the information about the shape of the building, where he can find the ticket office and information stand. Then the route towards platforms, or exit (depends whether he arrived or he is departing) with respect to his position, i.e. from each entrance or from platforms.

2.2.1.2 Semi-indoor

This section contains the list of semi-indoor environments we identified and which users can encounter in urban areas.

Pedestrian underpasses

We identified that user can appear in a situation that requires using the pedestrian underpass. For example, you can leave tram station only by using the underpass. In these cases, the underpasses have more entrances and also can have more complicated shape.

Passageway

The passageway can be described in a similar way as underpasses. The main difference is that it is not an underground environment, but they are mostly in ground floors of bigger, typically historical, buildings. Passageways often contain a lot of small shops and various objects such as columns, steps, etc.

2.2.1.3 Semi-outdoor

Identified examples of semi-outdoor environments:

- Courtyards
- Garden/Park
- Compound (e.g. Hospital compound)

We identified these environments as semi-outdoor because they differ from classical outdoor environments. Users can use different types of landmarks, instead of roads and sidewalks users follow paths or even can go on the roads that are used with cars also (it was part of our route for experiments). It is more probable that user will encounter walkthrough some free spaces more often than in the outdoor environment. Nevertheless, it is important to inform user clearly that user is in different environment, and we should still give him/her navigation instructions base on same principles as in outdoor, i.e. find some guiding line (building, edge of the path), and inform him/her about important landmarks.

2.2.2 Means of transport

This is the list of various means of transport that were identified for cities.

- Buses
- Electric buses
- Trams
- Underground
- Trains
- Cable cars

2.2.3 Types of Stations/Stops

The following section describes a various type of stations or stops that can pedestrians encounter in cities. For each type of station/stop was created a methodology how it should be present in the navigational instructions to visually impaired users, see section 3.1.2.4.

Underground station

Underground stations are often very crowded and noisy thanks to arriving or departing metro trains. Various types of underground stations exist, there are stations with a single tube and its platforms can be in the middle or on sides of the tube, there are also stations with three tubes which can have separated platforms from the corridor in the middle of the station.

Underground vestibule

Underground vestibules are complicated semi-indoor environments, often very crowded and noisy thanks to arriving or departing metro trains. Entrance to vestibule can be inside bigger building which is designed for the different purpose than public transport, e.g. shopping mall (*Národní třída* station in Prague), or university (CTU in Prague - *Karlovo Nám.*). There can be a corridor from vestibule directly to e.g. hospital compound (Faculty Hospital Motol in Prague).

Isle

Isle type of station is in most cases station for trams or buses, as it was identified in the city of Prague, and it is the common type of station in other cities of Europe. Finding of the isle can be challenging and sometimes even dangerous situation for blind pedestrians.

Sidewalk

Sidewalk type of station is another very common station type, it has its platform on the sidewalk. Mostly the tram stops right next to the sidewalk, less common is when tram stops few meters from the sidewalk, then you get on the tram after crossing the street, or we can encounter with wiener type of station when the road is raised to the level of the sidewalk.

Terminus station

Terminus stations can be built in various ways, most common in case of trams and bus its place where they turn around (road or rail loop), so it has the circle shape. The stops can be placed either in the section of the track before the loop, or in the loop. Stops can be also separated to exit-stop and stop for departure. It is common that terminus station serves for more modes of transport (tram and buses together).

Railway station

Railway stations are complicated indoor and outdoor environments, especially the main stations in cities, it has typically more than one platforms, platforms are long, you usually don't know in what part of the platform the train will stop. Platforms can be connected with underground corridors leading to railway building, or in some cases, the smaller railway stations have not underground corridors, but pedestrian crossing over the railroad tracks, which are dangerous even for sighted pedestrian and typically not marked for visually impaired people. The railway station buildings are big, crowded and in case of main stations often multi-storey buildings with a connection to other types of public platforms.

Railway stations divided by the type of access to platforms:

- Platforms are on the same level as railway station building (level access)
- Platforms can be accessed by an underground corridor or by overpass (off-level access)
- Combination of both

Types of platforms:

- Bay platform - track terminates there
- Through platform - track continues
  - Side platform - there is only one side where people get on the trains (platform has one number)
  - Island platform - this platform has two numbers, i.e. people get on the trains on both sides.

3 Design

This chapter presents the details about the design of the navigation system which utilizes the use of Bluetooth beacons as synchronization points together with the landmark-enhanced route instructions.

3.1 Route instructions

This thesis builds on the navigation system which is based on the automatically generated landmark-enhanced route instructions, presented in works of Balata et al. [3] (outdoor) and Vystrcil et al. [4] (indoor).

These navigation instructions are generated from efficiently collected data from sidewalk based GIS and forms human-like navigation itineraries for visually impaired pedestrians who are able to efficiently use it for navigation without any guide.

Furthermore, as we try to achieve the *"door-to-door"* navigation in this thesis, which means the outdoor-indoor navigation with seamless environment transitions and use of public transportations. These new modes of the navigation has to be taken into account and so we will use previously presented methodology and templates in chapter 2.2 to fill the yet missing parts in the itineraries, i.e. public transport stops and stations, descriptions of the environments, descriptions of the entrances and new identified environments (semi-indoor, semi-outdoor).

3.1.1 Route instructions structure

Same as in the works of Balata and Vystrcil [3, 4], the route is divided into more segments, where each segment is composed of the environment description and the action that should be performed by the user. Each segment has also its number.

We then composed these small segments of the route into bigger groups which represents each type of the environment (indoor, outdoor, semi-indoor, semi-outdoor) through which the route leads, each of these environment group of segments has its own numbering. Because of the environment transitions the route itinerary also includes the general environment descriptions, e.g. description of the building as a whole object (see section 2.2).

Each segment should end at the point of the route which is easily recognizable by the blind user, called **landmark**. There is a difference in the landmark characteristics for different types of environment. In outdoor it is often a corner of the street or pedestrian crossing, in indoor it could be doors, stairs, corridor bent, etc.

3.1.2 Iterative design of route instructions

This section presents the template design for route instructions divided by the environment classification as was presented before in section 2.2.1. Methodology for describing the environments and situations was designed with respect to principles of landmark-enhanced navigation instructions as it was recommended in [4, 12]. Each template is constructed from properties listed before the template. The templates were created by using the iterative design process. We conducted two qualitative studies (see sections 5.1 and 5.2) to evaluate and further improve proposed templates design. Both studies resulted in recommendations for future design.

The searching for the landmarks on the end of every segment can be the difficult task in an unknown environment, what more when the types environment are changing during the navigation also the landmarks are changing. There is a chance that users will miss the landmark or mistakenly search for an incorrect landmark. Some of these errors can be seen in the results of the second user study we conducted in section 5.2.4. And based on this result we recommended utilizing the Bluetooth beacons as the synchronization points on the route.

3.1.2.1 Indoor

Buildings

Properties:

- Name of the building
- Additional info - type of building (e.g. historical building), the building is under reconstruction, the building has not typical shape of corridors (e.g. corridors are not perpendicular)
- Door accessibility information – information about the method of opening the door (e.g. if chip or card is needed).
- Reception position – where is the reception after entering the building.

Description: {Name of the building}, {Additional info}. Building has {number} floors. In building {is/is not} lift. {Door accessibility information}. {Reception position}

Railway station buildings

Properties:

- Station name
- Building characteristics - shape and brief characteristic of station building
- Type of station - passable/not passable
- Ticket office - Position of ticket office and information stand
- Access to platforms - with respect to current position, there can be level or off-level access to platforms.
- Numbering of platforms
- Acoustic beacons - presence of acoustic beacons

- Guiding lines – presence of guiding lines
- Objects - present in station building (shops, columns, entrance to metro station, etc.)

Description: You are in {Station name}, station is {Type of station}. Building is {Building characteristics}. {Ticket office}. {Access to platforms}, {Numbering of platforms}. {Acoustic beacons}, {Guiding lines}. In building are {Objects}.

3.1.2.2 Semi-indoor

Pedestrian underpass

Properties:

- Shape of underpass – (e.g. *"underpass is perpendicular to its entrances from tram station"*)
- Exits – description of exits from underpass
- Guiding lines – presence of guiding lines

Description: You are in the underpass that is {Shape of underpass}. From underpass lead {Exits}. {Guiding lines}.

Underground vestibule

Properties:

- Objects in vestibules:
  - Shops.
  - Pillars in the middle of vestibule, pillar barriers.
  - Glass door separating vestibule and transport space - likely opened.
- Information about acoustic beacons at exits/entrances to vestibules
- Guiding lines – presence of guiding lines

Description (through the vestibule): After the {escalators/stairs} follows the vestibule, separated by glass door about {Number} meters. Metal pillars are on the way. {Guiding lines}. Vestibule has {Number} exit(s). In the vestibule are {Objects at {Position}}.

Action: Go straight in free space about {Number} meters. Then continue {Direction} {Number} meters. {Guiding line is by your {left/right} hand}. {Object will be by your {left/right} hand}.

Description (exit from vestibule): Exit has {{Stairs/Escalator} Stairs at {Left-/Right} side and escalator at {Left/Right}}. {Stairs has {Number} landings}. Exit leads to {Street Name/Building Name/Passageway}.

Action: Go up.

Passageway

Properties:

- Name of passageway – usual passageways in Prague have own name.
- Entrances – list of entrances, described as address, to passageway
- Shape of the passageway – passage can be form of just one straight corridor, but also exist much more complicated shapes of passageways.
- Objects in passageway – e.g. shops, restaurants, columns, steps.
- Guiding lines – the presence of guiding lines for visually impaired

Description: You are in passageway {Name of passageway}. There are entrances from {Entrances}. Passageway has {Shape of passageway}. {There are {Objects} at {Position}}. {Guiding lines}.

3.1.2.3 Semi-outdoor

Properties:

- Type of the path
  - Road, path, sidewalk
- Surface of the path – will help users to be sure they are at the right place
- Objects
  - Cars parking
  - Buildings, benches
- Additional information
  - Beware of riding cars/bikes

Description: You are on the {Road/Path/Sidewalk} of the {Courtyard/Park/Garden/Compound Name}. Surface is made of {Surface Type}. {Object is at {Position}}.

Action: Find borderline of the road and grass by your {Left/Right} hand. {Additional information}.

3.1.2.4 Public transport

Underground station

Properties:

- Additional Info:
  - Station has {Number} tubes.
  - Platform is separated from middle part of the station.

- Objects on platform:
  - Benches, info tables and dustbins are {in the middle/by the side} of the platform.

- Information about line transfer:
  - In the middle of the platform are opposite {stairs/escalators} going {up/down}, transfer to {Line Name}.

- Information about escalators or stairs leading from platform, e.g. number of escalators and presence of acoustic beacons.

- Guiding lines – presence of guiding lines

- Lift – presence of lift in the building

Description (before getting off): Station {Station Name} has platform on the {left/right} in the direction of ride. {Additional Info}. {Information about line transfer}. {There are {Objects} at {Position}}. Station has exits at {end/both ends} of the platform. {Guiding lines}. {Lift is at {Position}}.

Action: Get off the underground and step out from the train.

Description (on platform): You are on the platform. {Go through the columns to the middle of the station.}

Action: Turn {Direction} and go to {Escalators/Stairs}.

Description (to vestibule): You are at {Escalators/Stairs}, {Information about escalators}.

Action: Go {up/down}.

Isle

Properties:

- Pedestrian crossing

- Equipment of pedestrian crossing:
  - With/without tactile warning strip
  - With/without lowered curb
  - With/without acoustic signalization

- Pedestrian underpass
- No pedestrian crossing
- Objects on Isle:
  - Shelter, railing, info-table, benches, dustbin, ticket machine
- Tactile strip - presence of tactile strip

Description (arrival): You are at station {Station Name}. Station is isle type, which has {{Pedestrian crossing/Underpass} in {Front/Back/Middle} part of station}. {Object is at {Front/Back/Middle} part of station}. {Tactile strip}.

Action: Turn {Direction}, go about {Number} meters to {Crossing/Underpass}. Have tram strip by your {Left/Right} hand, have {Street/Railing} by your {Left-/Right} hand.

Description (entry): You are by the {Crossing/Underpass} to {Station Name} across {Street Name}. Station is isle type.

Action: Cross the street to isle and turn {Direction}. Crossing has {Equipment}.

Description (departure): You are at station {Station Name}. {Object is at {Front/Back/Middle} part of station}.

Action: Go about {Number} meters to info-table. Have tram strip by your {Left-/Right} hand, have {Street/Railing} by your {Left/Right} hand.

Sidewalk

Properties:

- Tram/bus stops right next to sidewalk
- Tram/bus stops few meters from sidewalk, pedestrian must cross roadway to get on tram.
  - Road {is/is not} raised to the level of sidewalk
- Objects on Isle:
  - Shelter, info-table, benches, dustbin, ticket machine
- Opposite side of the sidewalk – object on the opposite side of the sidewalk that can be used as guideline.
- Tactile strip - presence of tactile strip

Description (arrival): You are at station {Station Name}. Station is at sidewalk {with boarding over the road, road {is/is not} raised to the level of sidewalk}. {Object is at {Front/Back/Middle} part of station}. On the opposite side of the sidewalk is {Building/Park/. . . }. {Tactile strip}.

Action: After getting off go towards {Object} in front of you then turn {Direction}. Have {Object} by your {Left/Right} hand.

3.2 Route representation

We represent the route as a one-dimensional oriented graph. The graph has two types of the nodes:

- Correct Node
- Error Node

The correct nodes of the graph represent the decision point on the route, which means the end of one segment and start of the following one. The error nodes represent the end of the wrong turn off the route. Each node holds information about Beacon ID if it is present at the particular route segment and also if and if it is correct or error node. In our design, we presume that not all of the correct nodes will have the beacon installed, but every error node present in the route graph should. Every route graph has also the start and final node, representing start and end of the route.
The graph has two types of the edges:

- Edge on the route
- Edge off the route

The edges represent route segments they connect two correct nodes, edges on the correct route hold segment number, description and action, edges off the route lead to error node. The part of the route graph we created for evaluation can be seen in Fig. 5.

With this solution and the detailed route instructions, it is possible to reduce the number of beacons deployed in the environment to the minimum. We decided to place beacons only at the decision points of the route. To help users with environment transitions beacons are placed at entrances to buildings. The difficulties with finding the public transport stations are solved by placing beacon there as well. The key idea of our solution is that we do not estimate the user's distance to the particular beacon. We use the proximity-based approach. Beacons serve as proximity traps at decision points, therefore the number of installed beacons is highly reduced.

Thanks to the route represented as graph we are able to provide users error prevention and also error recovery at the more complicated decision points. This is supposed to give user more confidence while s/he is navigating using landmark-enhanced navigation instruction or to inform that s/he is going the wrong way. Compared to the other solution [18], which offers the distance announcement and turning instructions, but lacks the error recovery when taking the wrong turn.

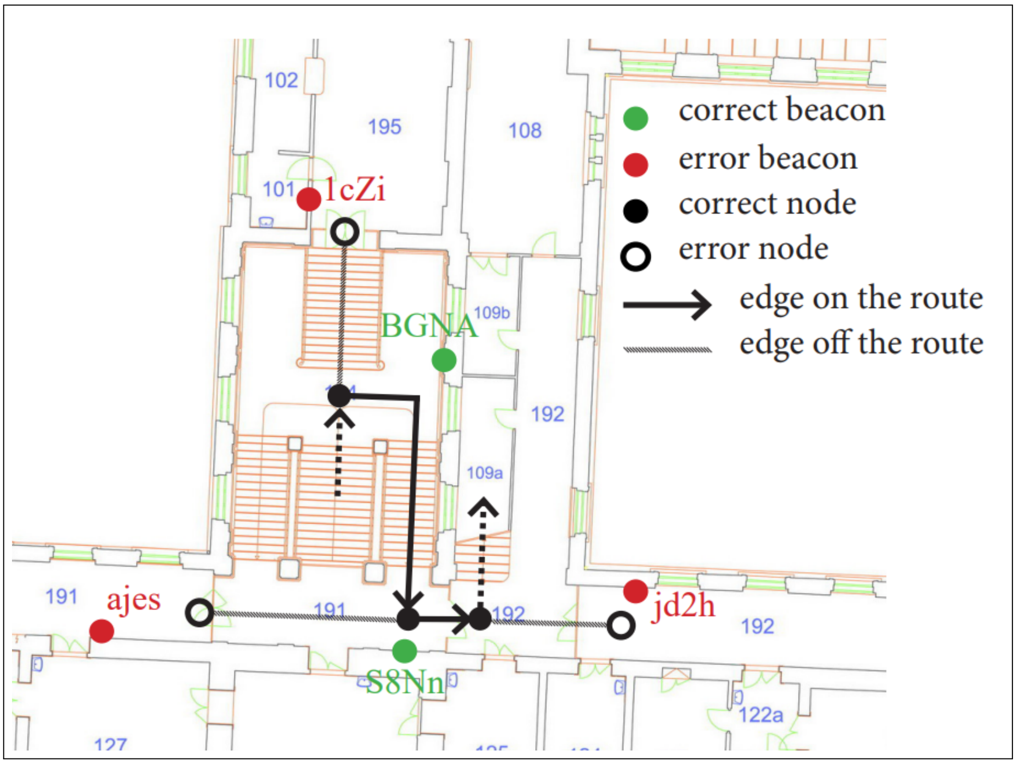

Figure 5 Part of the prototype route represented as 1D graph. With positions of installed beacons.

3.3 Bluetooth Low Energy beacons

Bluetooth as wireless communication technology for exchanging data over short distances was introduced in 1994 and as a standard had its first full release in 1999. Five companies (Ericsson, Nokia, IBM, Toshiba and Intel) formed the Bluetooth SIG - Special Interest Group. [20]

Bluetooth Low Energy (BLE), is a form of Bluetooth technology that has been developed to provide effective connectivity for many forms of small devices, particularly those associated with the Internet of Things, IoT. BLE is aimed at use in devices that may need to run of small batteries for long periods of time, while also being able to communicate with larger devices like smartphones or tablets. The BLE standard was merged into the main Bluetooth standard in 2010 with the adoption of the Bluetooth Core Specification Version 4.0. [21]

Beacon itself is a small low-power transmitter based on BLE technology. It periodically broadcasts data package containing beacon's ID and some additional data.

3.3.1 RSSI (Received Signal Strength Indication)

The Received Signal Strength Indication (RSSI) is used to measure the radio signal strength. RSSI is an indication of the power level being received by an antenna. It is measured in decibel-milliwatts (dBm) whereas RSSI is a signal strength percentage—the higher the RSSI number, the stronger the signal. A significant feather of radio transmission is that the signal strength decreases as the distance increases. The relationship between the RSSI value and distance is shown in Figure 6.

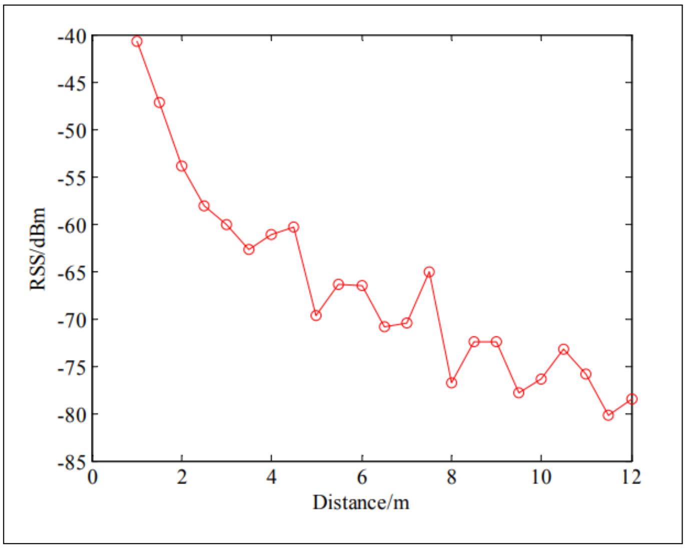

Figure 6 The relationship between distance and Received Signal Strength. Taken from [22]

3.3.2 Key features

Following key features of the BLE beacons are taken from the website of the manufacturer of the beacons we used - Kontakt.io [23].

- Broadcast advertising packets based on Bluetooth LE (4.0)
- Compatibility with all Bluetooth 4.0 devices
- Compatibility with both Apple iBeacon^{TM} standard and Google Eddystone^{TM} standard
- Configurable parameters protected by password:
  - Proximity UUID, Major and Minor values
  - Device name
  - Transmission power level
  - Advertising interval
- Over-the-air firmware upgrade
- Low power consumption
- Up to 48 months of each battery operation life at default settings (Basic Beacon model)
- Weather-proof hardware casing allowing for outdoor usage (tough-beacon)

3.3.3 Sources of the signal distortion

The signal can be absorbed by other persons moving nearby beacons, so we placed the beacons above the people's height, approximately 2.5 - 3.5 meters high. The signal can be interfered by other devices working on the same frequency spectrum as beacons - 2.4 GHz, which is the same spectrum used by Wi-Fi 802.11 channels. There are many materials that can be barriers for Bluetooth signal, e.g. plaster, concrete and bullet-proof glass have high interference potential, metal materials have very high interference potential and the signal can be reflected [24].

3.4 Beacons installation

To reduce the number of beacons deployed in the environment to the minimum, we decided to place beacons only at the end of the selected segments, at entrances to buildings and at public transport stations.

The key idea of our solution is that we do not estimate the user's distance to the particular beacon. We use the beacons as proximity traps, for a purpose to give user more confidence while s/he is navigating using route itineraries, or to inform that s/he is going the wrong way.

For every system depending on BLE beacons it is necessary to install and setup beacons correctly in the environment. As we can use received signal strength from beacons to estimate its proximity we had to prevent the signal interference and distortion, which can be caused by multiple factors.

In the indoor environment, we installed the beacons only at the decision points. These points are e.g. corridor junctions, corridor bents, near the doors on the corridor, floor mezzanines at complicated stair system. We placed the beacons mainly on the walls (see Fig. 7).

At the public transport station, the suggested place for installing the beacon is the info-table. Same as in indoor environment the beacon should be placed above the people's heads. In our case, we placed it at the tram station oriented towards the sidewalk.

To help users with environment transitions we placed the beacon near the building's entrances. The beacon should be placed with respect to possible directions of the user's approaches to an entrance. If possible, as much as possible in the sidewalk level. When placing the beacon at the entrance our intention is to slow down or stop the user. Then the user is expected to read the detailed description of the entrance from route instructions and find the correct door.

We also placed the beacon at the decision point in the semi-outdoor environment (university campus courtyard). This environment is composed of the roadways rather than sidewalks, users have to navigate through open spaces. To help them find the decision point at the roadway turn, we placed the beacon on the building near it at 3,5 - 4 m high.

During the installation, we encountered the signal interference from some other device at one of floor mezzanine. We then moved the beacon on the other side of the corridor, which solved the signal problem.

3.5 Beacons configuration

After placing the beacons on the decision points. We had to configure beacons properly, with possible interference in mind, we adjusted advertising interval and transmission power for each beacon individually with cooperation with an expert.

The Kontakt.io beacons are configured using Kontakt.io Android or iOS application. All the beacons were set to work on iBeacon protocol.

We collected RSSI values on two different smartphones (iPhone and Android) to determine the RSSI threshold values for beacons, which we needed for setting a *"proximity traps"* for each beacon.

Figure 7 Beacons installation at the suitable places.

3.6 Interaction design

The application is supposed to be running on the Android smart-phone with running TalkBack and supporting Bluetooth version 4.0 or higher to be able to range BLE beacons. TalkBack allows moving between the elements of the application by swiping to the left respectively right. When a particular element is focused TalkBack then reads the content to the user and user is also given a vibration feedback. If the focused element is a button the user is notified that to activate or click the button user should double-tap it.

3.6.1 Switching through route segments

As the route is represented as a one-dimensional graph, switching through the segments is basically graph traversal. It is expected that user will switch to the next segment as s/he finds the landmark on the end of the actual segment (e.g. corner of the street, door, etc.). The next segment starts at the user position and leads to another landmark which user has to find. The user can be also localized by the beacon and will receive the notification, which is supposed to help the user in correct landmark identification.

The user can move through the route segments using button "Next Segment" and "Previous Segment". At the first segment of the route, only "Next Segment" button will be displayed. At the final segment of the route, only "Previous Segment" button will be displayed.

3.6.2 Automatic location synchronization

The application is ranging the beacons for the actual segment that is displayed on the screen, i.e. it ranges for both correct and error beacons if available.

When the user approaches in the nearby of the correct beacon of an actual segment, the application will twice long vibrate and announce to user *"You are near the end of the segment."*

When the user turns off the route and approaches in the nearby of the error beacon from an actual segment, the application will four times short vibrate and announce to user *"You are on the wrong way, return to the start of this segment."*

The nearby of the beacon is defined during the configuration, every beacon in database holds its RSSI-trigger value. If the signal of the ranged beacon is higher than this value, then the notification is triggered. At first, we proposed to collect three samples of the RSSI, count the average and compare to RSSI-trigger value. Since it was too slow and with probability to miss the beacon without triggering the notification, we decided to collect only two samples of RSSI values from the beacon and then compare the average of two samples with trigger value.

3.6.3 Manual location synchronization

These two notifications from application happen automatically when the user is in the vicinity of the corresponding beacon. The automatic notification is triggered only once. Therefore the application also provides the possibility to manually verify user's position. When the user press "Verify location" button, which is only available for the segments with beacons, the 5 seconds time-out starts and application is ranging for correct or error beacons. When the 5 seconds limit expires and the user is not in the nearby of any beacon the application will announce *"Verification of your location was not successful."*. This functionality was implemented after the pilot test of the application when the user misheard the automatic notification on the rush street heading towards tram station.

4 Implementation

In this chapter, the practical implementation of the high-fidelity prototype application is presented.

4.1 A mobile navigation application

For the purpose of the third qualitative study, a prototype of mobile navigation application was implemented using the open-source Ionic framework in version 3.

4.2 Ionic framework

Ionic Framework is an open-source SDK that enables developers to create hybrid mobile apps using familiar web technologies (HTML 5, CSS, and JavaScript). Hybrid apps are essentially small websites running in a browser shell in an app that has access to the native platform layer. The underlying framework that powers Ionic is AngularJS, therefore Ionic applications are written in TypeScript language. Angular is responsible for the component API that is the building block of Ionic. [25]

Since the Ionic framework is cross-platform it is possible to build progressive native mobile apps for both platforms (iOS and Android), for the purposes of our qualitative study we build application only for Android.

4.2.1 Native functions

To provide native functionality to the users of an application, the Ionic framework offers an Ionic Native wrapper for Cordova/PhoneGap plugins (Bluetooth, BLE, iBeacon, Camera, etc.). *Ionic Native wraps plugin callbacks in a Promise or an Observable, providing a common interface for all plugins and ensuring that native events trigger change detection in Angular.* [25]

4.2.1.1 List of used native plugins

- Mobile Accessibility - exposes information on the status of various accessibility features of mobile operating systems, allows an application to send a string to be spoken by the screen reader, or a command to stop the screen reader from speaking.

- Vibration - allows an application to vibrate the device

- iBeacon - provides functions for working with iBeacon protocol

- File - implements a File API allowing read/write access to files residing on the device, used for creating the log file.

4.3 Application structure

The prototype of an application has following structure. A *src/index.html* is the main entry point for the app, its purpose is to set up scripts, include CSS files and start running our app. The Ionic look there for <ion-app> tag in HTML which is the root component of the application.

The app.module.ts is a root module that essentially controls the rest of the application, i.e. loading all the pages, components, plugins, providers, classes, etc. The diagram of the classes and components can be seen in Fig 8.

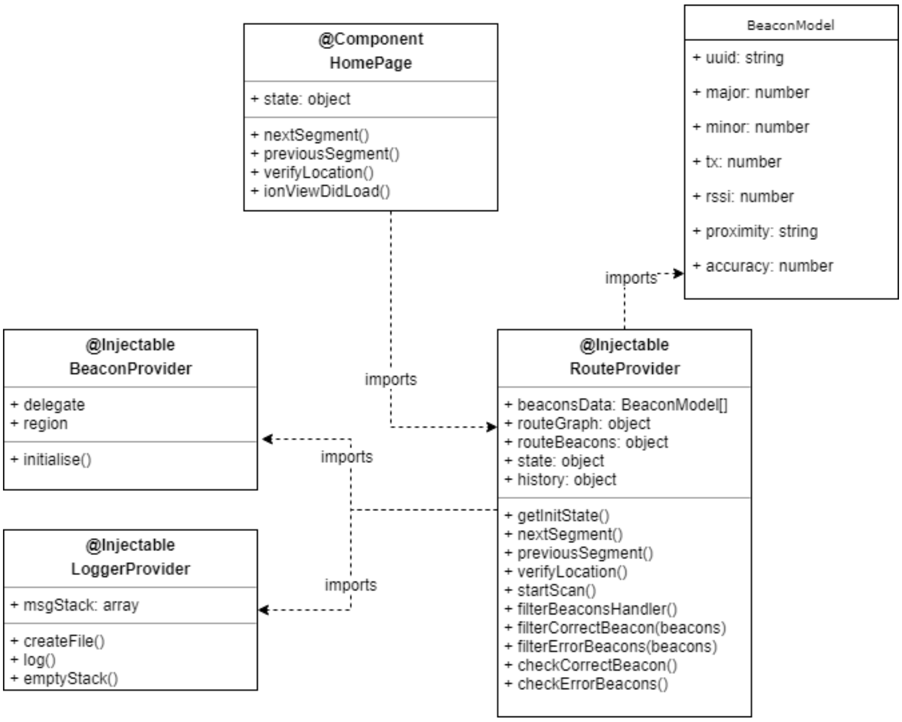

Figure 8 The class diagram of the application.

4.3.1 HomePage

The application contains only one page called HomePage (see Fig. 9). This page changes dynamically based on how is the state in RouteProvider changing. All of the previously generated pages are pushed onto the top of the navigation stack, which is handled by the NavController class provided by Ionic framework.
Home page contents all of the data and interface that user needs:

- Title of the page - used for the segment number
- Paragraph - Description + Action of the segment
- Next Segment button
- Previous Segment button
- Verify Location button

The HTML source code is short and simple, the buttons show conditionally thanks to Angular's **ngIf* directive. Buttons are default Ionic components with click event listeners.

```
<ion-content padding>
  <p class="description">
    {{state.actualDescription}}
  </p>
  <button *ngIf="state.showVerifyLocation" ion-button (click)="verifyLocation()">Verify Location</button><br>
  <button *ngIf="state.showNext" ion-button (click)="nextSegment()">Next Segment</button><br>
  <button *ngIf="state.showPrev" ion-button (click)="previousSegment()">Previous Segment</button>
</ion-content>
```

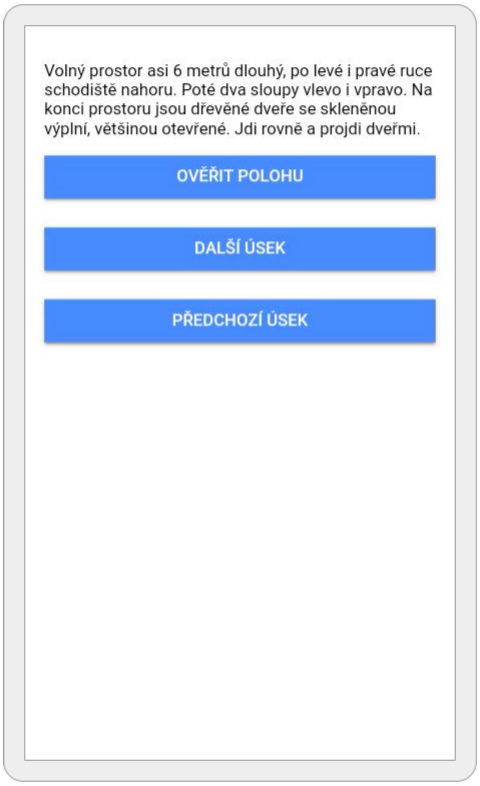

Figure 9 The main screen of the application.

4.3.2 Beacon model

BeaconModel class is a definition of Beacon data type. It holds following data about the beacon: *uuid, major, minor, RSSI, proximity, tx, accuracy.*

4.3.3 Route provider

RouteProvider class covers the main logic of this application. It handles the state of the application, it allows the user to switch between route segments and determines which beacons should be ranged in particular state.

List of functions:

- getInitState - sets application state to the first segment and creates a log file, when the application starts, returns the state
- nextSegment - traverse the graph to next node and changes the state accordingly, pushes that state into history stack and returns it
- previousSegment - pop previous state from the history stack and rewrites the actual state and returns it
- verifyLocation - sets the 5 second time-out for ranging beacons in the actual segment
- startScan - starts ranging the beacons in a nearby region
- filterBeaconsHandler - called when some beacons are ranged
- filterCorrectBeacons - filter the ranged array of beacons data, if the correct beacon is present then pushes the RSSI value into the RSSI array of this beacon
- filterErrorBeacons - filter the ranged array of beacons data, if the error beacon is present then pushes the RSSI value into the RSSI array of this beacon
- checkErrorBeacons - checks the array of RSSI values for each error beacon, if the length of the array is 2 then count the average and compare it to the trigger value if average is higher then trigger the notification
- checkCorrectBeacon - checks the array of RSSI values of the correct beacon, if the length of the array is 2 then count the average and compare it to the trigger value if average is higher then trigger the notification

```
 if (avg > beacon.rssiTrigger) {
                this.didNotificate = true;
                this.logger.log(`Triggered correct - avgRSSI: ${avg}
                    beacon.rssiTrigger: ${beacon.rssiTrigger}`, this.
                    fileName)
                this.vibration.vibrate([1000, 100, 1000]);
                this.mobileAccessibility.speak("Jsi blizko konce tohoto
                    useku", 1);

}
```

Listing 4.1 Way how the notification is triggered using Vibration and MobileAccessibility plugins.

Content of the state for generating the UI:

- String - Actual segment number
- String - Actual segment description
- String - Actual segment action
- Boolean - Show Next Button
- Boolean - Show Previous Button
- Boolean - Show Verify Location Button

4.3.4 Beacon provider

BeaconProvider class is responsible for ranging beacons with specific uuid. It uses the plugin iBeacon from Cordova. Both platforms Android and iOS are supported.

4.3.5 Logger provider

LoggerProvider class handles the logging into file. Each log is written with its time stamp. This class was created for evaluation purposes only. The log is created whenever user clicks button, correct or error beacon is ranged or notification of user's position is triggered.

Example of log:

```
Verify Location 5. úsek ze 7, beacon: 6bUB   2018-04-12T11:58:36
Ranged correct - Major: 64049 Minor: 65232 RSSI: -69   2018-04-12T11:58:37
Ranged correct - Major: 64049 Minor: 65232 RSSI: -69   2018-04-12T11:58:37
Triggered correct -  avgRSSI: -69  beacon.rssiTrigger: -75   2018-04-12T11:58:37
```

4.3.6 Route data structure

Navigation instructions are stored in the navigation application in the graph data structure (see Fig. 10 and Tables 2, 1) it also contains data about Beacon IDs and if they are on the correct route or not. In the application, the graph is stored using JSON format see the code example in appendix A.1.

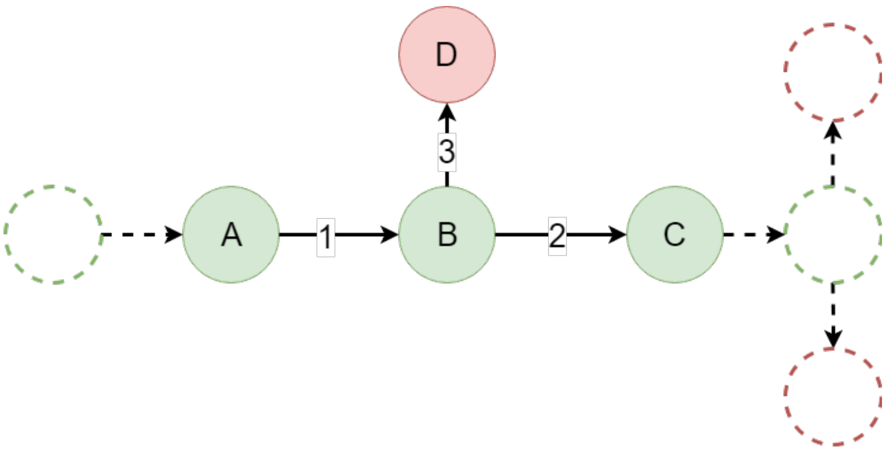

Figure 10 Example of the generated graph structure. The detailed information about the content of the nodes and edges are presented in Tables 2, 1.

Table 1 Example of the edges data in generated graph data structure.

Edge	isOnRoute	Segment Nr.	Segment Description	Segment Action
1	true	1	You are at the turning of the road, the building E is in front of you.	Turn left and go approximately 30 meters through open space to pyramidal stairs, by your right hand. There is an entrance to the building E.
2	true	2	You are by the entrance to the building E. Above the pyramidal stairs there is big wooden door and glass swing door right behind, leading inside the building.	Go up the stairs and through the doors inside the building.
3	false	undefined	undefined	You are on the wrong way, return back to the beginning of the segment.

Table 2 Example of the nodes data in graph data structure.

Node	isOnRoute	BeaconID
A	true	undefined
B	true	ODUM
C	true	vf3i
D	false	4vXL

5 Evaluation

In this chapter are presented the detailed information and results from conducted experiments within this thesis. In total three qualitative studies were conducted with users to evaluate proposed design. The evaluation process is a key step in the User Centered Design principle.

5.1 First qualitative study

For this experiment, two low-fidelity prototypes of the route itinerary were created, can be seen in appendix A. The location of the routes was in the vicinity of CTU FEE campus in the Karlovo náměstí. Routes start at tram respectively metro stations and the end of the routes is same in both cases - classroom inside the building of Faculty of Electrical Engineering. Routes go through all of the possible types of environments, as was classified in section Environment Classification.

5.1.1 Research questions

- How do participants understand created route itineraries?
- What information in itineraries are missing?
- What information in itineraries are redundant?

5.1.2 Participants

Six visually impaired participants were recruited via e-mail leaflet. They were aged from 25 to 69 years ($mean = 37.3$, $SD = 15.96$). Three participants congenitally blind and three were late blind. Three participants had Category 4 visual impairment (light perception) and three participants had Category 5 (no light perception) according to WHO classification. Two participants had a guiding dog, four participants do not and used only white cane. All of the participants were native Czech speakers, see Table 3.

Table 3 Demographic information about participants of the first experiment, Category 4 is light perception and Category 5 is no light perception.

ID	Gender	Category	Onset	Age	Guiding dog
P1	F	5	late	25	yes
P2	M	4	congenitally	36	no
P3	F	5	late	69	yes
P4	M	4	congenitally	33	no
P5	M	5	late	29	no
P6	M	5	congenitally	32	no

5.1.3 Procedure

The first iteration of user testing experiment did not take place in the field, it was conducted in the laboratory setting instead. The purpose of the experiment was to test whether the participants understand route itineraries (in terms of nomenclature and navigation principles), what information in itineraries are sufficient or redundant. Firstly, the purpose of the experiment was explained to the participants. Then the sections of routes itinerary were played individually to the participants using the screen reader on Android cell phone. Both routes were saved as HTML document so that each section of the route was one paragraph. After every section, the participant had time to express his or her opinion about the section.

Routes

The first route led from the metro station to classroom inside the campus building of CTU. It consisted of 41 segments and was about 300 meters long. It contained the combination of indoor, semi-indoor and semi-outdoor environments. The second route led from tram station to classroom inside the campus building of CTU. It consisted of 34 segments and was about 450 meters long. It contained the combination of all classified environments. For the route description and whole route itineraries see appendix A.1 for Route 1 and appendix A.2 for Route 2.

5.1.4 Results and Discussion

5.1.4.1 Route 1

Route description

In route description, there is a recommendation where to get on the metro (in the middle of the train). P1 appreciate this information. P4, P5 think that this information is redundant.

P6 would appreciate information about the length of the whole route in advance.

Station description

Participants P3 and P5 do not know how to imagine what the word "prostupy" is. They advised calling it "sloupy" (columns) instead.

P1 and P3 were confused by the information "(Station) Has platform on the left in direction of the ride." they thought that they are already on the platform. This was mainly due to the fact that this study was conducted in the laboratory and not in a real environment, so the participants could not get a real sense of the environment.

Metro station and vestibule

In second segment P4 said that it is useless to mention distance to escalators since it is not sure where exactly the user will get off the train.

In third and fifth segment P5 was annoyed about the repeated information about the acoustic beacon, mentioning it once is enough for her/him.

P1, P2 and P5 said that the action in the fifth segment - "Go up, using escalator" should be merged with the previous segment where is the action - "Go 10 meters to the escalator."

P1 and P5 said that the information about what is after the escalator is redundant for them. They also mentioned that there is duplicated information about distance and repeated information from the previous section about "area before vestibule" in the sixth segment.

In eight segment P5 and P6 were confused, participants do not know exactly where to go and where the shops will be. Information about guiding line was not clear. Participants had to repeat this section.

P5 would instead of "go at the end of the shop" use "go at the rounded corner of the shop" in the ninth segment.

P3, P4 and P6 in segment 10 would change the action from "turn slightly left and go approx. 15 meters to stairs" to: "turn slightly left and go straight in free space approx. 15 meters to stairs", they would like to be informed in advance about the walk through the free space.

P3, P5 and P6 said that the segment 14 (passageway) has too long description. Naming all the exits from the passageway to streets and to the metro vestibule seems to be useless for them.

Indoor Building A

Information about two possible entrances to building in the building A description is confusing for P4 and P5.

All participants appreciated the information about vending machine and that it is making noise. They also said that the vending machine is a good landmark in indoor environment mainly thanks to characteristic noise it is making.

Courtyard

In the courtyard description P4 and P6 would like to add distance to the action: "find the boundary of street and grass at your right hand". For P6 it would be better to say: "On the left and right are curbs, stay on the right" or "...go along the right curb".

P1, P2, P3 and P5 said that in the first segment is problematic information about having the building C by the left hand. The building can be far away if they are going on the other side of the road and for someone, it can be difficult to hear the building.

In second segment the road crossing may not be recognized by the blind pedestrians said P4 and P5. One solution could be to go to the building E in the previous segment. And in this segment then follow the wall of this building.

All participants said that they are not preferring barrier-free entrances to entrances with stairs.

In segment 3 the information about the main-entrance with pyramid stair is confusing for P1, P3, P5 and P6. Participants firstly thought that they will enter the building using this entrance. Going through the free space and not along the stairs is problematic too, far better would be to use the stairs as a guide line and go along them.

Indoor Building E

The ride with the elevator was problematic for most of the participants. P1, P3, P5 and P6 said that the information about calling the elevator is redundant, it is clear that the user should call it once he found it. These two segments should be merged into one segment. The description "Platform of the elevator" was confusing for participants, they were not sure if it is intended that they are inside an elevator or in front of the elevator's door. Inside the elevator cabin - segment 11, P3, P4 and P6 missed the information about where to place the card which is needed to control the elevator ride.

In segment 13 P3, P4 and P5 said that the information about the turn at the end of the corridor is redundant and confusing if the route not leads there.

At the final segment for all of the participants it would be better do not go from one door to another, but much better would be: "go by the left wall and count second door."

5.1.4.2 Route 2

Tram station description

P6 said that the presence of the ticket machine can be redundant for blind pedestrians. For P6 it would be safer, to go towards buildings on the other side of the sidewalk and then turn. He found turning immediately after getting off the tram as very dangerous.

P2 would change description: "on the other side of the sidewalk are buildings" to: "in front of you are buildings." As P2 and P4 said, there is a bad turning instruction, users will turn by 180 degrees at first and in next section they will turn again by 90 degrees.

Exterior

P5 does not understand what "marked crossing" means, the participant would like to hear "you can find crossing by cane".

P3 and P6 would appreciate the change in the description from: "You are located at" to: "You are at". The shorter version is better for them.

When finding the entrance to building participants P2, P5 and P06 said that the instruction about the building address (the building number) is not useful information to find the entrance. This segment should be divided into two sections. In the first segment should be "find the stick out facade of building" and in the second section should be "count the second niche and enter the building". Generally, participants want firstly find the place where to find an entrance and then obtain next information how to find correct door.

General

Actions like "go through the door" should be merged with the previous segment, when user firstly hear information about the door, said participants P1, P2 and P5. Similarly, with actions like "go up using escalators", "go upstairs", or "go to floor number 3", these should be merged with the previous segment as well. All participants said that the repeating information about shape and measurements of card reader was distracting, participants want to hear it only once.

Stairs

P3 would replace the action "Go up using stairs" with "Go up". P3 and P5 said that the information about handrail is useful only when there is no handrail or it is dangerous to use the stairs, otherwise, it is not necessary to have this information in instructions. Participants also said that the number of steps is redundant information. P3 was not sure what "triple stairs" mean, better description will be "stairs with two landings."

Building descriptions

For all participants were the general building descriptions too long. P1 thinks that the information about fire alarm is useless.

The instructions about turning and directions should be unified, i.e. "left/right" and "to the right/to the left".

5.1.5 Recommendations for design

This section describes recommendations for design, which were extracted from findings mentioned above. These recommendations should be considered in the future design. The questions about future design are specified too.

R1: Remove repeated information, e.g. acoustic beacon before every escalator, measurements of the card reader. Remove redundant turning.

R2: Unify direction instructions and other terminology (environments, areas, surfaces, etc.).

R3: Descriptions of environments are too long. Perhaps two level of details for environment description should be implemented.

R4: Remove redundant information about stairs (handrail, number of steps). Inform users only when the stairs can be dangerous for them. It means that there is no wall or handrail on the sides of stair, and user can easily fall off.

R5: Merge sections containing first mention about door/escalator/stairs/lift and next section containing door/escalator/stairs/lift action together. Do not merge these sections if there is added information e.g. where to put chip card.

Merging vs. not-merging should be furthermore tested because this finding can be biased by the experiment conducted in a laboratory because in field testing the time between sections will take longer.

R6: When navigation through open spaces, always inform about direction user should go through it.

R7: Navigation in semi-outdoor environments should be considered as navigation in classical outdoor. If it is possible use buildings as guiding line, if not use pavement or road borderlines. Avoid navigating through open spaces.

R8: Avoid dangerous turning immediately after getting off tram/bus/metro.

R9: Indoors in final section, don't go from one door to another. Say "count XX door..." instead.

R10: When entering the building, split this section into two. First section should contain how to recognize the place where entrance is (e.g. there are steps, different surface, ramp, change in facade, etc.), second section should contain detail information about the position and description of correct door (e.g. second door in the niche).

5.2 Second qualitative study

After the first experiment, we take into account recommendations R1, R2, R3, R4, R5, R6, R8, R9 and R10 for the creation of new prototype route for the second experiment. Recommendation R7 was not implemented because we have to follow information available in data structures for the semi-outdoor environment in our prototype route, which meant to go through open space.

5.2.1 Research questions

- How were **recommendations** from first experiment implemented?
- How participants **understand** route itineraries in **real environment**?
- How **comprehensively** were tram stations described?
- How **comprehensively** were entrances described?
- How **comprehensively** were indoor sections described?
- How **safe** did they feel?
- How **efficient** they think they navigated?

5.2.2 Participants

Six visually impaired participants were recruited via e-mail leaflet. They were aged from 25 to 70 years ($mean = 40.17$, $SD = 16.70$). Three participants congenitally blind and three were late blind. One participant had Category 4 visual impairment (light perception) and five participants had Category 5 (no light perception) according to WHO classification [26]. Two participants had a guiding dog, four participants do not and they used only white cane. All of the participants were native Czech speakers (see Table 4).

Table 4 Demographic information about participants of the second experiment, Category 4 is light perception, Category 5 is no light perception. Onset L is lately, C is congenitally.

ID	Gender	Category	Onset	Age	Was in prev. exp.	Guiding dog
P01	F	5	C	25	no	no
P02	M	4	C	32	yes	no
P03	M	5	L	27	no	no
P04	F	5	L	70	yes	yes
P05	M	5	L	41	no	no
P06	M	5	C	46	no	yes

5.2.3 Procedure

The second iteration of user testing experiment took place in the field. The purpose of the experiment was to test whether the participants understand route itineraries in a real environment and whether they can utilize these instructions for navigation to a destination. Firstly, the purpose of the experiment was explained to the participants. Then participant can choose the level of detail for building descriptions, with the assurance that s/he can change this decision during the route. To help them decide, we read an example of detailed and brief description.

5.2.3.1 Route

For the second experiment was created a prototype of one route itinerary. This route lead through multiple types of environment (outdoor, semi-outdoor and indoor) in the city centre near CTU FEE campus at *Karlovo náměstí*. The route includes one station ride by tram, to test tram stations descriptions. Two levels of details for building descriptions were created (detailed and brief). See the map of the route in Fig. 11, the whole route itinerary for this experiment can be seen in A.3.

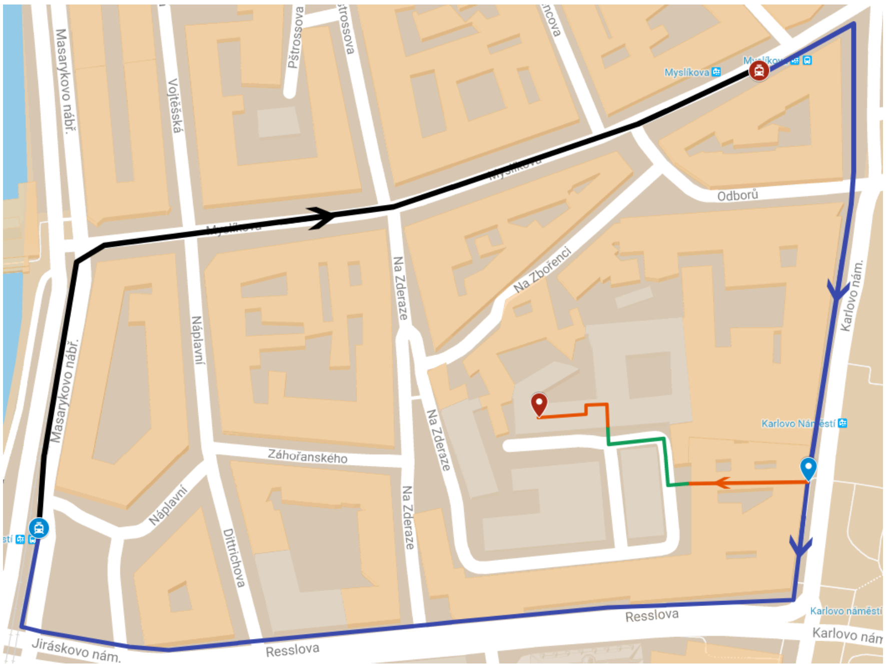

Figure 11 Map of the route, blue marker depicts the starting point and red marker is end of the route.

5.2.3.2 Equipment

Participants could use their own smartphone to read the route from the web browser because the route was saved on the web as a classic HTML document, participants were able to select from two versions first one with detailed general building descriptions and second one with brief descriptions. User can switch between these two versions during route with our assistance. The second option was to borrow Nokia 6120 phone with a pre-installed application which reads each segment of the route and user can select detailed or brief descriptions during the route.

Three participants used their own smartphone (iPhone), two participants used Nokia and for one of the participants, we had to read the route itinerary, because of the broken Nokia phone.

5.2.3.3 Data collection

During each route walkthrough we were shadowing participants and recording them from third person view on mobile phone camera (see Fig. 12). After the walkthrough brief interview with each participant was done. Participants were also asked about their subjective judgment about comprehension, efficiency and safety during the route.

Figure 12 Photo-documentation from second experiment.

5.2.4 Results and Discussion

First tram station

P1, P3, P4 missed the isle of tram station Jiráskovo náměstí and continued farther away on the pedestrian crossing, even if there was information about lowered curb. P6 did not go straight on the crossing and hit the railing of the isle, the participant had a guiding dog anyway it did not help for finding the isle. P2 and P5 found the isle without a problem but in the interview, they said that they did not feel safe.

Second tram station

All participants managed to get off the tram and navigate towards opposite buildings without problems. P1, P2, P3 and P5 used haptic strip on the ground. P4 and P6 did not because their dog guided them to buildings.

First entrance

P3, P4 did not recognize the protruding facade with entrance at all. P4 was guided by dog and went in the middle of the pavement and sporadically used white-cane to discover the facade. P6 found the facade and entrance but was not sure if it is the correct door, so he passed it. P1, P2 and P5 found the facade and door to building without a problem.

Courtyard

This section was complicated by heavy noise from ongoing reconstruction and objects (stands for posters and transferable railing) placed in the way. P6 stopped in the middle of the second segment and returned back to the beginning, then continued without major problems. P4 misunderstood the direction instruction in the third segment on the turn of the road and was confused where to go even she had a guiding dog. All participants had not a good feeling about going through open space in the last segment toward the stair. P2 appreciated the information about transformer station on the right because he was able to hear the noise from it and assure that he is on the right way.

Second entrance

All participants found the pyramidal stairs to the building and went through the door inside the building. P1 and P3 climb up the stairs from the side, there was a danger of falling. Other participants went up in the straight direction. P3 was for a while stuck in front of the second door of the entrance, where he was not able to find a correct leaf of this door that can be opened. P2, P5 complained about the distance to the pyramidal stairs, they said that it was less than 30 meters and as a consequence of this they thought that there is another stairway, but eventually they recognized the pyramidal shape of the stairs.

Interior

P5 missed the finish (door to the classroom) of the route because the door was open and he thought that it is some corridor. Other participants found the finish successfully. P2 missed the lift door, P3 missed it as well, but he was able to recover from this and returned back. All participants apart from P5 had a problem with lift control, because there was no information about the card time limit for controlling the lift.

Building descriptions

P1 was confused by information in building description about the position of reception, she thought that she should go there. P3 selected the version of route with detailed descriptions of buildings and afterwards was complaining about the redundant information in these descriptions. Participants with brief descriptions selected did not ask for detailed version and also evaluated the brief version as good and sufficient.

5.2.4.1 Subjective judgements

The results of subjective judgements can be seen in Fig. 13 and Fig. 14.

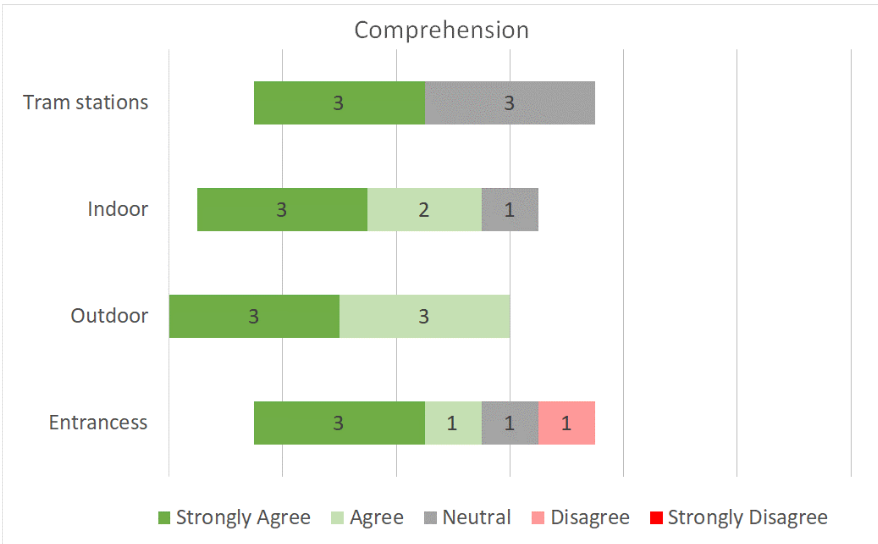

Figure 13 Subjective judgements about level of comprehension (n=6).

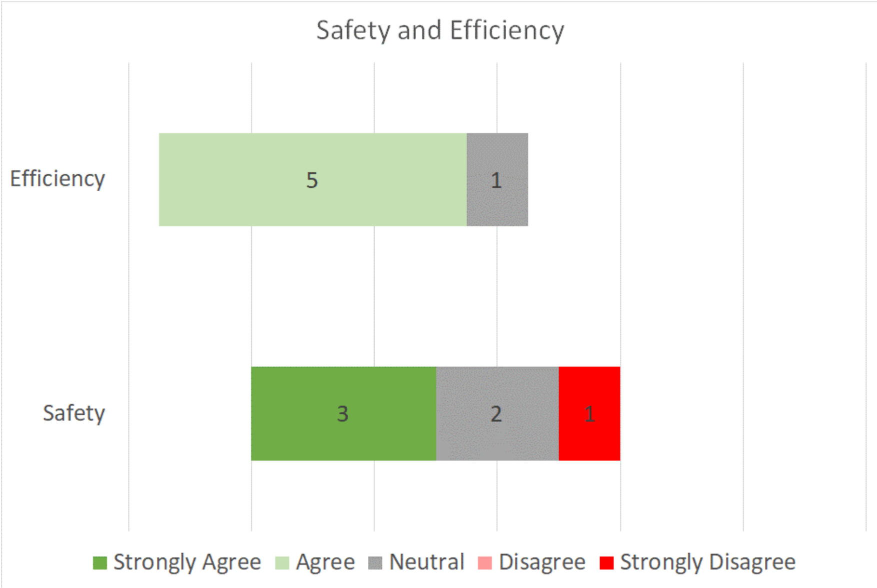

Figure 14 Subjective judgements about level of safety and efficiency (n=6).

5.2.5 Recommendations for design

Following recommendations were extracted from the findings collected during the second experiment:

R11: When navigation leads to the isle of the tram station, prefer using the front entrance if it is available. More than a half of the participants did not find or missed the isle. In the interview, they express themselves that they are used to enter the isle at the front where the info-table is. Also, the guiding dogs are trained to find the info-table.

R12: When user gets off the tram/bus inform where s/he should have it (behind the back, by the right/left hand). Not all of the participants use the haptic strips on the ground, mainly participants with guiding dogs. This information will help them to orientate when getting off the tram or bus.

R13: In segments where users have to find and recognize the place with entrance to the building, we should inform them in advance that there will be door to the building. (i.e. "Go ahead and slightly uphill for 150 meters to the facade that protruding to the pavement level. There will be an entrance to the building. Have buildings on your right.") Finding entrances is challenging for most of the visually impaired people, this information can be helpful because they will know what to expect and if they fail to find the place with entrance, they will be able to ask for the help from passer-by people.

R14: Give users precise and detailed description of the entrance to the building. Half of the participants were not able to recognize the first entrance, afterwards, they said that it was difficult to distinguish protruding facade from another protruding object during this segment.

R15: When door have two door leaves, inform if one or both leaves can be opened. Some participants had problems with opening the door, finally, they managed to open it on their own, but it unnecessarily took them a little more time.

5.3 Third qualitative study

The third experiment was conducted in the real environment as a qualitative study.

The goal of this study was to investigate whether the implementation of synchronization beacons into the route, with combination of text descriptions already tested before, is helpful for solving the navigation problems we identified, it means to help user find the right entrances to buildings, tram stations and preventing the errors during the navigation (e.g. missed turns or turnoffs).

5.3.1 Research questions

- How comprehensive was application feedback at synchronization points?
- Was information the participant received from application sufficient?
- How confident they were when finding tram station with the application?
- How confident they were when finding entrances with the application?
- How safe did they feel during the navigation?
- How efficient they think they navigated?

5.3.2 Participants

For this experiment, we need visually impaired participants with a various level of visual impairment (4 - 5) and various types of onset. Participants with and without guiding dog will be invited.

8 visually impaired participants were recruited via email leaflet. In the leaflet, we mentioned that touchscreen smart-phone will be used for the experiment. They were aged from 33 to 53 years ($mean = 40.25$, $SD = 7.27$). 5 participants congenitally blind and 3 were late blind. 3 participants had Category 4 visual impairment and 5 participants had Category 5 [26]. 1 participant had a guiding dog. All of the participants were native Czech speakers. See Fig 5.

Table 5 Demographic information about participants of third user testing experiment. Onset L is lately, C is congenitally. Category 4 is light perception, Category 5 is no light perception. Completion time is in minutes excluding waiting for tram.

ID	Age	Gender	Onset	Category	Touch-screen	Guiding dog	Completion time
P1	41	M	L	5	no	no	50
P2	33	M	C	4	yes	no	32
P3	33	F	C	4	yes	no	31
P4	42	F	L	4	no	no	53
P5	47	M	C	5	yes	yes	52
P6	40	M	L	5	no	no	48
P7	33	M	C	5	yes	no	41
P8	53	M	C	5	yes	no	40

5.3.3 Procedure

The experiment was conducted in the real environment and lasted 40 to 70 minutes. At first, we explained the participant the purpose of the experiment, collected the demographic information and explained the operation of the application. Participant had time to acquire knowledge of how to use the prototype of the application. S/he tried to move through the route itinerary inside an application.

After the participant finished the route, s/he was debriefed and asked about subjective judgement about the level of safety, efficiency, information sufficiency, comprehension and confidence when finding entrances and tram station.

Each session was recorded on camera (using shadowing method as on previous experiments).

5.3.3.1 Test scenario

This test scenario was read to participants during the briefing of the experiment.

"Imagine you have to come to user experiment in CTU Campus in building E, room 319. To reach the destination use the navigation application, which will give you navigation instructions and in several segments will notify you whether you are going on the correct respectively wrong way. The whole route is separated into segments and these are divided into bigger sections representing the different environments (interior, exterior)"

5.3.3.2 Application functions explanation

It is necessary to explain to the participant the functionality of the prototype application, we read participants following list of instructions:

- To move between individual segments of rout use buttons “Next Segment” and “Previous Segment”

- The application will notify you automatically when you are approaching the correct end of the actual segment, respectively your are going the wrong way. (In segments where are the synchronization beacons).
  - When you are approaching the correct end of an actual segment, the phone will twice long vibrate and will announce: “You are near the end of this segment.”
  - When you turn-off the correct route and you will be localized near error synchronization beacon, the phone will four-times short vibrate and will announce: “You are on the wrong way, return to the start of this segment.”

- If there is a synchronization beacon at the end of an actual segment, the button “Verify Location” will be available. Use it when you are not sure if you are at the correct end of the segment, or if you think you misheard the automatic notification.

- After you press “Verify Location” button there is 5 seconds time-out for the phone to range some synchronization beacons. If you will not be localized near any beacon, the phone will announce: “Failed to verify location”

- Location verification (automatic and manual) works only for segments you have currently displayed on the phone. If you will skip to next segment the phone will be ranging for the beacons from next segment and not for the one you are physically present.

We will also ask each participant to behave as s/he is alone during the whole route, but we assure him/her, that we will be always a couple of meters behind her/him and in case of any danger or emergency situation will help her/him.

5.3.3.3 Pre-test questionnaire

At first, we will guide participant to the starting point of the route. During it, we will collect demographic data from the participant.

1. How old are you?
2. What is the level of your visual impairment?
3. How long do you have this impairment?
4. Do you use mobile phone with a touchscreen?

5.3.3.4 Post-test interview

After the finish of the route, we will perform a short post-test interview with each participant. In this interview participant will be asked 5 questions about her/his feelings and impressions from the walkthrough using Likert scale 1-5 (strongly agree, agree, neutral, disagree, strongly disagree):

1. The Information I received from the application was sufficient.
2. The instructions in synchronization points of the route were comprehensive.
3. I felt confident thanks to the application when finding entrances to buildings.
4. I felt confident thanks to the application when finding tram station.
5. I felt safe during the route walkthrough.
6. I think that thanks to application and navigation instructions I proceeded efficiently.

And further 3 more open-ended questions:

A How do you rate the automatic notification from the application when you go correct respectively the wrong way?

B Would you welcome the same functionality in the outdoor environment as well?

C Compare navigation with this application with your navigation in a normal situation.

After this part of experiment, participants will receive their reward for participation.

Figure 15 Second test operator holding beacon on info table at tram station and by the entrance to building.

5.3.4 Apparatus

The test required 2 operators, first one was recording the whole test and took care of the participant, the second one held the beacons in two segments - first was at tram station where we did not get the permission to place it, second segment was near the entrance to first building, as we did have only one outdoor beacon available and it was used at second building entrance (see Fig. 15).

- 6 - 8 visually impaired participants
- 2 operators
- Video record from experiment
- Log from application

5.3.4.1 Route

For this experiment, the prototype of route itinerary in the busy city centre of Prague, Czech Republic with the combination of outdoor, semi-outdoor and indoor environments and use of public transportation (ride with tram), was created. The itinerary consisted of bigger parts for each environment and these contain individual segments (description + action) and also building and environment descriptions (e.g. campus compound description).

The route was approximately 700 m long (excluding tram ride), consisted of 36 segments. The whole route itinerary can be seen in appendix A.4. 26 Beacons Pro and 1 Tough Beacon from Kontakt.io[1] were installed on the route in total, 16 beacons

[1] https://kontakt.io/

were placed on the correct points and 11 beacons were placed on the turns-off from the route. A beacon that supposed to be placed on info table at tram station and by the first entrance to the building was held by assistant glued on the paper folder above the head because we did not get the permission to place the beacon there permanently.

5.3.4.2 Equipment

The participants were equipped with HTC One 801n smart-phone - Android 5.0.2, with running Talk Back screen reader set in Czech language and with installed high-fidelity prototype of navigation application, which was able to scan for Bluetooth beacons and inform participants whether they are going the right direction or if they turned off the route, as was described above. The smart-phone had a lanyard that participant could hang on his/her neck, to have free hands when necessary (see Fig. 16). We also gave participants chip card that is needed to open a door inside CTU campus buildings.

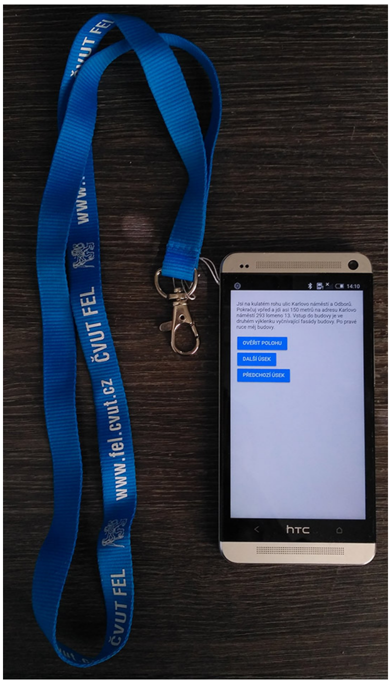

Figure 16 Android smartphone, HTC One 801n with lanyard, equipment for third user test.

5.3.4.3 Data collection

During each route walk-through, we were shadowing participants and recording them from third person view on the mobile phone camera. After the walk-through brief interview with each participant was done.

The application itself is saving the log file from each session. The log file contains data about the user interaction with application i.e. which buttons user pressed and when and if the application notified the user about her/his position. And data about ranged beacons during the walk-through, with information about Beacon ID and current RSSI, all records in log file have its timestamp, to be able to better evaluate the test session.

5.3.5 Results and Discussion

In this section are presented and discussed the results from the third user experiment.

5.3.5.1 Findings

In this section will be presented the findings collected during the experiment, divided into sections of the route. The results of the beacons triggering will be also provided. All participants successfully completed the route. The average completion time was 44.2 minutes ($SD = 8.7 minutes$).

Tram station

P1, P6, P8 found the tram station successfully, the beacon triggered the automatic notification.

P2 and P3 misheard the notification from the application when finding the tram station, but the manual verification of location afterwards was successful and helped in finding the tram station.

P4 switched off accidentally the application when going to tram station, but then the verification of location worked successfully.

P5 and P8 were mistaken by the telephone booth which was about 20 meters before the tram station and thought that it is the info table at the tram station, they tried to verify the location there and the application correctly failed. Afterwards, P5 was able to find the tram station without the location verification as he switched to next segment early and P8 found it successfully with help from automatic notification from the app.

P7 misheard the notification from the application and missed the info table at tram station, we take him/her back to verify the location manually, which worked successfully.

Semi-outdoor (courtyard)

P1 did not follow the curb curved to the right and he continued in a straight direction. He complained about the missing information about curved curb. P3 and P4 skipped to the next segment before they reached the turn, but they continued without problems. For P6 and P7 did not work the manual location verification as they tried it few meters after they passed the beacon. P7 did not receive the automatic notification when was near the beacon on the road turn but continued without problems. Rest of the participants did not have problems when walking through the university courtyard and received the location notification.

Entrances

Entrance to building A:
P1, P3, P4, P5 and P6 found the correct entrance to the first building. P3 found the entrance without the automatic notification but afterwards verified the location manually twice and twice it was successful. P2 missed the entrance to the first building, the beacon triggered late. P7 and P8 missed the entrance to the first building, the beacon did not trigger. P7 tried to verify location manually in the first niche, but the beacon did not trigger.

Entrance to building E (with pyramidal stairs):
P1, P2, P5 and P7 found the entrance with help of automatic notification from the application. P3 found the entrance but skipped to the next segment too early before the beacon can trigger. P4 found the entrance but the beacon did not trigger. P6

was proceeding to the entrance along the building and so the signal from beacon was shielded by the building, but participant found the entrance correctly. P8 stopped near the entrance when he got the notification at the right moment, but then continued straight and missed the stairs on the right, because he was proceeding on the very left side of the road during the segment leading to entrance stairs.

Indoor

In Indoor environment we installed the error beacons on the prototype route turn-offs. Only P2 (once) and P4 (twice) turned wrong during the walk-through the error beacons triggered correctly and participants were notified they should return to the start of the segment. P2 recovered from the error successfully alone. P4 at first recovered with an assist and on the second error turn recovered alone successfully. P1, P3, P5 and P8 needed an assistance when finding the chip card reader next to the door. All participants apart from P5 found the correct door in the final segment.

Beacons

The automatic notification about the user position near the beacon was expected to happen 126 times in total during the whole experiment with 8 participants. Not always was the notification triggered as expected. In Figure 17 we present the results of the automatic triggering. The reasons why the automatic notification failed are various, e.g. signal interference, bad configuration of a beacon. Bellow, we present the detailed list of the different types of failures.

More detailed results for each beacon triggering during the third experiment are in appendix 6 also with the table of how the beacons were configured.

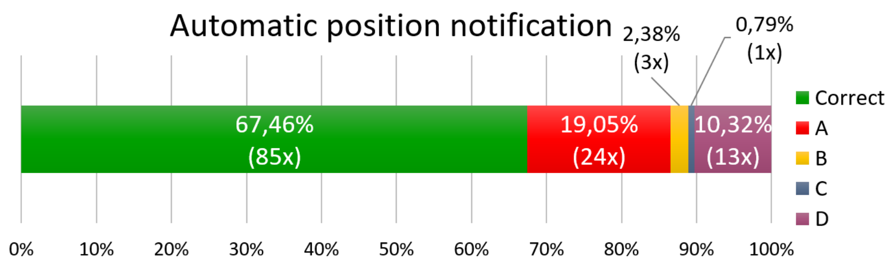

Figure 17 Results of automatic notifications at decision points (total=126).

A: Notification did not trigger, near the beacon. Due to signal distortion or interference, bad configuration of the beacon or the signal covered by participant's body when turned away from the beacon. In two cases the users were behind the thick wall which absorbed the beacon signal.

B: Notification triggered too early, on the beginning of the actual segment. It happened during the short segments indoors. The distance it should trigger was to approximately 4 meters, but it triggered 8-10 meters away. The signal could be mirrored by a metal surface.

C: Notification triggered too late, when the participants just passed the end of the segment, therefore, they missed the decision point.

D: The application is ranging only for beacons in particular segment displayed on the screen. For more information see Section 3.6.2. Some of the participants were reading the segments in advance and did not return to the actual segment in the application. We do not evaluate this situation as a failure.

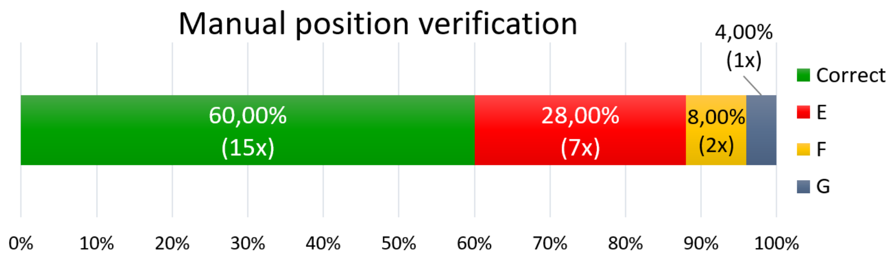

Figure 18 Results of the manual position verification (total=25).

The manual verification was used by participants 25 times in total during the experiment. Some participants tried to verify their location after they received the automatic notification and continued few steps ahead. The manual verification then could fail, because they stepped out of the beacon's range, or they covered the signal with their body. In Figure 18 we present the results of the manual position verification. Bellow is the list of various types of the manual verification failures.

E: Manual verification did not trigger the notification, near the beacon. Due to the signal distortion or interference, bad configuration of the beacon or the signal covered by participant's body when turned away from the beacon.

F: Manual verification failed, after the correct automatic notification. Participants stepped out of the range of the beacon, or the signal was covered by their own body.

G: Manual verification was successful on the second attempt.

5.3.5.2 Subjective judgements

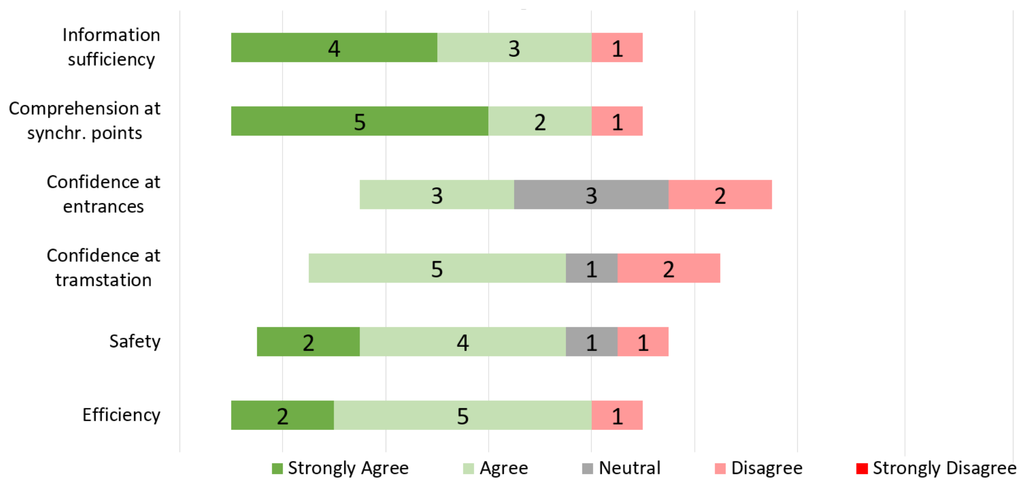

Figure 19 Subjective judgements about level of information sufficiency, comprehension, confidence, safety and efficiency (N=8).

Fig. 19 shows that 50% of the participants strongly agreed on information sufficiency they obtain from the application, one participant disagreed. 63% of the participants strongly agreed on comprehension at the synchronization points, one participant disagreed. 38% of the participants agreed about confidence when finding entrances, 2 participants disagreed. 63% of the participants agreed about the confidence when finding the tram station, 2 participants disagreed. 25% strongly agreed on safety and efficiency, one participant disagreed on safety and one disagreed on efficiency.

5.3.5.3 Post-test interview

How do you rate the automatic notification from the application when you go correct respectively the wrong way?

Participant P1 mentioned that he does not see extra benefit of this solution if it is not providing information about the direction and distance toward the beacon. *“It does not come to me as an extra great benefit if I do not know the direction, the distance or even the azimuth towards the beacon.”*

P7 explained that he lacked information about the distance and direction to the beacon as well: *“I would welcome the information about the distance to the decision point, now I am not sure if it is in front or behind me.”*

Participants P4 and P5 said that it is really good functionality and it will speed them up and assure during the walkthrough. *“I know when I am going correctly or wrong. It will assure me.”*

Participant P6 was impressed by the automatic notification at the tram station, he said: *“As a blind when I am finding the tram station I have to walk near the building due to public notice so it is hard to find the station at the sidewalk, the automatic notification is very helpful.”*

Would you welcome the same functionality in the outdoor environment as well?

Participants P2, P3, P4, P5, P6, P7 said that they would definitely welcome this functionality in the outdoor environment. Participant P1 would like only if it was able to tell him when if he went the wrong way and how to get back exactly. P3 would like this functionality outdoor even more than in the indoor environment. P8 had the similar opinion about and said: *“It is not necessary to receive the notifications everywhere but at tram station or near the entrances it is very good.”*

Compare navigation with this application with your navigation in a normal situation.

Participants P1 and P6 usually ask for help from other people and walk the routes they know. They mentioned that this application would be good in unfamiliar environments. P2 said: *"This application would be more time consuming than my normal navigation because I need to switch between holding the phone and white cane. But in terms of certainty in an unfamiliar environment, it is certainly good."* P6 said: *"I would never go to unfamiliar building alone, but this application replaces the personal guide."*

Participant P8 liked the route division into segments: *"I like how the instructions are divided into segments. Most of the applications do not have it like that. Usually, I use Blind Square."*

Most of the participants use BlindSquare and maps from Google or Apple, but it does not provide the environment transition, participant P3 appreciated that this application can: *"use BlindSquare with Google Maps usually, but this application is way more detailed. And I really like the connection between the outdoor and indoor environment."*

5.3.6 Discussion

The results clearly show that correct configuration and placement of the beacons is crucial for the proper functioning of this navigation system.

When placing a beacon at the entrance to a building, it should be remembered that users can come from different directions and that all of them should be covered by the signal. If it is a proportionally complicated entrance, it can be considerate to place a larger number of beacons to cover user's arrivals from all directions. It is not necessary to have beacons installed on each segment, sometimes it is not even physically possible, specifically on very short segments there may be a problem that the correct and error beacon will be very close to each other, which may result in an error location notification to the user even he is near the correct beacon or vice versa.

We experienced that there can be spaces where it is really difficult to correctly configure the beacons. In our case, it was the atrium with metal glass construction connecting two buildings. We tried to place there two beacons on the opposite sides of the atrium. But the signal distortion was too high, we decided to install there only one beacon to prevent the signal interference with the second beacon.

During the evaluation, some of the beacons triggered the position notification too early or too late. This issue can be solved either by the reconfiguration of the beacon or by moving the beacon 1m forward/backwards.

Two of the participants took the wrong turn during the evaluation. They were able to recover from this error. We can say that even without the distance and direction information our proposed combination of navigation instructions with beacons only at decision points can solve the user's walkthrough errors.

The manual location verification feature did not result in high reliability. The participants tend to stop using this feature during the walkthrough. It happened often that the automatic verification of the location worked correctly, but the manual verification afterwards did not. The main reason was that the participant crossed the decision point by few steps and tried to verify the location beyond the beacon range. This could have influenced the user's confidence level at the decision point. We think that this feature can be omitted from the application.

If we compare our solution to NavCog [18] in terms of the number of beacons necessary. For the route, only in the indoor and semi-outdoor environment (250m and 26 segments) we needed 26 beacons in total. If we placed the beacons every 6 meters we would need approximately 42 beacons to cover only the one prototype route, not mentioning the turnoffs.

6 Conclusion

In this work, we analysed the literature, and existing systems concerning about navigation systems for visually impaired people. Further, we identified situations in city navigation with environment transitions and the use of public transportation. With gained knowledge from the first user study, the methodology for these situations was created and can be used for future design and for data structures modification.

For purposes of the user testing, low-fidelity prototype routes were created. Two iterations of experiments were conducted with visually impaired participants, first in the laboratory and the second in the real environment.

After the second user experiment we found out that there are still many problematic situations in navigation, e.g. find the entrance to building, navigation through semi-outdoor environments. With that in mind, we tried to propose our solution with using the Bluetooth Low Energy Beacons that were expected to be used as synchronization points.

We designed a navigation application that has two main building blocks, the landmark-enhanced navigation instructions and the location synchronization system that uses the minimum number of beacons possible and is also capable of error prevention and error recovery.

We conducted a qualitative study of high-fidelity prototype application with 8 visually impaired participants. As previous studies shown [3] the landmark-enhanced navigation instructions are suitable navigation for blind pedestrians, still there are many difficulties which we wanted to solve with utilizing beacons as synchronization points, i.e. finding entrances, public transport stations, help when identifying the landmarks and give users more confidence during the walk-through.

As we found out the synchronization points successfully complement the navigation system using only navigation instructions. The main benefit of our solution lies in the use of a minimum number of beacons. But maintaining the effectiveness of navigation. Mainly thanks to detailed and landmark-enhanced navigation instructions and then thanks to route graph representation. Additionally, with the possibility of self-recovering from errors during the route.

Since it is obvious that deploying the system based on Bluetooth-trilateration in urban outdoor is financially impossible we see the big potential for the future to install the beacons only on the most used and hard-to-find decision points, e.g. tram stops, entrances to important buildings.

Bibliography

[1] Reginald G Golledge. "Geography and the disabled: a survey with special reference to vision impaired and blind populations". In: *Tran. of the Inst. of British Geographers* (1993), pp. 63–85. DOI: 10.2307/623069.

[2] Limin Zeng and Gerhard Weber. "A pilot study of collaborative accessibility: How blind people find an entrance". In: *MobileHCI '15*. ACM. 2015, pp. 347–356.

[3] Jan Balata et al. "Automatically generated landmark-enhanced navigation instructions for blind pedestrians". In: *Computer Science and Information Systems (FedCSIS), 2016 Federated Conference on*. IEEE. 2016, pp. 1605–1612.

[4] Jan Vystrcil, Zdenek Mikovec, and Pavel Slavik. "Naviterier-indoor navigation system for visually impaired". In: (2012).

[5] Marko Modsching, Ronny Kramer, and Klaus ten Hagen. "Field trial on GPS Accuracy in a medium size city: The influence of built-up". In: *3rd workshop on positioning, navigation and communication*. 2006, pp. 209–218.

[6] José Faria et al. "Electronic white cane for blind people navigation assistance". In: *WAC 2010*. IEEE. 2010, pp. 1–7.

[7] M Bujacz et al. "Remote guidance for the blind – A proposed teleassistance system and navigation trials". In: *HSI 2008*. IEEE. 2008, pp. 888–892. DOI: 10.1109/hsi.2008.4581561.

[8] Simon Ungar. "Cognitive mapping without visual experience". In: *Cognitive mapping: past, present, and future* 4 (2000), pp. 221–248.

[9] Reginald G Golledge. "Human wayfinding and cognitive maps". In: *Wayfinding behavior: Cognitive mapping and other spatial processes* (1999), pp. 5–45.

[10] Jakub Franc. "Psychologické aspekty navigace nevidomých". in Czech. Dissertation Thesis. Charles University, Faculty of Psychology, 2014.

[11] Thomas Strothotte et al. "Development of Dialogue Systems for a Mobility Aid for Blind People: Initial Design and Usability Testing". In: *Proceedings of the Second Annual ACM Conference on Assistive Technologies*. Assets '96. Vancouver, British Columbia, Canada: ACM, 1996, pp. 139–144. ISBN: 0-89791-776-6. DOI: 10.1145/228347.228369. URL: http://doi.acm.org/10.1145/228347.228369.

[12] Irene Fellner. "Automatic Generation of Landmark-based Indoor Routing Instructions". In: *GI_Forum 2017*, 1 (), pp. 106–113.

[13] Yao Guo, Wenjun Wang, and Xiangqun Chen. "FreeNavi: Landmark-Based Mapless Indoor Navigation Based on WiFi Fingerprints". In: (June 2017), pp. 1–5.

[14] Gerd Sammer et al. "Identification of mobility-impaired persons and analysis of their travel behavior and needs". In: *Transportation Research Record: Journal of the Transportation Research Board* 2320 (2012), pp. 46–54.

[15] Markus Guentert. "Improving public transit accessibility for blind riders: a train station navigation assistant". In: *ASSETS*. 2011.

[16] I. Gorovyi et al. “Real-time system for indoor user localization and navigation using bluetooth beacons”. In: *2017 IEEE First Ukraine Conference on Electrical and Computer Engineering (UKRCON)*. May 2017, pp. 1025–1030. DOI: 10.1109/UKRCON.2017.8100406.

[17] O. Czogalla and S. Naumann. “Pedestrian indoor navigation for complex public facilities”. In: *2016 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*. Oct. 2016, pp. 1–8. DOI: 10.1109/IPIN.2016.7743672.

[18] Dragan Ahmetovic et al. “Achieving Practical and Accurate Indoor Navigation for People with Visual Impairments”. In: *Proceedings of the 14th Web for All Conference on The Future of Accessible Work*. W4A ’17. Perth, Western Australia, Australia: ACM, 2017, 31:1–31:10. ISBN: 978-1-4503-4900-0. DOI: 10.1145/3058555.3058560. URL: http://doi.acm.org/10.1145/3058555.3058560.

[19] Euan Freeman et al. “Audible Beacons and Wearables in Schools: Helping Young Visually Impaired Children Play and Move Independently”. In: *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. CHI ’17. Denver, Colorado, USA: ACM, 2017, pp. 4146–4157. ISBN: 978-1-4503-4655-9. DOI: 10.1145/3025453.3025518. URL: http://doi.acm.org/10.1145/3025453.3025518.

[20] Radio-Electronics.com. *Bluetooth Technology Tutorial*. Available at http://www.radio-electronics.com/info/wireless/bluetooth/bluetooth_overview.php, last visited 04/2018.

[21] Radio-Electronics.com. *What is Bluetooth Smart: Bluetooth Low Energy, BLE*. Available at http://www.radio-electronics.com/info/wireless/bluetooth/what-is-bluetooth-smart-low-energy-ble.php, last visited 04/2018.

[22] Hao Chu and Chengdong Wu. “HAO CHU et al: A LOCALIZATION METHOD BASED ON BLUETOOTH NETWORK USING RECEIVED”. In: 2016.

[23] Kontakt.io. Available at https://support.kontakt.io/hc/en-gb/articles/201628101-What-is-a-beacon-, last visited 04/2018.

[24] Apple. *Potential sources of Wi-Fi and Bluetooth interference*. Available at https://support.apple.com/en-us/HT201542, last visited 05/2018.

[25] Ionicframework.com. *Ionic framework documentation*. Available at https://ionicframework.com/docs/, last visited 04/2018.

[26] WHO. *ICD update and revision platform: change the definition of blindness*. 2009. URL: http://www.who.int/blindness/Change%5C%20the%5C%20Definition%5C%20of%5C%20Blindness.pdf.

Appendix A

Prototype route itineraries

A.1 Route 1

Popis trasy:
Trasa ze stanice metra B - Karlovo náměstí (příjezd ze směru od Národní třídy, doporučujeme prostřední část soupravy metra) na adresu Karlovo náměstí 293/13, Fakulta elektrotechnická ČVUT, budova E, místnost KN:E-328.

Následuje prostor stanice metra B, Karlovo náměstí. Má nástupiště vlevo ve směru jízdy, stanice má oddělené nástupiště a střední část prostupy, informační a reklamní tabule jsou uprostřed nástupiště. Stanice má 2 výstupy na obou koncích nástupiště, oba s eskalátory, jeden směr Karlovo náměstí a druhý Palackého náměstí. Vodící linie nejsou přítomny. Na nástupišti je akustický majáček o oznámení směru eskalátoru. Stanice nemá výtah.

1. úsek z 15. Jsi na nástupišti. Před tebou jsou prostupy do střední části stanice. Vystup a jdi asi 5 metrů rovně, vůz měj za zády, projdi mezi sloupy do střední části stanice.

2. úsek z 15. Střední část nástupiště, před tebou jsou prostupy na nástupiště směr Černý Most, vlevo eskalátory směr Karlovo náměstí, vpravo eskalátory směr Palackého náměstí. Otoč se vlevo a pokračuj vpřed asi 25 metrů volným prostorem k eskalátoru.

3. úsek z 15. Krátký eskalátor, eskalátor má majáček. Za eskalátorem následuje mezipatro. Vyjeď eskalátorem do mezipatra.

4. úsek z 15. Prostor mezipatra eskalátorů, před tebou je dlouhý eskalátor. Jdi rovně volným prostorem asi 10 metrů k eskalátoru.

5. úsek z 15. Dlouhý eskalátor, eskalátor má majáček. Za eskalátorem následuje prostor před vestibulem. Vyjeď eskalátorem nahoru.

6. úsek z 15. Prostor před vestibulem. Prostor je ukončen otevřenými prosklenými dveřmi asi po 10 metrech. Pozor po cestě jsou kovové sloupky a vlevo zábradlí. Jdi rovně volným prostorem asi 10 metrů ke skleněným dveřím většinou otevřeným.

7. úsek z 15. Skleněné dvěře do prostoru vestibulu, dveře jsou většinou otevřené. Projdi prosklenými dveřmi.

8. úsek z 15. Prostor vestibulu. Vestibul je pod úrovní ulice. Vestibul má čtyři výstupy, má čtvercový tvar, uprostřed vestibulu jsou prosklené obchody. Vodící linie vede vpravo od obchodů. Jdi rovně asi 5 metrů a najdi prosklenou stěnu obchodu po levé ruce.

9. úsek z 15. Prosklený obchod máš po levé ruce. Vodící linie je vpravo od stěny obchodu. Jdi rovně asi 10 metrů na konec obchodu po tvé levé ruce.

10. úsek z 15. Kulatý roh proskleného obchodu. Otoč se mírně doleva a jdi asi 15 metrů ke schodišti.

11. úsek z 15. Schodiště výstupu směr areál ČVUT, počet schodů je 8, zábradlí na obou stranách. Vyjdi po schodišti nahoru.

12. úsek z 15. Mezichodba, před tebou je trojité schodiště vedoucí do pasáže budovy A, v areálu ČVUT. Jdi rovně asi 10 metrů ke schodiši.

13. úsek z 15. Schodiště s mezipodestami, počet schodů je 12, 12 a 12, zábradlí je po obou stranách. Vyjdi po schodišti nahoru.

14. úsek z 15. Nacházíš se v podloubí budovy A, ČVUT na Karlově náměstí. Z podloubí vede 5 průchodů na chodník v ulici Karlovo náměstí a jeden průchod do ulice Resslova, vstup do budovy A a vstup do vestibulu metra B stanice Karlovo náměstí. Před tebou je vstup do budovy A tvořený třemi schody dolů a automatickými dvoukřídlými dveřmi. Jdi rovně asi 10 metrů ke schodišti do budovy A.

15. úsek z 15. Nacházíš se před vstupem do budovy A, ČVUT na Karlově náměstí. Vstup je tvořen třemi schody směrem dolů a automatickými dvoukřídlými dveřmi. Projdi dveřmi.

Nacházíš se v budově A, ČVUT na Karlově náměstí. Jedná se o historickou budovu. Budova je velmi rozmanitá, má několik různých typů schodišť, počet pater je čtyři. Mnoho zavřených dveří se otevírá pomocí čipové karty, kterou je nutné přiložit ke čtečce karet a po krátkém pípnutí otevřít. Vrátnice se nachází přímo proti vstupu z pasáže, na druhém konci místnosti, potažmo vpravo po vstupu z ulice.

1. úsek z 11. Nacházíš se ve vstupní hale budovy A. Jdi rovně asi 10 metrů volným prostorem k turniketům po levé ruce.

2. úsek z 11. Vstupní turnikety uprostřed vstupní haly. Pro vstup je nutné přiložit čipovou kartu a počkat na krátké pípnutí. Čtečka karet je malá krabička 10 krát 5 krát 3 cm ve výšce pasu po levé ruce u každého z celkem 4 turniketů. Otoč se doleva a projdi turnikety

3. úsek z 11. Volný prostor asi 6 metrů dlouhý, po levé i pravé ruce schodiště nahoru. Poté dva sloupy vlevo i vpravo. Na konci prostoru jsou dřevěné dveře se skleněnou výplní. Jdi rovně ke dveřím.

4. úsek z 11. Dřevěné dveře se skleněnou výplní, většinou otevřené. Projdi dveřmi.

5. úsek z 11. Uzká rovná chodba asi 10 m dlouhá, před koncem chodby většinou otevřené dvojkřídlé skleněné dveře. Jdi chodbou ke dveřím.

6. úsek z 11. Dvoukřídlé prosklené dveře s madlem, většinou otevřené. Projdi dveřmi.

7. úsek z 11. Atrium spojující budovu A s budovou B. Po obvodu jsou dřevěné stoly a lavice, mírně vpravo před tebou je schodiště směrem dolů, zábradlí na levé straně. Jdi mírně vpravo asi 10 metrů ke schodům.

8. úsek z 11. Schodiště krátké, počet schodů je 3, zábradlí vpravo. Sejdi schody dolu.

9. úsek z 11. Dvoukřídlé skleněné dveře s madly, většinou otevřené. Projdi dveřmi.

10. úsek z 11. Chodba asi 13 metrů dlouhá. Po levé ruce jsou nápojové automaty (hučí), na konci chodby dveře. Jdi rovně na konec chodby ke dveřím.

11. úsek z 11. Dvoje dřevěné dveře se skleněnou výplní hned za sebou, mezi nimi krátká rampa mírně do kopce, následuje vstup na dvůr areálu ČVUT. Projdi oběmi dveřmi.

Nacházíš se ve dvoře areálu ČVUT, povrch dvoru je tvořen kočičími hlavami (kamennou dlažbou) s nízkými obrubníky, které v některých částech již chybí. Pozor ve dvoře jezdí a parkují vozidla, nemají vyhrazené stání. Z dvora vedou vstupy do budov B, C, D, E, F, G. Po pravé ruce vyhledej rozhraní chodníku a trávníku s nízkým obrubníkem.

1. úsek z 15. Nacházíš se na vozovce dvoru u vstupu do budovy B. Na druhé straně vozovky je budova C. Chodník se stáčí mírným obloukem doprava. Je možné narazit na zaparkovaná auta u obrubníku. Jdi doprava po okraji vozovky asi 30 metrů, budovu C měj po levé ruce.

2. úsek z 15. Nacházíš se na rohu vozovky, před tebou je budova E. Otoč se vlevo a jdi asi 30 metrů na křížení vozovky, budovu E měj po pravé ruce.

3. úsek z 15. Nacházíš se na křížení vozovky, vpravo hlavní vstup do budovy E tvořen pyramidovým schodištěm, vlevo je vozovka. Jdi rovně asi 5 metrů.

4. úsek z 15. Po pravé ruce máš bezbariérový vstup do budovy E tvořen dřevěnými dvoukřídlými dveřmi, chodník u vstupu je snížený. Vpravo od vstupu je lavička. Otoč se doprava a jdi rovně ke dveřím.

5. úsek z 15. Nacházíš se u dveří do budovy E. Dveře jsou dvoukřídlé, dřevěné. Dveře se otvírájí přiložením karty na čtečku. Čtečka je na stěně vpravo od dveří, čtečka je malá krabička 10 krát 5 krát 3 cm. Dveře se otevírají směrem ven. Projdi dveřmi.

6. úsek z 15. Nacházíš se v budově E v areálu ČVUT, jedná se o historickou budovu. Budova je velmi rozmanitá. Nachází se zde několik různých typů schodišť. V budově je výtah. Mnoho zavřených dveří se otevírá pomocí čipové karty, kterou je nutné přiložit ke čtečce karet a po krátkém pípnutí otevřít. Na otevření dveří je limit asi 5 sekund od pípnutí, jinak je nutné znovu použít kartu. Čtečka karet je malá krabička 10 krát 5 krát 3 cm. V budově se také můžete setkat s mnoha dveřmi, které jsou označeny jako většinou otevřené. Tyto dveře je proto možné snadno minout. Požární hlásič není možné nechtěně omylem spustit.

7. úsek z 15. Rampa asi 5 metrů dlouhá, mírně z kopce, se zdvihací plošinou po levé ruce, zábradlí po pravé ruce, na podlaze dlaždice. Jdi rovně k zalomení na konec rampy a otoč se doprava.

8. úsek z 15. Chodba asi 20 metrů dlouhá, po 10 metrech vlevo výtah ve výklenku, povrch dlaždice. Jdi rovně asi 10 metrů k výtahu, drž se u stěny vlevo.

9. úsek z 15. Plošina výtahu v přízemí. Otoč se doleva, ke dveřím výtahu.

10. úsek z 15. Dveře výtahu v přízemí, ovládání výtahu vpravo od dveří výtahu. Přivolej výtah a nastup dovnitř.

11. úsek z 15. Výtah funguje pouze na kartu. Výtah je vybaven sklopným sedátkem (v dosahu tlačítek), akustickou i hlasovou signalizací a hmatovým značením. Dojeď výtahem do třetího patra.

12. úsek z 15. Třetí patro. Vyjdi ven z výtahu a otoč se doprava.

13. úsek z 15. Chodba asi 30 metrů dlouhá, vpravo jsou okna, vlevo jsou dveře učeben, drž se vlevo, chodba je na konci zalomená vpravo. Jsi v cílovém segmentu. Postupuj dveře od dveří. Dojdi k prvním dveřím na levé straně.

14. úsek z 15. Dveře místnosti Ká 327. Dojdi k dalším dveřím po levé straně.

15. úsek z 15. Dveře místnosti Ká 328. Jsi v cíli.

A.2 Route 2

Popis trasy:
Trasa ze stanice tramvaje Myslíkova (příjezd ze směru od Národní třídy) na adresu Karlovo náměstí 293/13, Fakulta elektrotechnická ČVUT, budova E, místnost KN:E-328.

1. úsek z 8. Zastávka Myslíkova u chodníku, na zastávce se nachází označník zastávky v přední části zastávky, přístřešek, automat na jízdenky a koš. U druhého okraje chodníku jsou budovy. Vystup z tramvaje a otoč se tak abys měl budovy za zády.

2. úsek z 8. Nacházíš se na adrese Myslíkova 1415/27. Otoč se vpravo a jdi asi 30 metrů k přechodu po levé ruce. Po pravé ruce měj budovy.

3. úsek z 8. Nacházíš se u přechodu přes ulici Myslíkova. Otoč se vlevo a přejdi ulici Myslíkova na protější roh přes značený přechod s obousměrným provozem a tramvají.

4. úsek z 8. Nacházíš se na rohu ulic Myslíkova a Odborů. Pokračuj vpřed a jdi asi 100 metrů mírně do kopce na zkosený roh s ulicí Karlovo náměstí. Ulice je zalomená doleva. Po levé ruce měj budovy.

5. úsek z 8. Nacházíš se na zkoseném rohu ulic Odborů a Karlovo náměstí. Otoč se vpravo a přejdi ulici Odborů na protější roh přes značený přechod se světelnou signalizací s jednosměrným provozem zleva.

6. úsek z 8. Nacházíš se na kulatém rohu ulic Odborů a Karlovo náměstí. Pokračuj vpřed a jdi asi 150 metrů mírně do kopce na adresu Karlovo náměstí 293/13 po pravé ruce. Po pravé ruce měj budovy.

7. úsek z 8. Nacházíš se na adrese Karlovo náměstí 293/13. Před vstupem do budovy A, ČVUT na Karlově náměstí. Vstup do budovy je v druhém výklenku ve fasádě budovy vyčnívající do úrovně chodníku. Jdi ke druhému výklenku.

8. úsek z 8. Vstup do budovy A. Je tvořen dvěma dvoukřídlými dveřmi. Vnější vysoké, dřevěné, historické dveře jsou během výuky stále otevřené. Vnitřní prosklené dveře jsou mechanicky otevíravé směrem ven. Projdi dveřmi.

Nacházíš se v budově A, ČVUT na Karlově náměstí. Jedná se o historickou budovu. Budova je velmi rozmanitá, má několik různých typů schodišť, počet pater je čtyři. Mnoho zavřených dveří se otevírá pomocí čipové karty, kterou je nutné přiložit ke čtečce karet a po krátkém pípnutí otevřít. Vrátnice se nachází přímo proti vstupu z pasáže, na druhém konci místnosti, potažmo vpravo po vstupu z ulice.

1. úsek z 11. Nacházíš se ve vstupní hale budovy A, ČVUT. Jdi rovně asi 5 metrů volným prostorem k turniketům před tebou.

2. úsek z 11. Vstupní turnikety uprostřed vstupní haly. Pro vstup je nutné přiložit čipovou kartu a počkat na krátké pípnutí. Čtečka karet je malá krabička 10 krát 5 krát 3 cm ve výšce pasu po levé ruce u každého z celkem 4 turniketů. Otoč se doleva a projdi turnikety

3. úsek z 11. Volný prostor asi 6 metrů dlouhý, po levé i pravé ruce schodiště nahoru. Poté dva sloupy vlevo i vpravo. Na konci prostoru jsou dřevěné dveře se skleněnou výplní. Jdi rovně ke dveřím.

4. úsek z 11. Dřevěné dveře se skleněnou výplní, většinou otevřené. Projdi dveřmi.

5. úsek z 11. Uzká rovná chodba asi 10 m dlouhá, před koncem chodby většinou otvřené dvojkřídlé skleněné dveře. Jdi chodbou ke dveřím.

6. úsek z 11. Dvoukřídlé prosklené dveře s madlem, většinou otevřené. Projdi dveřmi.

7. úsek z 11. Atrium spojující budovu A s budovou B. Po obvodu jsou dřevěné stoly a lavice, mírně vpravo před tebou je schodiště směrem dolů, zábradlí na levé straně. Jdi mírně vpravo asi 10 metrů ke schodům.

8. úsek z 11. Schodiště krátké, počet schodů je 3, zábradlí vpravo. Sejdi schody dolu.

9. úsek z 11. Dvoukřídlé skleněné dveře s madly, většinou otevřené. Projdi dveřmi.

10. úsek z 11. Chodba asi 13 metrů dlouhá. Po levé ruce jsou nápojové automaty (hučí), na konci chodby dveře. Jdi rovně na konec chodby ke dveřím.

11. úsek z 11. Dvoje dřevěné dveře se skleněnou výplní hned za sebou, mezi nimi krátká rampa mírně do kopce, následuje vstup na dvůr areálu ČVUT. Projdi oběmi dveřmi.

Nacházíš se ve dvoře areálu ČVUT, povrch dvoru je tvořen kočičími hlavami (kamennou dlažbou) s nízkými obrubníky, které v některých částech již chybí. Pozor ve dvoře jezdí a parkují vozidla, nemají vyhrazené stání. Z dvora vedou vstupy do budov B, C, D, E, F, G. Po pravé ruce vyhledej rozhraní chodníku a trávníku s nízkým obrubníkem.

1. úsek z 15. Nacházíš se na vozovce dvoru u vstupu do budovy B. Na druhé straně vozovky je budova C. Chodník se stáčí mírným obloukem doprava. Je možné narazit na zaparkovaná auta u obrubníku. Jdi doprava po okraji vozovky asi 30 metrů, budovu C měj po levé ruce.

2. úsek z 15. Nacházíš se na rohu vozovky, před tebou je budova E. Otoč se vlevo a jdi asi 30 metrů na křížení vozovky, budovu E měj po pravé ruce.

3. úsek z 15. Nacházíš se na křížení vozovky, vpravo hlavní vstup do budovy E tvořen pyramidovým schodištěm, vlevo je vozovka. Jdi rovně asi 5 metrů.

4. úsek z 15. Po pravé ruce máš bezbariérový vstup do budovy E tvořen dřevěnými dvoukřídlými dveřmi, chodník u vstupu je snížený. Vpravo od vstupu je lavička. Otoč se doprava a jdi rovně ke dveřím.

5. úsek z 15. Nacházíš se u dveří do budovy E. Dveře jsou dvoukřídlé, dřevěné. Dveře se otvírájí přiložením karty na čtečku. Čtečka je na stěně vpravo od dveří, čtečka je malá krabička 10 krát 5 krát 3 cm. Dveře se otevírají směrem ven. Projdi dveřmi.

6. úsek z 15. Nacházíš se v budově E v areálu ČVUT, jedná se o historickou budovu. Budova je velmi rozmanitá. Nachází se zde několik různých typů schodišť. V budově je výtah. Mnoho zavřených dveří se otevírá pomocí čipové karty, kterou je nutné přiložit ke čtečce karet a po krátkém pípnutí otevřít. Na otevření dveří je limit asi 5 sekund od pípnutí, jinak je nutné znovu použít kartu. Čtečka karet je malá krabička 10 krát 5 krát 3 cm. V budově se také můžete setkat s mnoha dveřmi, které jsou označeny jako většinou otevřené. Tyto dveře je proto možné snadno minout. Požární hlásič není možné nechtěně omylem spustit.

7. úsek z 15. Rampa asi 5 metrů dlouhá, mírně z kopce, se zdvihací plošinou po levé ruce, zábradlí po pravé ruce, na podlaze dlaždice. Jdi rovně k zalomení na konec rampy a otoč se doprava.

8. úsek z 15. Chodba asi 20 metrů dlouhá, po 10 metrech vlevo výtah ve výklenku, povrch dlaždice. Jdi rovně asi 10 metrů k výtahu, drž se u stěny vlevo.

9. úsek z 15. Plošina výtahu v přízemí. Otoč se doleva, ke dveřím výtahu.

10. úsek z 15. Dveře výtahu v přízemí, ovládání výtahu vpravo od dveří výtahu. Přivolej výtah a nastup dovnitř.

11. úsek z 15. Výtah funguje pouze na kartu. Výtah je vybaven sklopným sedátkem (v dosahu tlačítek), akustickou i hlasovou signalizací a hmatovým značením. Dojeď výtahem do třetího patra.

12. úsek z 15. Třetí patro. Vyjdi ven z výtahu a otoč se doprava.

13. úsek z 15. Chodba asi 30 metrů dlouhá, vpravo jsou okna, vlevo jsou dveře učeben, drž se vlevo, chodba je na konci zalomená vpravo. Jsi v cílovém segmentu. Postupuj dveře od dveří. Dojdi k prvním dveřím na levé straně.

14. úsek z 15. Dveře místnosti Ká 327. Dojdi k dalším dveřím po levé straně.

15. úsek z 15. Dveře místnosti Ká 328. Jsi v cíli.

A.3 Route 3

Route description:
From CTU FEE building E at Karlovo Náměstí 13, to tram station Jiráskovo Náměstí. Then take tram to Myslikova station and then return back to Karlovo Náměstí 13 to building E, classroom KN:E 328 (third floor).

Popis trasy: Trasa z adresy Karlovo náměstí 293/13 na adresu Karlovo náměstí 293/13 do učebny Ká 328 v budově E. Trasa je dlouhá asi 1000 metrů a vede přes 5 přechodů. Součástí trasy je cesta tramvají ze zastávky Jiráskovo náměstí na zastávku Myslíkova. Postav se tak, abys měl budovy za zády.

1. úsek z 11. Jsi na adrese Karlovo náměstí 293/13 před budovou A. Otoč se vpravo a jdi asi 30 metrů na roh s ulicí Resslova. Po pravé ruce měj budovy.

2. úsek z 11. Jsi na rohu ulic Karlovo náměstí a Resslova. Odboč mírně vpravo a jdi asi 170 metrů mírně z kopce na roh s ulicí Na Zderaze. Po pravé ruce měj budovy.

3. úsek z 11. Jsi na rohu ulic Resslova a Na Zderaze. Pokračuj vpřed a přejdi ulici Na Zderaze na protější roh přes značený přechod s jednosměrným provozem zprava.

4. úsek z 11. Jsi na rohu ulic Resslova a Na Zderaze. Pokračuj vpřed a jdi asi 60 metrů mírně z kopce na roh s ulicí Dittrichova. Po pravé ruce měj budovy.

5. úsek z 11. Jsi na rohu ulic Resslova a Dittrichova. Pokračuj vpřed a přejdi ulici Dittrichova na protější roh přes značený přechod s jednosměrným provozem zprava.

6. úsek z 11. Jsi na rohu ulic Resslova a Dittrichova. Pokračuj vpřed a jdi asi 40 metrů mírně z kopce na zkosený roh s ulicí Jiráskovo náměstí. Po pravé ruce měj budovy.

7. úsek z 11. Jsi na zkoseném rohu ulic Resslova a Jiráskovo náměstí. Pokračuj vpřed a přejdi ulici Jiráskovo náměstí na protější chodník přes značený přechod s jednosměrným provozem zleva.

8. úsek z 11. Jsi v ulici Jiráskovo náměstí. Pokračuj vpřed a jdi asi 20 metrů k přechodu proti tobě. Po pravé ruce měj zeleň. Po levé ruce měj vozovku.

9. úsek z 11. Jsi u přechodu na zastávku Jiráskovo náměstí přes ulici Masarykovo nábřeží. Zastávka je typu ostrůvek. Přejdi ulici Masarykovo nábřeží na ostrůvek přes značený přechod se světelnou signalizací s jednosměrným provozem zleva. Pozor přechod má snížený obrubník.

10. úsek z 11. Jsi na ostrůvku zastávky Jiráskovo náměstí. Otoč se vpravo a jdi asi 40 metrů k označníku v přední části zastávky. Po pravé ruce měj zábradlí. Po levé ruce měj tramvajový pás.

11. úsek z 11. Jsi u označníku zastávky. Dojeď tramvají číslo 5 na zastávku Myslíkova. Počet zastávek je jedna.

1. úsek z 7. Zastávka Myslíkova u chodníku, na zastávce se nachází označník zastávky v přední části zastávky, přístřešek a koš v prostřední části. U druhého okraje chodníku jsou budovy. Dojdi k budově před tebou pomocí signálního pásu a otoč se vlevo.

2. úsek z 7. Jsi v ulici Myslíkova. Jdi rovně asi 60 metrů. Ulice je zalomená doprava. Po pravé ruce měj budovy.

3. úsek z 7. Jsi v ulici Spálená. Otoč se vpravo a jdi asi 60 metrů na zkosený roh s ulicí Odborů. Po pravé ruce měj budovy.

4. úsek z 7. Jsi na zkoseném rohu ulic Karlovo náměstí a Odborů. Pokračuj vpřed a přejdi ulici Odborů na protější roh přes značený přechod se světelnou signalizací s jednosměrným provozem zleva.

5. úsek z 7. Jsi na kulatém rohu ulic Karlovo náměstí a Odborů. Pokračuj vpřed a jdi asi 150 metrů mírně do kopce k fasádě vyčnívající do prostoru chodníku. Po pravé ruce měj budovy.

6. úsek z 7. Jsi na adrese Karlovo náměstí 293/13. Před vstupem do budovy A, ČVUT na Karlově náměstí. Vstup do budovy je v druhém výklenku vyčnívající fasády budovy. Jdi ke druhému výklenku.

7. úsek z 7. Vstup do budovy A. Je tvořen dvěma dvoukřídlými dveřmi. Vnější vysoké, dřevěné, historické dveře jsou během výuky stále otevřené. Vnitřní prosklené dveře se mechanicky otevírají směrem ven. Projdi dveřmi.

Stručný popis: Jsi v budově A, ČVUT na Karlově náměstí. Počet pater je 4. Mnoho zavřených dveří se otevírá pomocí čipové karty, kterou je nutné přiložit ke čtečce karet a po krátkém pípnutí otevřít. Vrátnice je po pravé ruce po vstupu z ulice.

Detailní popis: Jsi v budově A, ČVUT na Karlově náměstí. Jedná se o historickou budovu. Budova je velmi rozmanitá, má několik různých typů schodišť, počet pater je čtyři. Mnoho zavřených dveří se otevírá pomocí čipové karty, kterou je nutné přiložit ke čtečce karet o velikosti 10 krát 5 krát 3 cm a po krátkém pípnutí otevřít. Vrátnice se nachází po pravé ruce po vstupu z ulice, potažmo přímo proti vstupu z pasáže, na druhém konci místnosti.

1. úsek z 7. Jsi ve vstupní hale budovy A, ČVUT. Jdi rovně asi 5 metrů volným prostorem k turniketům před tebou.

2. úsek z 7. Vstupní turnikety uprostřed vstupní haly. Čtečka karet je ve výšce pasu po levé ruce u každého z celkem 4 turniketů. Projdi turnikety

3. úsek z 7. Volný prostor asi 6 metrů dlouhý, po levé i pravé ruce schodiště nahoru. Poté dva sloupy vlevo i vpravo. Na konci prostoru jsou dřevěné dveře se skleněnou výplní, většinou otevřené. Jdi rovně a projdi dveřmi.

4. úsek z 7. Úzká rovná chodba asi 10 m dlouhá, před koncem chodby většinou otevřené dvojkřídlé skleněné dveře s madlem. Jdi chodbou ke dveřím a projdi.

5. úsek z 7. Atrium spojující budovu A s budovou B. Po obvodu jsou dřevěné stoly a lavice, mírně vpravo před tebou je krátké schodiště směrem dolů. Jdi mírně vpravo volným prostorem asi 10 metrů ke schodišti a sejdi dolu.

6. úsek z 7. Před tebou jsou Dvoukřídlé skleněné dveře s madly, většinou otevřené. Projdi dveřmi.

7. úsek z 7. Chodba asi 13 metrů dlouhá. Po levé ruce jsou nápojové automaty (hučí), na konci chodby dvoje dřevěné dveře se skleněnou výplní hned za sebou. Jdi rovně na konec chodby ke dveřím a projdi. Pozor následuje vstup na dvůr areálu ČVUT.

Stručný popis: Jsi na vozovce ve dvoře areálu ČVUT, povrch vozovky je tvořen kočičími hlavami. Po pravé ruce vyhledej rozhraní vozovky a trávníku s nízkým obrubníkem. Pozor ve dvoře jezdí a parkují vozidla, nemají vyhrazené stání.

Detailní popis: Jsi na vozovce ve dvoře areálu ČVUT, povrch vozovky je tvořen kočičími hlavami s nízkými obrubníky, které v některých částech již chybí. Z dvora vedou vstupy do budov B, C, D, E, F, G. Po pravé ruce vyhledej rozhraní chodníku a trávníku s nízkým obrubníkem. Pozor ve dvoře jezdí a parkují vozidla, nemají vyhrazené stání.

1. úsek z 4. Jsi u rozhraní vozovky a trávníku u vstupu do budovy B. Jdi asi pět metrů rovně volným prostorem na křížení vozovky.

2.úsek z 4. Jsi na křížení vozovky. Otoč se vpravo a jdi rovně asi 40 metrů volným prostorem na odbočku vozovky, po pravé ruce bude nejprve zeleň poté bude trafo stanice.

3. úsek z 4. Jsi na odbočce vozovky, před tebou je budova E. Otoč se vlevo a jdi asi 30 metrů rovně volným prostorem k pyramidovému schodišti po pravé ruce, budovu E měj po pravé ruce.

4. úsek z 4. Jsi u vstupu do budovy E tvořeného pyramidovým schodištěm. Nad schodištěm jsou velké dřevěné dveře do budovy a hned za nimi dřevěné prosklené lítačky. Vyjdi schodiště nahoru a projdi oběma dveřmi.

Stručný popis: Jsi v budově E v areálu ČVUT. Počet pater je čtyři. Mnoho zavřených dveří se otevírá pomocí čipové karty, kterou je nutné přiložit ke čtečce karet a po krátkém pípnutí otevřít. V budově je výtah. Vrátnice je po tvé pravé ruce.

Detailní popis: Jsi v budově E v areálu ČVUT. Počet pater je čtyři. Jedná se o historickou budovu. Budova je velmi rozmanitá. Nachází se zde několik různých typů schodišť. V budově je výtah. Vrátnice je po tvé pravé ruce. Mnoho zavřených dveří se otevírá pomocí čipové karty, kterou je nutné přiložit ke čtečce karet o velikosti 10 krát 5 krát 3 cm a po krátkém pípnutí otevřít. V budově se také můžete setkat s mnoha dveřmi, které jsou označeny jako většinou otevřené. Tyto dveře je proto možné snadno minout.

1. úsek z 10. Plošina asi 5 metrů dlouhá. Povrch gumová rohož. Na konci plošiny je přímé schodiště nahoru. Dojdi ke schodišti na konec plošiny.

2. úsek z 10. Přímé kamenné schodiště. Hned nad schodištěm jsou dřevěné lítačky. Vyjdi nahoru a projdi dveřmi. Pozor plošina nad schodištěm je velmi krátká.

3. úsek z 10. Plošina hlavního schodiště v přízemí. Povrch dlaždice. Před tebou jsou schody nahoru. Vlevo jsou dřevěné dveře se skleněnou výplní. Otoč se vlevo a dojdi ke dveřím. Pozor, vpravo i vlevo od schodiště nahoru jsou schody dolů.

4. úsek z 10. Dveře se otvírají na kartu. Čtečka je na stěně vlevo od dveří. Projdi dveřmi.

5. úsek z 10. Chodba asi 20 metrů dlouhá, vpravo za dveřmi je výtah ve výklenku. Dojdi k výtahu, drž se u stěny vpravo.

6. úsek z 10. Výtah v nultém patře, tlačítko přivolání výtahu vpravo od dveří výtahu. Otoč se vpravo, ke dveřím výtahu a přivolej výtah.

7. úsek z 10. Výtah. Ovládání je vlevo hned za dveřmi výtahu. Stanici je možné zvolit pouze po přiložení karty ke čtečce karet nad ovládacím panelem. Ovládání má 6 tlačítek ve dvou sloupcích. Výtah je vybaven akustickou i hlasovou signalizací a hmatovým značením. Dojeď výtahem do třetího patra.

8. úsek z 10. Třetí patro. Vyjdi ven z výtahu a otoč se vpravo.

9. úsek z 10. Chodba asi 30 metrů dlouhá, vpravo jsou okna, vlevo jsou dveře učeben, drž se vlevo. Jsi v cílovém segmentu. Dojdi k prvním dveřím na levé straně.

10. úsek z 10. Jsi v cíli. Dveře místnosti Ká 328.

A.4 Route 4

Popis trasy:
Trasa z adresy Karlovo náměstí 557/30 na adresu Karlovo náměstí 293/13 do místnosti 317 v budově E areálu ČVUT. Trasa je asi 700 metrů dlouhá a vede přes 3 přechody. Součástí trasy je jízda tramvají ze zastávky Štěpánská na zastávku Novoměstská radnice. Postav se tak, ať máš budovy za zády.

1. úsek z 3. Jsi na adrese Karlovo náměstí 557/30. Otoč se vlevo a jdi asi 120 metrů na kulatý roh s ulicí Ječná. Po levé ruce měj budovy.

2. úsek z 3. Jsi na kulatém rohu ulic Karlovo náměstí a Ječná. Otoč se vlevo a jdi asi 110 metrů k označníku zastávky Štěpánská. Zastávka je u chodníku, označník je v přední části zastávky. Po levé ruce měj budovy.

3. úsek z 3. Jsi u označníku zastávky Štěpánská. Dojeď tramvají číslo 6, 22 nebo 23 na zastávku Novoměstská radnice. Počet zastávek je dva.

1. úsek z 8. Zastávka Novoměstská radnice u chodníku, na zastávce se nachází označník zastávky v přední části zastávky, přístřešek v prostřední části. U druhého okraje chodníku je park. Po výstupu z tramvaje dojdi rovně k rozhraní chodníku a zeleně před tebou za sebou měj tramvajový pás.

2. úsek z 8. Jsi v ulici Karlovo náměstí, u zastávky Novoměstská radnice. Otoč se vlevo a jdi rovně asi 10 metrů na roh chodníků.

3. úsek z 8. Jsi na rohu chodníků. Pokračuj vpřed a přejdi ulici Žitná na protější chodník přes značený přechod se světelnou signalizací s jednosměrným provozem zprava.

4. úsek z 8. Jsi na rohu chodníků. Otoč se vlevo a přejdi ulici Karlovo náměstí na protější chodník přes značený přechod se světelnou signalizací s jednosměrným provozem zprava a tramvají.

5. úsek z 8. Jsi v ulici Karlovo náměstí. Otoč se vlevo a jdi asi 10 metrů na zkosený roh s ulicí Odborů. Po pravé ruce měj budovy.

6. úsek z 8. Jsi na zkoseném rohu ulic Karlovo náměstí a Odborů. Pokračuj vpřed a přejdi ulici Odborů na protější roh přes značený přechod se světelnou signalizací s jednosměrným provozem zleva.

7. úsek z 8. Jsi na kulatém rohu ulic Karlovo náměstí a Odborů. Pokračuj vpřed a jdi asi 150 metrů na adresu Karlovo náměstí 293/13. Vstup do budovy je ve druhém výklenku vyčnívající fasády budovy. Po pravé ruce měj budovy.

8. úsek z 8. Jsi u vstupu do budovy A. Je tvořen dvěma dvoukřídlými dveřmi. Vnější vysoké, dřevěné, historické dveře jsou během výuky stále otevřené. Vnitřní prosklené dveře se mechanicky otevírají směrem ven. Projdi dveřmi.

Stručný popis: Jsi v budově A, ČVUT na Karlově náměstí. Počet pater je 4. Mnoho zavřených dveří se otevírá pomocí čipové karty, kterou je nutné přiložit ke čtečce karet o velikosti 10 krát 5 krát 3 cm a po krátkém pípnutí otevřít. Vrátnice je po pravé ruce po vstupu z ulice.

1. úsek z 7. Jsi ve vstupní hale budovy A, ČVUT. Jdi rovně asi 5 metrů volným prostorem k turniketům před tebou.

2. úsek z 7. Vstupní turnikety uprostřed vstupní haly. Čtečka karet je ve výšce pasu po levé ruce u každého z celkem 4 turniketů. Projdi turnikety

3. úsek z 7. Volný prostor asi 6 metrů dlouhý, po levé i pravé ruce schodiště nahoru. Poté dva sloupy vlevo i vpravo. Na konci prostoru jsou dřevěné dveře se skleněnou výplní, většinou otevřené. Jdi rovně a projdi dveřmi.

4. úsek z 7. Úzká rovná chodba asi 10 m dlouhá, před koncem chodby většinou otevřené dvojkřídlé skleněné dveře s madlem. Jdi chodbou ke dveřím a projdi.

5. úsek z 7. Atrium spojující budovu A s budovou B. Po obvodu jsou dřevěné stoly a lavice, mírně vpravo před tebou je krátké schodiště směrem dolů. Jdi mírně vpravo volným prostorem asi 10 metrů ke schodišti a sejdi dolu.

6. úsek z 7. Před tebou jsou dvoukřídlé skleněné dveře s madly, většinou otevřené. Projdi dveřmi.

7. úsek z 7. Chodba asi 13 metrů dlouhá. Po levé ruce jsou nápojové automaty (hučí), na konci chodby dvoje dřevěné dveře se skleněnou výplní hned za sebou. Jdi rovně na konec chodby ke dveřím a projdi. Pozor následuje vstup na dvůr areálu ČVUT.

Stručný popis: Jsi na vozovce ve dvoře areálu ČVUT, povrch vozovky je tvořen kočičími hlavami. Po pravé ruce vyhledej rozhraní vozovky a trávníku s nízkým obrubníkem. Pozor ve dvoře jezdí a parkují vozidla, nemají vyhrazené stání.

1. úsek z 3. Jsi u rozhraní vozovky a trávníku u vstupu do budovy B. Jdi podél rozhraní chodníku asi 40 metrů na odbočku vozovky. Po pravé ruce bude nejprve zeleň poté bude trafo stanice.

2. úsek z 3. Jsi na odbočce vozovky, před tebou je budova E. Otoč se vlevo a jdi asi 30 metrů rovně volným prostorem k pyramidovému schodišti po pravé ruce, kde je vstup do budovy. Budovu E měj po pravé ruce.

3. úsek z 3. Jsi u vstupu do budovy E tvořeného pyramidovým schodištěm. Nad schodištěm jsou velké dřevěné dveře do budovy a hned za nimi dřevěné prosklené lítačky. Vyjdi schodiště nahoru a projdi oběma dveřmi.

Stručný popis: Jsi v budově E v areálu ČVUT. Počet pater je čtyři. Mnoho zavřených dveří se otevírá pomocí čipové karty, kterou je nutné přiložit ke čtečce karet a po krátkém pípnutí otevřít. V budově je výtah. Vrátnice je po tvé pravé ruce.

1. úsek z 15. Plošina asi 5 metrů dlouhá. Povrch gumová rohož. Na konci plošiny je přímé schodiště nahoru. Dojdi ke schodišti na konec plošiny.

2. úsek z 15. Přímé kamenné schodiště. Hned nad schodištěm jsou dřevěné lítačky. Vyjdi nahoru a projdi dveřmi. Pozor plošina nad schodištěm je velmi krátká.

3. úsek z 15. Plošina hlavního schodiště v přízemí. Povrch dlaždice. Před tebou jsou schody nahoru. Vyjdi schody nahoru do mezipatra. POZOR, vpravo i vlevo od schodů nahoru jsou schody dolů.

4.úsek z 15. Mezipatro schodišťové haly. Před tebou jsou schody nahoru. Vpravo za tebou je zpětné rameno schodiště nahoru. Otoč se doprava dozadu a vyjdi schodištěm do prvního patra.

5.úsek z 15. Plošina schodišťové haly v prvním patře. Vlevo jsou dvoukřídlé dveře, vetšinou otevřené. Otoč se doleva a projdi dveřmi.

6.úsek z 15. Chodba asi 5 metrů dlouhá. Vlevo jsou schody nahoru. Otoč se doleva vyjdi schody nahoru do mezipatra.

7.úsek z 15. Mezipatro schodišťové haly. Před tebou jsou schody nahoru, vpravo za tebou je zpětné rameno schodiště nahoru. Vyjdi schody před tebou nahoru do mezipatra.

8.úsek z 15. Mezipatro schodišťové haly. Vpravo za tebou je schodiště nahoru. Otoč se doprava a vyjdi schody nahoru do mezipatra.

9.úsek z 15. Mezipatro schodišťové haly. Před tebou jsou schody nahoru, Vpravo za tebou je zpětné rameno schodiště nahoru. Vyjdi schody před tebou nahoru do třetího patra.

10.úsek z 15. Jsi na chodbě ve třetím patře. Chodba je dlouhá asi 5 metrů. Vpravo za tebou je zpětné rameno schodiště nahoru. Vlevo jsou dvojkřídlé skleněné dveře. Otoč se doleva a dojdi ke dveřím.

11.úsek z 15. Dveře se otvírají na kartu. Čtečka je vpravo od dveří. Projdi dveřmi.

12.úsek z 15. Chodba asi 30 metrů dlouhá na konci zalomená doleva. Vpravo jsou dveře do kanceláří, vlevo jsou okna. Drž se vpravo a dojdi na konec chodby až k zalomení. POZOR po levé ruce jsou květiny v úrovni očí.

13.úsek z 15. Jsi u zalomení chodby doleva. Vlevo jsou dveře většinou otevřené a následuje chodba. Po levé straně jsou dveře do učeben a výklenek. Otoč se doleva a jdi asi 8 metrů ke dveřím většinou otevřeným a výklenku.

14.úsek z 15. Dřevěné dvoukřídlé dveře většinou otevřené, následuje chodba asi 7 metrů dlouhá. Vlevo jsou dveře do místností. Projdi dveřmi a odpočítej první dveře po levé ruce.

15.úsek z 15. Dveře do místnosti 319. Jsi v cíli.

A.5 Route itinerary data structure example

```
routeGraph = {
            routeDescription: "Route from XXX to YYY.",
            "adjacency": {
                "a": ["1"],
                "b": ["2", "3"],
                "c": [],
            },
            "nodes": {
                "a": {
                    isOnRoute: true,
                    beaconID: "undefined"
                },
                "b": {
                    isOnRoute: true,
                    beaconID: "ODUM"
                },
                "c": {
                    isOnRoute: true,
                    beaconID: "vf3i"
                },
                "d": {
                    isOnRoute: false,
                    beaconID: "4vXL"
                }
            },
            "edges": {
                "1": {
                    "from": "a", "to": "b",
                    isOnRoute: true,
                    "data": {
                        segmentNumber: "1st segment from 2",
                        description: "You are at the turning of the road, the building E is in front of you.",
                        action: "Turn left and go approximately 30 meters through open space to pyramidal stairs, by your right hand. There is an entrance to the building E."
                    }
                },
                "2": {
                    "from": "b", "to": "c",
                    isOnRoute: true,
                    "data": {
                        segmentNumber: "2nd segment from 2",
                        description: "You are by the entrance to the building E. Above the pyramidal stairs there is big wooden door and glass swing door right behind, leading inside the building.",
                        action: "Go up the stairs and through the doors inside the building."
                    }

                },
                "3": {
                    "from": "b", "to": "d",
                    isOnRoute: false

                }
            }
```

Listing A.1 Route data structure in JSON format.

Appendix B

Beacons data

Here, we include detailed results of the beacon triggering in Table 6 form the third user study and also how were the beacons configured in Table 7.

Table 6 Beacons triggering results

	P1	P2	P3	P4	P5	P6	P7	P8
Tram station (U4tv)	correct	correct but misheard	correct but misheard	app switched off	skipped to next early	correct	correct but misheard	correct
Verify Location	correct	correct	correct	correct	-	not triggered ~10m distance	correct	-
Entrance A (U4tv)	correct	late		correct but misheard	skipped to next early	correct		
Verify Location	-	-	correct	-	-	correct	in first niche	second attemp
segment 3 of 7 (6pDr)		correct	correct	correct	correct	correct		correct
Verify Location		-	correct	-	correct	correct		-
segment 5 of 7 (6bUB)		early	correct	correct	correct	correct	correct	correct
Verify Location	-	-	-	-	correct	correct	-	-
segment 7 of 7 (Lto1)	correct	correct	correct	correct	correct	correct		correct
Verify Location	-	-	-	-	-	-	-	-
segment 1 of 3 (m46J)	correct	correct	skipped to next early	skipped to next early	correct	correct		correct
Verify Location	-	-	-	-		few steps behind beacon	not triggered ~10m distance	-
Entrance E (2LxK)	correct	correct	skipped to next early		correct	behind the wall	correct	correct
Verify Location	-	-	-	-	-	behind the wall	-	-
segment 2 of 15 (ulWB)	correct	early	correct	correct	correct	correct	correct	correct
Verify Location	-	-	-	-	correct	-	-	-
segment 3 of 15 (BGNA)		correct	correct	correct	correct	correct	correct	correct
Verify Location	-	-	-	-	-	-	-	-
segment 4 of 15 (S8Nn)	correct	correct	skipped to next early	correct	correct	correct	correct	correct
Verify Location	correct	-	-	-	-	-	-	-
segment 6 of 15 (xTni)	correct	correct	skipped to next early	skipped to next early	correct	correct	correct	correct
Verify Location	-	-	-	-	-	-	-	-
segment 7 of 15 (dwR7)	correct	correct	skipped to next early	correct	correct		correct	
Verify Location	-	-	-	-	-	-	-	-
segment 8 of 15 (2Y5M)			skipped to next early	correct	correct		correct	correct
Verify Location	-		-	-	-	-	-	-
segment 9 of 15 (yODr)	skipped to next		skipped to next early		correct	correct	correct	correct
Verify Location	-	-	-	correct	-	-	-	-
segment 12 of 15 (y4Wl)	correct	correct	skipped to next early	correct	correct	correct		correct
Verify Location	-	-	-	-	-	-	-	-
segment 13 of 15 (bz7E)					early			correct
Verify Location	-	-	-	-	-	-	-	-
error beacon (kDaJ)	-	-	-	-	-	-	-	-
error beacon (U6ne)	-	-	-	-	-	-	-	-
error beacon (0DIb)	-	-	-	-	-	-	-	-
error beacon (1cZi)	-	-	-	correct and recovered	-	-	-	-
error beacon (wapV)	-	-	-	-	-	-	-	-
error beacon (jd2h)	-	correct and recovered	-	correct	-	-	-	-
error beacon (ajes)	-	-	-	-	-	-	-	-
error beacon (uTlg)	-	-	-	-	-	-	-	-
error beacon (gwIq)	-	-	-	-	-	-	-	-
error beacon (6ezy)	-	-	-	-	-	-	-	-
error beacon (1YdZ)	-	-	-	-	-	-	-	-

Table 7 Beacons configuration

Beacon ID	Major	Minor	Interval (ms)	TX Power	RSSI Trigger
U4tv	42123	49791	150	3	-80
6pDr	12196	27432	150	1	-85
6bUB	64049	65232	150	3	-75
Lto1	48587	51204	150	2	-80
m46J	46864	40873	150	2	-80
2LxK (tough beacon)	36798	31395	150	3	-90
ulWB	12943	40394	150	3	-85
BGNA	38913	52322	150	3	-85
S8Nn	53001	10385	150	4	-80
xTni	680	24994	150	4	-80
dwR7	32536	58292	150	2	-80
2Y5M	2000	201	150	3	-80
yODr	5719	48569	150	3	-80
y4Wl	2000	202	150	2	-80
bz7E	17116	60729	150	3	-75
error beacons:					
kDaJ	26530	43364	150	3	-85
U6ne	36926	26828	150	3	-85
0DIb	54785	31317	150	3	-80
wapV	21389	581	150	2	-80
1cZi	21476	5427	150	2	-85
jd2h	3843	21525	150	3	-80
ajes	16124	19363	150	3	-80
uTlg	33340	34828	150	2	-85
gwIq	999	100	150	1	-80
6eZY	51439	40631	150	3	-80
1Ydz	59862	25684	150	3	-80

Appendix C

Contents of the attached .zip file

```
/
├── navigation-beacons/ ........................ Source code of the application
│   ├── resources/
│   ├── src/
│   │   ├── app/
│   │   ├── assets/
│   │   ├── models/
│   │   ├── pages/
│   │   ├── providers/
│   │   ├── theme/
│   │   └── index.html
│   ├── config.xml
│   ├── package.json
│   ├── ionic.config.json
│   ├── tsconfig.json
│   └── tslint.json
├── log-files/ ........................ Log files from the third user experiment
└── beacons-installation/ ................ Building plans with installed beacons
```