CZECH TECHNICAL
UNIVERSITY
IN PRAGUE

F3

Faculty of Electrical Engineering
Department of Computer Science

Bachelor's Thesis

Prototype application for indoor navigation with evaluation using crowdsourcing

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Software Engineering and Technology

January 2020
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ZADÁNÍ BAKALÁŘSKÉ PRÁCE

I. OSOBNÍ A STUDIJNÍ ÚDAJE

Příjmení: **Šourková** Jméno: **Barbora** Osobní číslo: **434656**

Fakulta/ústav: **Fakulta elektrotechnická**

Zadávající katedra/ústav: **Katedra počítačů**

Studijní program: **Softwarové inženýrství a technologie**

II. ÚDAJE K BAKALÁŘSKÉ PRÁCI

Název bakalářské práce:

Prototyp aplikace pro davové ověřování parametrů při navigaci interiérem

Název bakalářské práce anglicky:

Prototype application for indoor navigation with evaluation using crowdsourcing

Pokyny pro vypracování:

Analyzujte existující nástroje a aplikace pro interiérovou navigaci. Dále analyzujte existující literaturu zabývající se interiérovou navigací a potřebami navigovaných uživatelů. Nakonec také analyzujte existující literaturu zabývající se oblastí davového a komunitního přispívání (crowdsourcing).
Na základě analýzy navrhněte prototyp aplikace, která umožní navigaci zvolenou trasou. V rámci navigace aplikace umožní verifikaci významných bodů na trase (landmark) a nebo jejich sběr. Pro tyto účely navrhněte vhodné datové struktury a číselníky. Prototyp vyhodnoťte dle metodiky User-Centered Design (UCD).
Prototyp aplikace implementujte formou mobilní aplikace. Funkčnost aplikace ověřte na alespoň dvou různých trasách pomocí kvalitativních uživatelských testů s alespoň 5 uživateli.

Seznam doporučené literatury:

[1] Riganova, M., Balata, J. and Mikovec, Z., 2017, September. Crowdsourcing of Accessibility Attributes on Sidewalk-Based Geodatabase. In IFIP Conference on Human-Computer Interaction (pp. 436-440). Springer, Cham.
[2] T. Lowdermilk, User-Centered Design, O'Reilly Media, 2013.
[3] B. Fling, Mobile Design and Development, O'Reilly Media, 2009

Jméno a pracoviště vedoucí(ho) bakalářské práce:

Ing. Ivo Malý, Ph.D., katedra počítačové grafiky a interakce FEL

Jméno a pracoviště druhé(ho) vedoucí(ho) nebo konzultanta(ky) bakalářské práce:

Datum zadání bakalářské práce: **20.09.2019** Termín odevzdání bakalářské práce: **07.01.2020**

Platnost zadání bakalářské práce: **19.02.2021**

Ing. Ivo Malý, Ph.D. podpis vedoucí(ho) práce	podpis vedoucí(ho) ústavu/katedry	prof. Mgr. Petr Páta, Ph.D. podpis děkana(ky)

III. PŘEVZETÍ ZADÁNÍ

Studentka bere na vědomí, že je povinna vypracovat bakalářskou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací.
Seznam použité literatury, jiných pramenů a jmen konzultantů je třeba uvést v bakalářské práci.

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Datum převzetí zadání Podpis studentky

Acknowledgement / Declaration

I would like to show my greatest appreciation to my supervisor Ing. Ivo Malý, Ph.D. for the invaluable advice and observations. Without his continuous guidance, this paper would not have materialized. I would also like to thank my family for their endless support.

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, 6.1.2020

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Abstrakt / Abstract

Po velkém úspěchu globálních navigačních satelitních systémů ve venkovním prostředí se výzkum začal přesouvat dovnitř budov a výzkumníci začali přemýšlet nad tím, zda by bylo možné poskytovat takové služby i uvnitř budov. Dodnes neexistuje žádný vnitřní navigační systém, který by se vyrovnal globálním navigačním satelitním systémům z hlediska globálního pokrytí, vysoké přesnosti, krátké latence, vysoké dostupnosti, vysoké integrity a nízkých nákladů. Systémy založené na signálových vysílačích vyžadují stabilní a drahou infrastrukturu a navíc poskytují pouze omezenou přesnost. Tato práce podává zprávu o výsledcích výzkumu zaměřeného na návrh uživatelského rozhraní mobilní aplikace pro sběr a hodnocení navigačních dat pomocí crowdsourcingu. Podkladem pro návrh této práce je proces lidské navigace a orientace v prostředí založený na rozpoznávání určitých jedinečných objektů a vizuálních stop na trase. Data, jmenovitě orientační body, shromážděna v našem návrhu řešení, představují nízkonákladovou techniku fingerprintingu, která se v tomto výzkumu ukázala být proveditelná a použitelná pro účely navigace.

Klíčová slova: navigace interiérem; navigace podle významných bodů na trase; navigace bez mapy; crowdsourcing; mobilní aplikace.

Překlad titulu: Prototyp aplikace pro davové ověřování parametrů při navigaci interiérem

Following the great success of Global Navigation Satellite Systems (GNSS) in outdoor environment, the focus of research has shifted indoors, exploring whether such or similar services could be provided for the indoor navigation as well. To this day, there is no system that possesses the excellent performance of GNSS in terms of global coverage, high accuracy, short latency, high availability, high integrity and low costs. Systems based on signal transmitters require stable and costly architecture and on top of that they only provide limited accuracy. In this thesis, we report on results of the research focused on designing the user interface of mobile application for collecting and evaluating navigation data using crowdsourcing. The human navigation and orientation process based on recognition of certain unique objects and visual clues is the foundation of this work. The data, namely the landmarks, collected in our design represent a low-cost fingerprinting technique which proved feasible and usable in this research.

Keywords: indoor navigation; landmark–based navigation; map–free navigation; crowdsourcing; mobile application.

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Chapter 1
Introduction

Indoor navigation systems are highly limited in the use of the methods proved in outdoor navigation. Global Positioning System, the essential part of outdoor navigation today, becomes practically useless indoors and methods based on Bluetooth Low Energy, Wifi or other signal transmitters require stable and rather costly architecture. The stability of such systems is usually questionable as the transmitters can be moved, removed or other transmitters can introduce errors into the system.

Another issue of indoor navigation is the floor plan or building model. We are limited in use of open source APIs such as Google Maps or Mapy.cz, as the insides of the buildings are generally not mapped by these providers, and to create useful digital floor plans for buildings is highly cost and time consuming. The existing floor plans are usually on paper only or in Computer Aided Design formats which are inappropriate considering usability and user experience, especially on mobile devices.

The aim of this work is to analyse the problematics of indoor navigation in order to design and implement a prototype application for indoor navigation in a form of mobile phone app. The ambition of the designed solution is to be gradually evaluated and enhanced by its users, namely by collecting, describing and evaluating significant landmarks along the route.

In this work we will first present an analysis of existing approaches on indoor localization and navigation. Both the techniques and technologies will be outlined, the advantages and disadvantages of each approach will be discussed and some existing research and commercial solutions will be mentioned. We will also go through the requirements on the navigation system for people with limitations in mobility and explain the term crowdsourcing.

A design section will follow where we will define the use cases of our application, the data structure and present the first design of low-fidelity prototypes. The tests that were conducted and the test results will also be presented in this chapter. User Centred Design methodology was used in the design process; it will be briefly explained in the beginning of the chapter.

Based on the evaluated low-fidelity prototype, a high-fidelity prototype has been developed and will be presented in the chapter dedicated to implementation. Used implementation tools and technologies will be listed and the developed prototype will be described — both its functionality and user interface. This testing process and results will be presented in the end of this chapter.

Finally, in the last section, the conclusion and future work will be presented.

Chapter 2
Analysis

2.1 Indoor navigation techniques and methodologies

Following the great success of satellite–based location services outdoors the focus of research has shifted to indoor environments, exploring whether such or similar services could be provided for the indoor navigation.[1] Navigation in complex buildings can be a difficult task for various groups of people, especially for those limited in movement or visually impaired.

In this section, positioning, a principal stage of indoor navigation process, will be described. For the positioning process description, we will first define useful signal properties and subsequently we will present the usage of these measurable properties in the positioning techniques. Furthermore, a sub-section focusing on the needs of users, particularly impaired users, during navigation will be presented.

2.1.1 Measurable signal properties

For positioning calculations, signal's geometrical parameters can be used. [2, 1, 3] These parameters consist of metrics such as angle, distance and signal attenuation, and various methods of signal measurement can be employed. In this work, we will discuss the Angle of Arrival (AOA), Time of Arrival (TOA), Time Difference of Arrival (TDOA) and Received Signal Strength Indication (RSSI) methods.

- **Angle of Arrival**
  AoA is an angle–based method in which the estimation of the signal reception angles from two or multiple sources is compared with either the signal amplitude or carrier phase across multiple antennas. [2, 4] AoA estimation method is very sensitive to many factors which may decrease its accuracy, yet it can be used with other methods to compensate the errors. Another drawback of this method is that the essential hardware for AoA estimations tends to be complex and expensive.

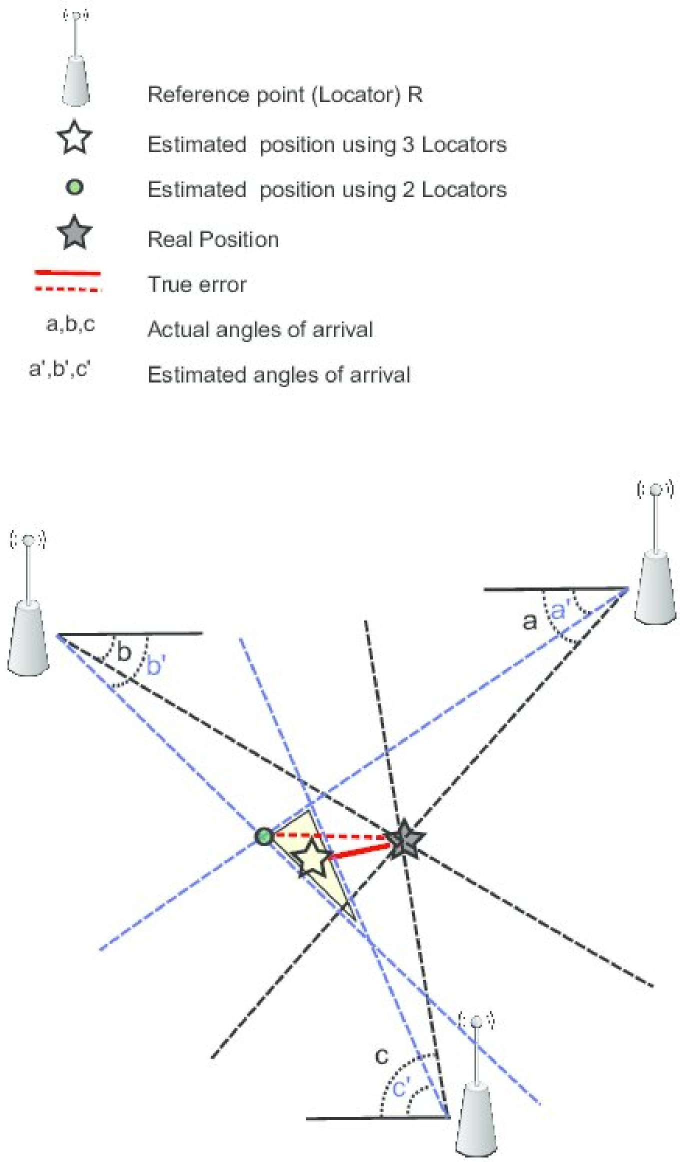

Figure 2.1. Angle of arrival (AoA)-based methods adopted from Al-Hadhrami et al. (2016) [4]

- **Time of Arrival**

  ToA, sometimes called Time of Flight (ToF), is mainly a distance–based method in which the time taken by a signal to arrive at a receiver from a fixed transmitter is measured. [2, 4] ToA uses the absolute time of arrival at the receiver, therefore, all the transmitters must be synchronized. It provides high accuracy for positioning at a cost of higher hardware complexity; it is only possible to effectively measure ToA on dedicated chips with extra time accuracy as the mili–second or nano–second accuracy is required, resp. for sound or light signals.

- **Time Difference of Arrival**

  TDoA is also a distance–based method typically based on measuring the time difference of arrival of a signal sent by a transmitter and received by three or more reference points. [2, 4] In some scenarios the roles can be reversed so a receiver can determine the location by measuring the difference in arrival times of two or more transmitted signals. TDoA eliminates the requirement for absolute arrival time, therefore, it reduces the necessary hardware complexity. However, due to the reference points cooperation it requires significant bandwidth.

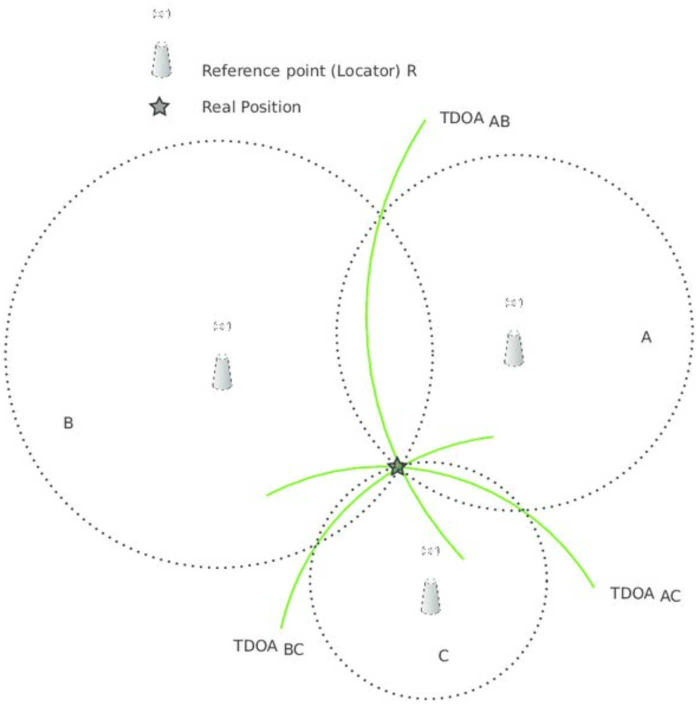

Figure 2.2. Time Difference of arrival (TDoA)-based methods adopted from Al-Hadhrami et al. (2016) [4]

- **Received Signal Strength Indication**

  RSSI is method based on signal attenuation which measures of the power level of the Received Signal Strength (RSS) present in a radio infrastructure. [5, 2, 4] The signal strength reduction or loss can be used to estimate the distance between mobile devices. The method's accuracy may be strongly affected by multipath and show low results in non-line-of-sight (NLOS) environments. However, in comparison to the other methods mentioned, the RSSI is easy to measure and low-cost.

2.1.2 Positioning techniques

The localization and navigation are problems people have been dealing with for centuries. However, it has only been a few decades back since the way we approach these problems utterly changed with the launch of Global Positioning System (GPS) project. GPS is a global navigation satellite system that provides geolocation and time information to a GPS receiver anywhere on or near the Earth where there is an unobstructed line of sight (LoS) to four or more GPS satellites.[6] Since 1983, when it became public, the receiver sensors greatly reduced in size and became essential parts of navigation devices.

When approaching the indoor navigation, however, GPS must be omitted. Due to the signal attenuation caused by construction materials, GPS loses significant power indoors. Furthermore, the multiple reflections at surfaces cause multi-path propagation and therefore serve for uncontrollable errors.[6, 2]

Techniques that can be used in indoor localization instead of GPS will now be discussed. We will use the classification by Gu et al. (2009) consisting of four categories: Triangulation, Fingerprinting, Proximity and Vision Analysis which we will extend with Trilateration. The signal transmitters reffered in these techniques can be of various technologies which will be described in 2.2. It is important to mention that two or more positioning techniques can be applied together to compensate for the limitations of a standalone technique.[7]

- **Triangulation**
  In triangulation, the location of a transmitter can be found from the intersection of the angle line for each signal source, see Figure... The signal reception angles can be estimated by the AoA method.
- **Trilateration**
  Trilateration, or multilateration in general, calculates with distances from multiple known positions of transmitters.[5] The distance from the transmitter can be estimated with ToA or TDoA methods and used as the radius of a circle. Once three or more transmitters are in range, the location of the receiver can be found on the intersection of the circles, see Figure...%. With ToA, the distance is calculated from the time measured and the speed of the signal. TDoA measurements can be used in a slightly modified form of trilateration as shown in Figure...%
  Theoretically, distances which have been estimated from RSSI method can be used for trilateration as well. However, in real–world application, interference, multipath propagation and presence of obstacles and people leads to a complex spatial distribution of RSSI values, which is unfavourable for the estimation of distances from RSSI. [1]
- **Fingerprinting**
  Suitable method for processing the RSSI values is to create a fingerprint referring to the expected signal strength of each transmitter when the device is at the location.[5] By collecting these fingerprints, a coordinate signal strength map can be built and used later as a reference for localization. This offline stage requires a significant amount of effort and time and, on top of that, it must be performed repeatedly to keep the map of fingerprints up-to-date as the transmitters' position often change.
- **Proximity**
  There are three general approaches to sensing proximity: [3]

  1. Detecting physical contact with an object with pressure sensors or touch sensors.
  2. Monitor wireless cellular access points when a mobile device is in range of one or more of them.
  3. Observe automatic ID systems such as credit card point-of-sale terminals, computer login histories, land-line telephone records, etc.

  From the methods described in 2.1.1, RSSI can be used for this technique, particularly for the 2nd mentioned approach.
- **Vision Analysis**
  Vision or Scene Analysis
  The vision analysis method estimates a location from the images received at one or multiple points.[3] From the images, the targets previously tracked in database are identified. This information is de facto a fingerprint, therefore the same drawbacks apply to this technique as to fingerprinting.

2.1.3 Indoor Location Usages

The most obvious application of indoor location, and also the most relevant for this work, is wayfinding, i.e. finding the way from one place to another. Other important applications such as asset tracking and analytics will be briefly discussed.

- **Wayfinding**
  The basic process of wayfinding can be described in four stages:[8]

  1. Orientation, i.e. the attempt to determine one's location, in relation to objects that may be nearby and the desired destination.
  2. Route decision, i.e. the selection of a course of direction to the destination.
  3. Route monitoring, i.e. checking to make sure that the selected route is heading towards the destination.
  4. Destination recognition, i.e. when the destination is recognized.

  Frequent wayfinding aids are the use of colour coding and signage clustering.
- **Asset tracking**
  Asset tracking refers to the method of tracking physical assets in the building, e.g. medical devices in hospitals or devices in manufacturing or logistics. This can be done by scanning coded labels attached to the assets or by using tags and broadcasting their location. A person wearing a tag can also be tracked, e.g. to find your friend scenario or to find the surgeon on duty.
- **Analytics**
  How the buildings are used is an important concern of every building owner or company, as the buildings are one of the largest costs. The cumulative data from the indoor positioning or navigation system can be used for further optimization, such as changing the location of a store in a shopping centre.

2.1.4 Navigation and orientation methodologies

Traditionally, navigation meant the process of guiding, monitoring and controlling of vehicles or crafts from a starting point along the most suitable route to a defined destination.[9] In this work we will focus on a specific type of navigation, the **pedestrian navigation**, where the navigation information is provided directly to the human beings.

The high level of human mobility introduces certain specific features to pedestrian navigation. The environment and surroundings where pedestrians move is very diverse and the walking habits and patterns differ with each individual. Route planning and optimization is decided by experience, topographic and topological knowledge in known environments.

In unknown environments, a very detailed and up-to-date map data is required for pedestrian navigation, particularly in the complex indoor environments. Moreover, inside of multistorey buildings, 3D models or multi–layered maps are more appropriate than conventional 2D maps. Since the operation area is usually known and limited, remote positioning using a fixed sensor configuration may be applied. Remote positioning is further described in the next section 2.2.

Pedestrian navigation process basically represents guided wayfinding as described in 2.1.3. Before the navigation begins, it is important to determine the initial position, the destination and the information necessary to determine the best route between them.?? That helps the traveller to arrive at the destination, and on time. The challenge in pedestrian navigation systems is that they should deliver accurate and reliable navigation information regardless of the current environment; a seamless transition between indoor and outdoor areas is most desired.

When navigating impaired people, special attention must be paid to accessibility and danger level of routes and landmarks.

Visually impaired people use two main senses, touch and hearing, for navigation and orientation in space. To identify the tactile guidelines and obstacles of an environment mainly the echo of long white cane is used. In addition, special audio technologies are used for acoustic orientation, such as voice synthesizers and beacons. A successful implementation of pedestrian navigation for visually impaired people is Naviterier.[1]

Many routes are not accessible or comfortable for **wheelchair users**, therefore the shortest feasible route criterion is not always suitable when navigating the wheelchair users. Routes with better path quality (slope and surface condition) can often be preferred. In many contexts, public and private buildings are difficult to access in a wheelchair. Some accessibility features, such as disability-friendly transit options can be found in Google Maps.[10]

2.2 Indoor navigation technologies and applications

Indoor navigation has generated interest in users and researchers resulting in a development of several applications to aid indoor navigation services.[2] However, contrary to the outdoor environment, the ability to locate objects and people inside the buildings remains a considerable challenge as many of the indoor positioning applications lack the satisfactory technical solution.[1] According to Mautz (2012, p.8), in 2012 there was ”no system that possesses the excellent performance of outdoor GNSS in terms of global coverage, high accuracy, short latency, high availability, high integrity and low user-costs.“

Thus, indoor navigation with the use of mobile devices became an attractive subject in the past few years. To this day, no ground-breaking service has appeared in the field and current solutions still contend with the performance.[11] Once the performance of the indoor positioning is improved, it has the potential to create unparalleled opportunities for businesses.

In this section we will present an overview of the prevalent indoor positioning technologies applicable in the indoor environment for navigation purposes. Researchers classify indoor positioning technologies in many different ways.[3] The classification used in this work will be that of Gu et al. (2009) based on the main medium used to determine position, i.e. Infrared (IR), Optical, Visible Light (VL), Ultrasound, Audible Sound, Magnetic, Radio Frequency (RF), Dead Reckoning (DR) and Hybrid.

Starting with the IR positioning system, the principles, selected applications, benefits and limitations of these technologies will be described successively. The last subsection will be focused on a few indoor navigation applications for mobile phones available online as freeware or demo versions which have used as an initial illustration of indoor navigation applications for this work.

2.2.1 Infrared

When discussing the IR positioning systems, we can divide them into two categories, the active IR positioning system and the passive IR positioning system. The **Active IR**

[1] `https://naviterier.cz/`

positioning system uses IR signals and is made up of a network of IR sensors linked by wires and connected to a centralised location or server.[1] It is beneficial because of its good battery life, cheap sensors and lightweight badges carried by users. A widely recognized Active IR positioning system is the Active Badge used for positioning and tracking purposes.[12]

A **Passive IR** indoor positioning system without badges or tags based on passive thermal IR sensors known as thermopiles was proposed by Kemper & Linde in 2008 and implemented by Hauschildt & Kirchhof in 2010.[13–14] It consists of thermal IR sensors that measures the thermal radiation emitted by a human body within its range. However, the system is limited as there are other sources of heat in the indoor environment which can influence the signals received by the sensors. Another products based on passive IR include the StarGazer, Kinect or NorthStar.[1]

A major disadvantage of IR systems is that a direct line of sight (LoS) between sender and receiver is required.[15] However, if the emitters can be mounted at exposed places, this restriction does not severely limit their use, although some interference of IR waves with sunlight or fluorescent light may occur. Another disadvantage is that although the IR sensors are low-cost, researchers tend to concur that the IR positioning system is expensive.[1, 7] Typical coverage of a single IR sensor is about 1—5 m with accuracy of cm—m. Therefore, for the use in a large space, an IR system would need several receivers to improve accuracy and scaling the solution can also become costly over time.[1]

2.2.2 Optical

The principle of Optical positioning systems is the identification of a marker or image that is within view. The marker is a fixed object that has patterns recognizable by an imagery sensor such as mobile camera, e.g. barcode or QR code.[1]

Mautz[1] declares that “cameras are becoming a dominating technique for positioning which cover a wide field of applications at all levels of accuracy.” That is due the improvement and miniaturization of both the actuators (e.g. lasers) and detectors (e.g. CCD sensors) but also due the development in image processing, increase in data transmission rates and computational capabilities. When we think of camera use only, we can categorize the optical navigation systems into categories based on the manner how reference information is obtained. According to Mautz, the reference can be primarily obtained from 3D building models, images, deployed coded targets or projected targets.

The **3D building models** can be used for navigation in the systems capable of detecting objects in images. These objects can be matched to the building model data base populated with the position information of the objects.

In the **view–based** approach the current view of a mobile camera is compared with a sequence of images taken throughout the building beforehand. The computational load in this approach is particularly high, therefore the real–time capability of such systems is challenging.

In systems with demanding requirements for positioning, dedicated **coded markers**, such as QR codes, are used in order to improve accuracy and increase applicability. These systems are less prone to deterioration of performance under conditions with varying illumination, however the accuracy achieved depends on the range of the marker position to the device and the resolution of the device’s camera.

Additionally, in the environments where the physical deployment of targets is not desirable or feasible, reference points can be **projected**. The projected patterns can be of distinct colour, shape and brightness to facilitate the camera detection.

The main advantage of these systems is that they do not depend on infrastructure, thus they have the potential for large scale coverage without significant increase of costs, however they may require extra time and effort in configuration.

2.2.3 Visible Light

In VL positioning systems, the transmitter (a light source) and the receiver (a mobile terminal or image sensor) communicate over a LoS channel.[16, 1] The systems use Visible Light Communication (VLC) technology which has been known since the nineteenth century. The increase in popularity and use of this technology during the twentieth century led to the discovery of white LED for indoor applications. The LED lamps have many advantages such as long lifespan, energy efficiency, high tolerance to humidity, minimal heat generation and data modulation which make them strong tool for both the lightning and communication. The systems use mainly trilateration or triangulation for the determination of position. Industry production application include that of Philips, Qualcomm, Acuity and General Electric.[2]

A major advantage of the VL is that it does not suffer from multipath effect.[16] In general, the VL systems are considerably accurate, reliable, scalable, real-time and, apart from the initial cost of the system deployment in environments where the LED lighting infrastructure does not yet exist, they are low-cost. The limitation with VL positioning is that it is mostly useful in continuously lighted areas like shopping malls, airports and museums. Moreover, there are various different standards for VLC, yet none of them is the one cohesive, universal, acceptable and comprehensive standard covering all aspects of VLC, LED and their corresponding positioning systems.[17]

2.2.4 Ultrasound

As well as the IR, the Ultrasound positioning systems show considerably good performance at room level with typical coverage 2—10 m for one node.[1] Similarly to IR, there are Ultrasound systems using active devices or passive devices as beacons or tags, but also systems using echolocation without any tags at all. For positioning, the systems use combination of TOA, TDOA and trilateration techniques. The broadly known implementations of Ultrasound positioning systems are the Active Bat, Cricket system and Dolphin system.

In the **Active Bat** system, tags emit an ultrasonic pulse to a grid of ceiling-mounted receivers.[18] The deployment of such system is rather complex, primarily the precise installation of the sensor grid on the ceiling. However, once deployed the system can locate tags with the accuracy of 10cm.

The **Cricket** system combines the use of ultrasound with RF for position determination, thereby improving upon the performance of the Active Bat.[19] The computation is performed locally on the mobile device, which increases user privacy. The attempts to implement the Cricket system for indoor navigation have been made and while the system aids orientation within a building, determining position while navigating is not real-time.[20]

The **Dolphin**, Distributed Object Locating System for Physical-space Internetworking, is based on broadband signals and attempts to improve upon the scalability limitations of the Cricket system.[21] Moreover, the broadband technique can overcome other limitations, such as low performance in the presence of noise and multipath effect. The system consists of two types of nodes with RF, ultrasound transmission function and one-chip Central Processing Unit (CPU). The two types of nodes used in the system are normal node and reference node with known location. Dolphin requires only a few preconfigured reference nodes for locating all other nodes in the system over concurrently transmitted RF signals and ultrasound pulses.

In general, the deployment of Ultrasound positioning systems for navigation purposes on a large scale and space requires additional infrastructure to improve accuracy, performance and convenience, resulting in a high cost of the system.

2.2.5 Audible Sound

The Audible Sound positioning systems are less affected by the attenuation while propagating in the air than the Ultrasound systems, therefore less limited in range.[22, 1] In these systems, the mobile device, e.g. mobile phone, acts as a transmitter that sends sound to the acoustic receivers. Each receiver has a processing unit, a wireless network interface card and a microphone for detecting acoustic signals. The receiver estimates the position of the mobile device using the TOF or TOA technique and sends it to the CPU via the wireless network, along with its own position information. The CPU (server) then computes the mobile device position and sends the information back to the mobile device. Examples of such a system are Beep, BeepBeep and Guoguo.

In general, the Audible Sound positioning system has the potential to provide a high positioning accuracy at a low cost.[1] However, to maintain high accuracy high numbers of sensors are needed; more so when the acoustic signal is weak. The system performance is also negatively impacted by noise, interference, reflection, attenuation of signals and low transmission through obstacles.[2]

2.2.6 Magnetic

The Magnetic positioning is based on works on static or low frequency alternating magnetic fields, the earth's magnetic field and the compass.[2] The static magnetic field is generated with permanent magnets, or coils using Alternating Current (AC) or pulsed Direct Current (DC). In the low frequency alternating magnetic field, static charges produce electric fields, and current produce magnetic fields to form electromagnetic field.[1]

In brief, the process of localization is such that the receivers mounted on the user or tracked object receive magnetic signals from the transmitter and send the position information to a centralised location for position determination.[2] The majority of approaches and studies on these systems fit into four categories described by Mautz (2012): systems using antenna near field, systems using magnetic fields from currents, systems using permanent magnets and systems using magnetic fingerprinting.[2]

Magnetic tracking is commonly used in VR, motion capture applications and mines or tunnels. Approaches based on magnetic localization techniques that have reached commercial level of market maturity include Ascension, InfraSurvey and Polhemus.[1]

The advantage of magnetic localization is that it does not require the maintenance of LoS. Drawbacks of magnetic positioning are limited coverage and the influence of steel and metal structures within the building when using the fingerprinting method. Similarly to the infrared and sound systems, on a large-scale implementation, the accuracy and performance of the magnetic positioning systems is degraded.

2.2.7 Radio Frequency

The RF positioning systems are based on RF signals. The RF signals are able to penetrate walls and obstacles which results in a wider coverage area. Moreover, these systems benefit from the possibility of reusing existing RF infrastructures, e.g. WLAN, leading to a relative cost reduction. However, their accuracy is significantly degraded by propagation effects such as absorption, reflection, scattering, refraction, interference, multipath and fading effects.[7, 1] These factors lead to the fact that the RF–based systems often cannot distinguish between different rooms in office–like buildings, however, they can be suitable for certain industrial applications. The positioning techniques used in these systems include triangulation, trilateration, fingerprinting and proximity.

The RF positioning systems can be further categorised into Radio-Frequency Identification (RFID), Near Field Communication (NFC), Bluetooth, Wireless Local Area Network (WLAN), Ultra-wideband (UWB), Wireless Sensor Network (WSN) and ZigBee.

2.2.8 Dead Reckoning

In DR, current position is being estimated by using a previously known position, the time it was obtained and known or approximate direction and speed.[2, 1, 3] Similarly, the prediction of a future position can be made. The required motion and orientation data are obtained through inertial sensors such as accelerometer, gyroscope, compass, pedometer, magnetometer and clock, while the initial position may be obtained from external sources, e.g. GPS. The major advantage of this technology is that it can be used in all environments, however, the use of DR alone is prone to cumulative errors over time and the accuracy decreases with sensor size.

As the inertial sensors are now a common feature in modern smartphones and mobile devices, DR for pedestrians can be used in indoor navigation. Pedestrian Dead Reckoning (PDR) is simple, low-cost, accurate and real-time. It can be smoothly integrated with other positioning systems for navigation to reduce the progressive accumulation of errors.

2.2.9 Hybrid

The hybrid positioning system merges two or more of the positioning technologies to improve its accuracy, robustness and performance. In general, various systems can be used in a hybrid composition. For example, a combination of VL and PDR, RFID and DR, RFID and WLAN or various composites of Ultrasound, such as Ultrasound and RF, Ultrasound and Optical or Ultrasound and WLAN.[2]

According to Sakpere et al. (2017), the hybrid systems show considerably higher accuracy, robustness and performance than the standalone technologies. However, they are also generally more complex and costly.

2.2.10 Mobile applications for indoor navigation

In this sub-section, a selection of existing mobile applications for indoor navigation will be presented and their main features will be described.

- IndoorAtlas

  IndoorAtlas[1] SDK is an indoor positioning platform for mobile applications. It uses a hybrid positioning technology that combines PDR, Bluetooth and WLAN. MapCreator 2, tool released by the company in 2016, provides a way to map the chosen indoor location/venue to enable IndoorAtlas' indoor positioning service.[23] This tool enables user to map and record sensor data throughout the chosen venue.

[1] https://www.indooratlas.com/positioning-technology/

Before mapping begins, user must sign-up[1] to create the indoor location and create the floor plan.

- Google Indoor Maps

  Google Indoor Maps[2] service is an inbuilt indoor navigation feature within Google Maps which, however, often does not support positioning service. Only certain types of buildings can be found mapped on the Google Maps, such as airports, bus bays, shopping malls or stadiums. The new entries are restricted for users other than the property owners and their authorized representatives. Only these authorized users can upload floor plans and building layouts that get approved only if the building is from any of the allowed categories. Despite of these multiple restrictions, according to Google's website, over 10,000 locations are already available around the world. Naturally, the majority of them is located in the USA.
- Indoorway

  Indoorway[3] is a UWB-based Real-Time Location System (RTLS) for manufacturing companies. It aims to help the companies to understand the movement and actual utilization of monitored mobile assets. It also provides analytical reports and Key Performance Indicators (KPIs).
- Path Guide

  Path Guide[4] is a map-free, infrastructure-free, plug-and-play indoor navigation service by Microsoft.[24] It focuses on navigation only without positioning the user first. Using this application, user records sensory data with his/her device during an indoor walk. The geomagnetic features extracted from the sensory data are combined with the user's walking patterns (e.g., steps, turns, going upstairs/downstairs) to build a reference trace. Reference trace is pushed to the cloud and can be searched by others for navigation. Once downloaded a reference trace, Path Guide compares and synchronizes current sensor readings with the reference trace, and guides the user, in real time, from the same starting location to the final destination.

2.3 Crowdsourcing

Crowdsourcing is a type of outsourcing where the outsourcing target is "the crowd"; that may be one of the many different definitions published for crowdsourcing, since 2006, when the term was coined by Jeff Howe.[25] However, despite their multiplicity, the core of all of them has consisted of two constants - the broadcasting of problems to the public, and an open call for contributions to help solve the problem. In some cases, the contributors of the solution are compensated monetarily with prizes or with recognition. In other cases, the only rewards may be kudos or intellectual satisfaction. In this work, spatial data will be collected using geo-crowdsourcing. Thanks to modern technology it is very easy for anybody to collect and share data.

While the professional level of the participants is not usually guaranteed, there is a high probability that it should be above average because students, young graduates and even scientists are more likely to join these processes than average person. However, still, non-expert contributors cannot produce the same quality of data as legitimate professionals.

[1] https://app.indooratlas.com
[2] https://www.google.com/maps/about/partners/indoormaps/
[3] https://www.indoorway.com/
[4] https://mspg.azurewebsites.net/

When it comes to the quality of the solutions it can be separated according to the type of the tasks. For simple tasks there is a need mostly for quantity which crowdsourcing can satisfy. For complex tasks, high solution quality of the crowdsourcing process has been proven by numerous security code cracking contests. Then there are creative tasks where quality correlates with originality of the solution which can be achieved by large amount of individual ideas.

In general, the right problem statement formulation is crucial for high quality solutions, however, it is even more important in the complex crowdsourcing tasks. As the amount of the participants may be large and dispersed, any form of a feedback loop usage to determine ”real needs” is problematic.

Another factor which is crucial is motivation. The right kind of motivation must be found to attract larger amount of the participants. Both extrinsic and intrinsic motivation could be used. For the creative tasks intrinsic motivation could be evoked by self-realization, for the complex tasks it could be evoked by the joy of solving complex problem. As for the simple tasks, intrinsic motivation is harder to raise so the extrinsic motivation such as payment is more important here. To sum up, every contributor has a different motivation for participating in crowdsourcing and this motivation may be hard to evoke. Some of contributors might even intentionally abuse the system with wrong data, which may be a concern.

In conclusion there are both advantages and disadvantages in usage of the crowdsourcing. The main advantage is rather low cost and relatively high quality of the solutions. The challenge of this approach is to find a way to attract enough participants and to define the problem statement well and precisely.

Chapter 3
Design

Among the technologies usable for indoor environments, described in 2.2, we have decided to focus on image-based navigation systems in this work as they are well suited for indoor applications. Indoor environments are often characterized by unique structures which facilitate image-based self-positioning.[9] While remote positioning will typically provide improved performance, self-positioning requires less infrastructure and offers increased flexibility of the application.

We have conducted the design process according to the user-centered design methodology in order to create usable and accessible service.

3.1 User-centered design methodology

User-centred design is an iterative design process in which designers focus on the users and their needs in each phase of the design process.[26] UCD calls for involving users throughout the design process via a variety of research and design techniques to create highly usable and accessible products for them.

Generally, each iteration of the UCD approach involves four distinct phases. First, designers attempt to **understand the context** in which users may use the system. Subsequently, we identify and specify the **users' requirements**. A **design** phase follows, wherein the design team develops solutions. The team then proceeds to an **evaluation** phase and assesses the outcomes of the evaluation against the users' context and requirements to check how well the design is performing—namely, how close it is to a level that matches the users' specific context and satisfies all their relevant needs. From here, the team makes further iterations of these four phases, continuing until the evaluation results are satisfactory.

3.2 System requirements

- **R1** – Navigating from one place to another inside an unknown building **(high priority)**
  The system will allow the user to display and follow a created route.
- **R2** – Creating a route **(high priority)**
  The system will allow the user to describe and save a route inside a building with a sequence of photos and directions. The system will allow the user to input the directions in multiple ways.
- **R3** – Collect ladmarks **(high priority)**
  The system will allow the user to collect landmarks during the route creation and navigation.
- **R4** – Usability **(high priority)**
  The system will be implemented according to UCD methodology so that it is easy to use.

3.3 Data structure

The concept of the designed data structure follows the human cognitive navigation process. Subconsciously, person creates a unique cognitive map from the the starting point to the end point of the route, which is divided into sections between **steps**. This route is characterized by start point, end point and **landmarks**. A landmark is a unique recognizable reference point used for user orientation and location. In our system, if there is no such object available that may use as a unique reference, a combination of objects may suit the case.

3.3.1 Entity-relationship model

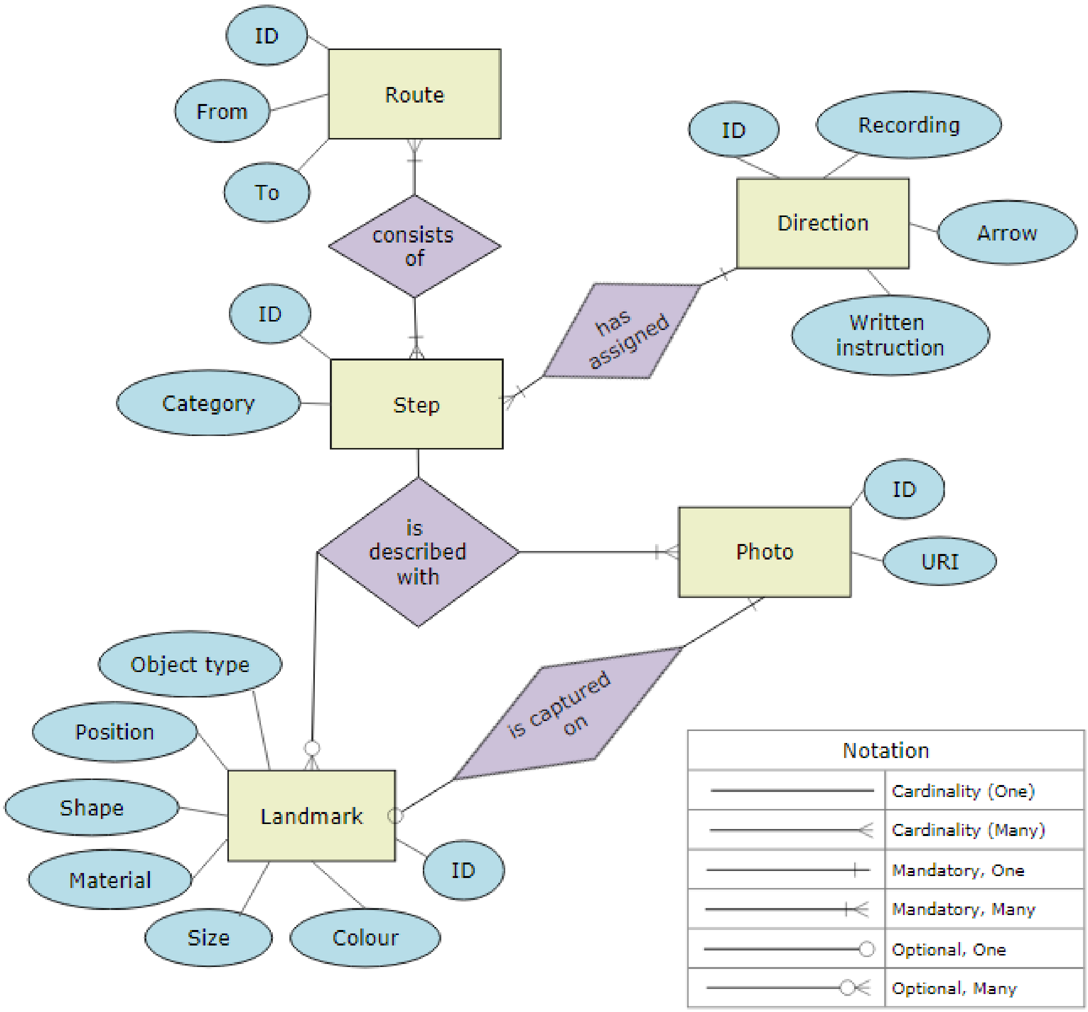

Figure 3.1. Entity-relationship diagram

3.3.2 Landmarks

For the landmarks collection, the following scheme has been created. For each identified object, its characteristics such as size, colour and position are registered. In the future work the data structure may vary considering the number of categorized objects and attributes gathered, e.g. sound, texture or sense attribute, so that the application meets the needs of impaired people.

- **objects**: Door, Stairs, Trash bin, Window, Bench, Sign, Board, Fire extinguisher, Lamp, Table, Clock, Carpet, Notice–board, Vending machine, Hydrant, Plant, Painting, Shelf, Elevator, Handrail
- **positions**: On the wall, On the floor, By the door, Near the wall, On the ceiling
- **materials** : Wood, Glass, Plastic, Metal, Paper, Textile
- **shapes** : Rectangle, Square, Circle, Oval, Triangle

3.4 User interface design

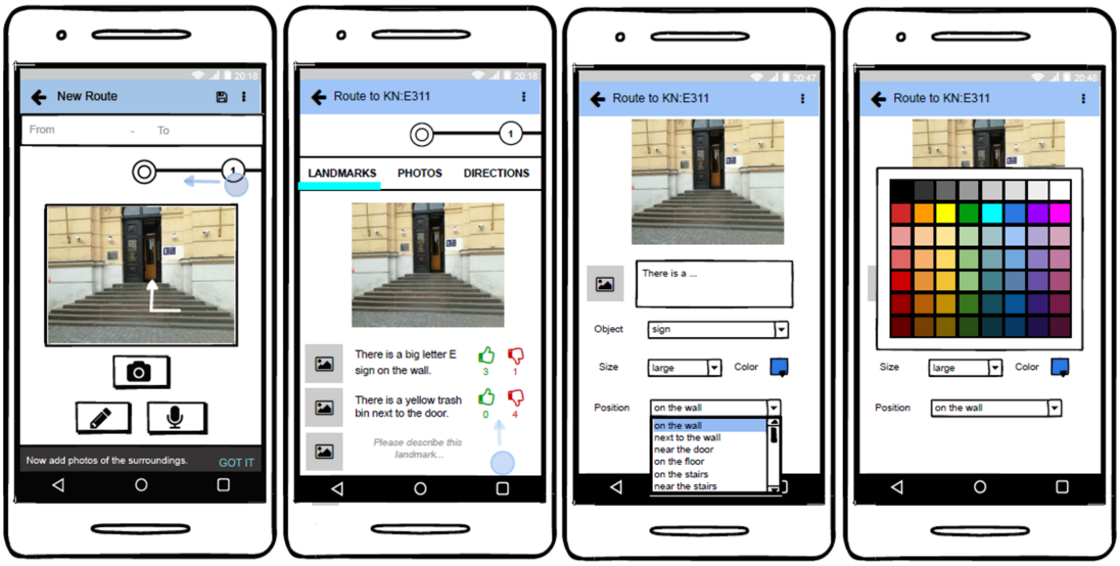

Figure 3.2. Low-fidelity prototype design

3.5 Testing

In this section we will describe the process of design evaluation and its results. To test and evaluate the low—fidelity prototype a qualitative test was chosen that will help to detect thoughts, feelings and behaviour of the target group. To gain a detailed insight into the user experience with the prototype, the think-aloud method was used, i.e. all the participants were asked to think out loud about what he/she was doing and what was possibly causing troubles to him/her.

3.5.1 Goals of evaluation

The main goal of the evaluation was to test prototype functionality on the main use-cases of the application, i.e., navigating in an unfamiliar building, collecting information about landmarks to positively identify a location, creating new routes, and identify potential problems. The second goal was to find out people's views and opinions on the tested prototype through the think-aloud method and the after the test interviews.

3.5.2 Participants

The low-fidelity prototype was tested with 10 different participants in 2 iterations. Participants were young adults both females and males, who were experienced in the use of smartphones and mobile applications.

	P1	P2	P3	P4	P5
age	23	24	25	19	27
gender	F	F	F	M	M

Table 3.1. Participant identification: 1st iteration

	P1	P2	P3	P4	P5
age	28	20	20	24	31
gender	M	M	F	M	M

Table 3.2. Participant identification: 2nd iteration

3.5.3 Procedure

With each participant one 20-minute session was held. The purpose of the application was explained briefly and a short insight into the test scenario was given. Then each participant was given 2 tasks which he/she had to perform. Once the tasks were done, a short interview with each participant was done on their experience.

3.5.4 Test scenario

1. Follow the described route in the application from the CTU building courtyard at Karlovo náměstí, Prague (KN yard) to the KN: E-311 room. (Pages 16 – 59 of the prototype)
2. Try to create a route in the from the CTU building courtyard on Karlovo náměstí to the KN: E-109 room. (Pages 4-15 of the prototype)

3.5.5 After test questions

1. Did you get to your destination/ created a path without difficulty? Describe the issues in the application you have encountered along the way.
2. Did you understand all the steps and elements during the navigation / route creation?
3. Do you think the application is user friendly? Describe the elements that you did not like or understand.

3.5.6 Test results

- The navigation axis feature has been identified by 4 out of 8 participants as confusing, in 2 cases it even prevented them from successful transition to the next step.
- Categorization of routes was requested by 2 participants.
- Simplification of the landmark object, colour and size specification was requested by 3 participants, from which 2 requested an autocomplete search components instead of combo boxes.

Other findings were collected individually, such as

- The photos should be bigger on the screen – as big as possible.
- I am not sure if save button saves route as draft or as finished.
- I would add a button finish route somewhere down.
- It's not clear what the thumbs (at the landmarks) are for.
- It would be good to know how many more steps I have left.

- Arrows would be better to draw with a gesture.
- I'd like to see the directions right on the first screen.
- Make one 360 degrees photo instead of individual photos.
- It would be nice if those photos of the surroundings were put into some layout according to where I should be looking.
- Keyboard icon instead of a pencil icon for writing down the directions.
- At the end, let me know that I've come to the end.

3.5.7 Following actions

After the feedback from the 1st iteration was collected, a new version of the prototype was created, focusing on the issues identified by the participants. The changes of screens from both the navigation and route creation part of the prototype are shown in **Figure** 3.3.The 2nd iteration feedback was implemented in the high-fidelity prototype described in 4.

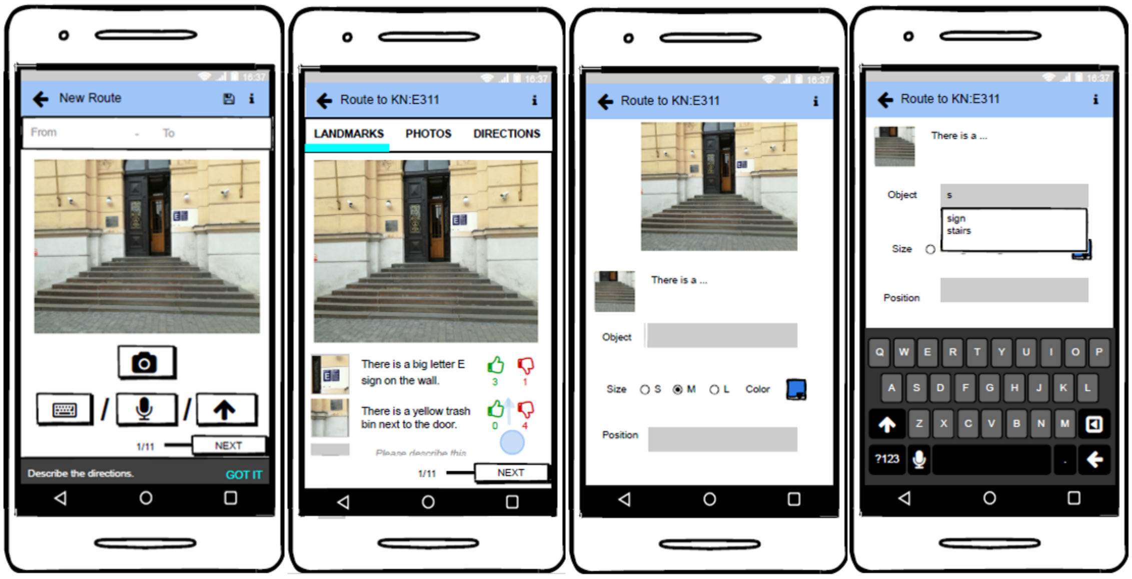

Figure 3.3. New low–fidelity prototype design

Chapter 4
Implementation

In this chapter, the process of implementation will be described, from the choice of selected development technologies and description of the implemented solution design, to testing and evaluation.

4.1 Implementation tools and technologies

4.1.1 Development tools and technologies

A **native mobile app** has been chosen for the implementation due to the high load of mobile sensor requests in our design. **Android OS** has been chosen as the platform for its highest share in Europe market, accessible documentation, developer community and personal previous experience.

At the time of this work, the latest Android 10 (API version 29) is available for devices with Android OS. For this work, the target API 28 (Android 9) was chosen with the minimum API version 23 (Android 6), which should ensure safe run for the application on a vast majority of devices. [1]

The source code has been written in **Java 8** and **Gradle** has been used as the build tool.

Apart from standard Android and AndroidX libraries, Glide has been used for fast and efficient image loading. [2]

4.1.2 Database

For the initial phase of the application prototype, a small local database has been chosen to enable rather fast development necessary for the functional and usability testing process. **ObjectBox**, a fast database for mobile devices, has been chosen for its features, such as:

- NoSQL
- ACID-compliant
- on-device
- object-oriented
- key-value
- easy to use

For future development, connection and use of a server or cloud database will be necessary as the data sharing and user profiles would create the essential aspects of this service. **Firebase** may be one of the platforms to start with.

[1] https://developer.android.com/about/dashboards

[2] https://bumptech.github.io/glide/

4.2 User interface design

The design of the high-fidelity prototype is made simple with user comfort in mind.[27] A palette of contrasting colors has been used to increase recognition and readability. The colours used in the prototype are pink-red, dark-cyan, black and white. Cyan shade with white icons is used for upper bar navigation, e.g. Figure [UI-navigation], while black with white icons is used for the bottom toolbar in route creation part, see Figure 4.3, and contextual action buttons. Pink shade is used for floating action buttons meant for addition or deletion of entries.

The navigation use case of the app is shown in Figure 4.1. All the information collected about the route are displayed, enabling user to switch back and forth between the steps, monitor the progress in route and swipe or tap between tabs with landmarks, surroundings and directions.

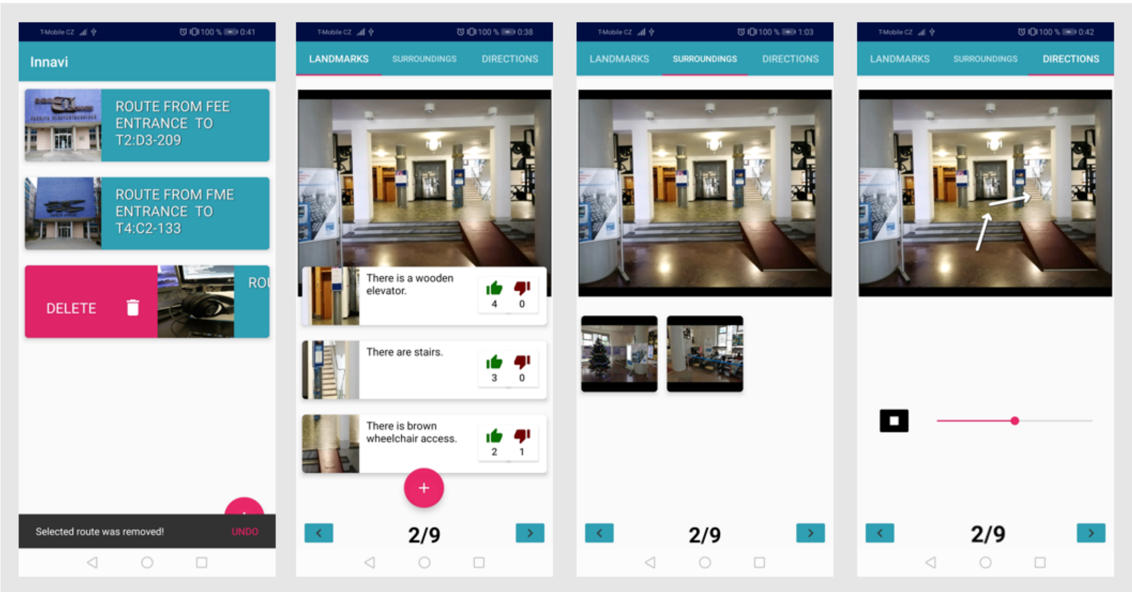

Figure 4.1. UI - Navigation

The data collection layer is pictured on Figure 4.2. First, user chooses photo containing the landmark he/she wants to describe. It may not yet be taken, so there are options to take another photo or choose one from gallery. When the photo is chosen, user is asked to specify the part of the photo containing the landmark with a finger gesture. He/she can do so in an unspecified form or shape, however, some form of circle appeared to be the most common during tests. When the selection is confirmed, a rectangle is cropped from the picture according to the area selected and displayed to ease the data collection process. As for now, the data collected are object, position, shape, material, colour and size.

To help the data collection process, autocomplete text input are used, populated beforehand with relevant values for each property. In the description, a simple english sentence is generated using a template while user populates the fields. In the end, user can edit the generated description to correct mistakes. In this moment, the only required field is object, as the other properties can be tricky to define.

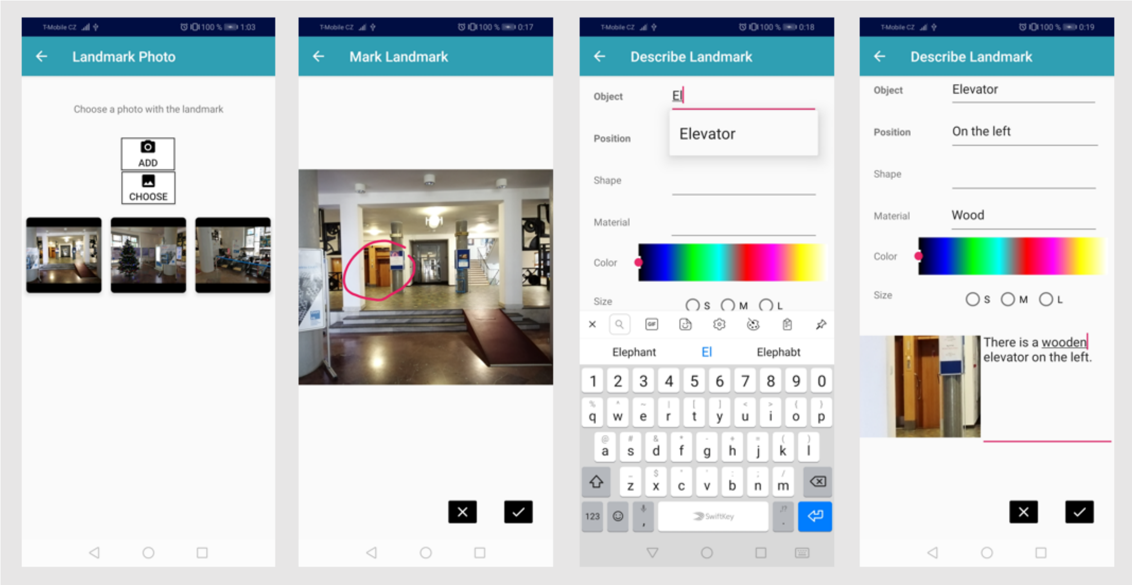

Figure 4.2. UI – Data collection

Selected parts of the route creation process are displayed on Figure 4.3. Starting with the first step, user can either take a photo characterizing the step in the direction he/she is heading or choose it from gallery. The bottom toolbar includes actions to describe directions as well as to add photos of the surrounding area and creating a landmark. During the whole process, user can specify the starting and finishing point of the route which will then use as the identification of the route for search. The directions can be given in three different ways; user can select the one he/she finds the most comfortable. The easiest and fastest method to show directions has proved to be the arrow creation. Moreover, from the tests conducted with the regular users, it has shown to be the most effective even during navigation. The voice direction approach enables user to record, play back and re-record voice directions. In future, this approach may be beneficial for visually impaired users. Written directions are the easiest to work with, however, they are slow to collect and very little engaging.

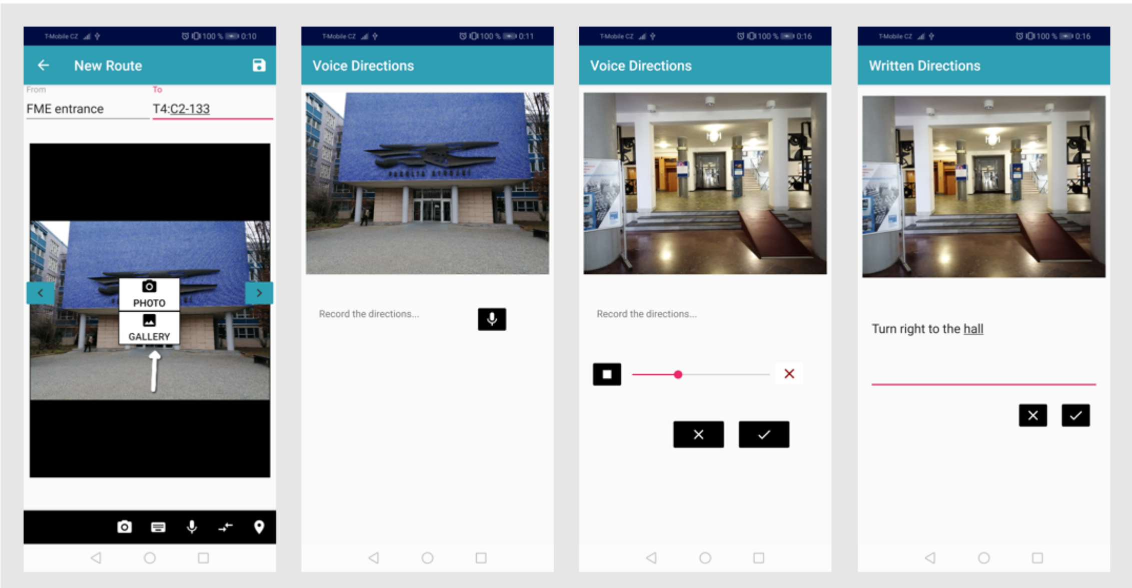

Figure 4.3. UI – Route creation

4.3 Testing

The qualitative test was also used to test and evaluate the high-fidelity prototype.

4.3.1 Goals of evaluation

The main goal of the evaluation was to test the prototype usability on the navigating in an unfamiliar building and collecting information about landmarks to help with identifying or verifying a location. The second goal was to explore whether the regular users can identify, describe and rate relevant data useful for the impaired users. The third goal was to find out people's views and opinions on the tested prototype through the think-aloud method and the after the test interviews.

4.3.2 Participants

The high-fidelity prototype was tested with 7 participants, both females and males, who were experienced in the use of smartphones and mobile applications.

	P1	P2	P3	P4	P5	P6	P7
age	20	22	24	19	25	21	23
gender	M	F	F	M	M	M	M

Table 4.1. Participant identification

4.3.3 Procedure

With each participant one session was held which lasts from 30 to 45 minutes. First the participant was asked two filter questions about their age and gender, then a couple of informative questions about indoor navigation and their experience with it. After that the participants were familiarized with the high-fidelity prototype application, its control elements and the main features. Then they were asked to follow 2 prepared routes according to the information provided by the application. Finally, when both routes were passed through, a series of questions about the testing process and the application was asked.

4.3.4 Test scenario

Route 1

Follow through the 1st route described in the application.

Recommended process:

1. Display the landmarks to identify your position.
2. If you need to verify your position, display the surroundings photos.
   - Case 1: You have not verified your position. → Go back to the previous step and check the directions.
   - Case 2: You have verified your position. → Rate the landmarks given. Is it present, helpful and well described? If yes, rate thumb up. If not, rate thumb down. If you are not sure, do not rate.
   - Case 3: You have verified your position and you have been asked to contribute. → Add a landmark. Focus on the significant (defining) attributes.
3. Display the directions leading to the next step.
4. Follow the directions.

5. Repeat steps 1—4 till you get to the destination.

Route 2
Follow the same routine as with Route 1. This time focus on the landmarks that would be accessible and helpful for visually challenged people.

4.3.5 Pre-Test Questionnaire

1. Have you ever asked for extra navigation in large buildings/complexes, e.g. hospital, school, shopping centre, town hall? If yes, how often and where?
2. Do you have any experience with mobile applications for indoor navigation, e.g. Path Guide, Google Indoor Maps or IndoorAtlas? If yes, which ones?

participant	asked	frequency	place
P1	Yes	Once a month	Hospitals, institutions, school, shopping centres
P2	Yes	Once a month	School, hospital, shopping centres
P3	Yes	Once in 2 months	Hospital, school
P4	Yes	Once 2 weeks	Hospitals, institutions, school, workplace
P5	Yes	Once 2 weeks	Hospitals, institutions
P6	Yes	Once a month	Hospitals, institutions, school, shopping centres
P7	Yes	Once in 6 months	School, workplace

Table 4.2. Question 1 responses

	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
experience	None	None	None	None	None	None	Google Indoor Maps

Table 4.3. Question 2 responses

4.3.6 Post-Test Questionnaire

1. How did you find the process of testing?
2. What do you like/dislike about the application?
3. What was the most difficult part/thing for you in the process?
4. How would you improve the application / what features would you like to see in the application?
5. Would you use a map-free application like this for the purpose of navigating?

	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
feeling	OK	Fine	Alright	OK	Good	OK	OK

Table 4.4. Question 1 responses

	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
would use	Yes	Yes	Probably not	Yes	Maybe	Yes, with more routes	Yes

Table 4.8. Question 5 responses

P1	I like the idea, it might be helpful
P2	I would prefer a GPS-like navigation
P3	I didn't like it too much
P4	It was quite easy to use
P5	I liked the colours
P6	I don't know
P7	It was intuitive

Table 4.5. Question 2 responses

P1	Probably describing the landmark right
P2	Describing the landmarks for the visually impaired
P3	Get use to the concept
P4	It was quite easy to use
P5	Describing the landmarks for the visually impaired
P6	It was a bit confusing switching back and forth between the directions and the landmarks
P7	Describing the landmarks for the visually impaired

Table 4.6. Question 3 responses

P1	I would like to be able to add sound describing the landmark
P2	I would like to know the approx. number of footsteps to the next step, also better visibility of the progress in steps
P3	I would like to ne able to switch to a backwards mode, also reduce the colour picker
P4	I would make the landmark description process a bit more user friendly and intuitive
P5	I would change the arrow colour/design, so it is more evident, also reduce the number of landmarks shown to the most relevant ones only
P6	I would put all the information about the step on one screen so I could just swipe between the steps
P7	I don't know

Table 4.7. Question 4 responses

4.3.7 Test results

All the participants reached the destination according to the route without any difficulty. There had been just one incident where the participant took a wrong turn because he did not check the directions first and made a wrong assumption about the direction. When only following the navigation, the time taken to reach the destination was same as if familiar with the route. With landmarks creation the time taken was significantly higher.

The data collection useful for the impaired users was a struggle for majority of the users. A lot of irrelevant landmarks were collected, and the participants were able to collect desired data only with guidance. The concept of collecting, displaying and rating the landmarks useful for regular users and impaired users both at the same time and place in the application proved to be inapplicable as the regular users did not find helpful the landmarks aimed for the impaired users.

4.3.8 Evaluation

In this testing phase we focused on the usability of the two main use cases in our design, navigation and data collection. From the navigation part, the results were quite satisfying, having vast majority of the participants express contentment and some even genuine interest in such service. There was one participant, who was rather disappointed by the lack of GPS-like experience. It can be assumed that there will be a large group of potential users with the same feeling.

The data collection part was way more demanding. Considering unspecified landmarks, some participants have shown significantly better skills in discovering and defining useful landmarks than others. However, in the proposed design, useless and poorly described landmarks would get discarded or corrected in time thanks to the rating system, so it would not make much of a problem.

A big problem proved to be the data collection aimed for visually impaired people. Participants struggled with identification of useful landmarks and, apart from one participant, they all needed guidance to distinguish relevant data. Prior to that, a lot of pointless landmarks have been collected. Moreover, the proposed rating system showed to be inapplicable in the mixed environment of data collection both for regular and visually impaired people. Participants were asked to rate the landmarks according to whether or not they found them present, helpful and well described. Majority of the participants found the data for visually impaired users, which according to 2.1.4 we consider relevant, useless. They were doing so in the first part of the testing, when they did not yet know they should also focus on the visually impaired users, therefore they rated them negatively. This would very likely be the case in the real–world scenario, therefore, the design of the data collection needs to change.

Many ideas for improvement have come out of the testing. Some minor improvements have been already worked in the prototype which is attached to this work. Other challenges are up to future development, whether it is to incorporate pedometer to count footsteps in between the steps, to introduce user profile system with expert roles in it, possibility to switch to a backwards mode or to redesign the navigation so that all the information about one step is on one screen only.

Chapter 5
Conclusion and future work

The main objectives of this work was to design and implement a prototype application for mobile devices facilitating indoor navigation based on the analysis on the problematics of indoor navigation. The designed solution aimed to to be gradually evaluated and enhanced by its users by collecting, describing and evaluating significant landmarks along the route.

We analyzed the techniques and technologies applicable for navigation in indoor environment, we discussed their advantages and disadvantages and outlined some existing solutions. We went briefly through the challenges of people with limitations in mobility in respect to navigation and explained the term crowdsourcing.

Based on the limitations of most technologies we selected an approach which does not require extensive infrastructure and costly devices. In our design users are not given floor maps or building models, they are navigated by a sequence of steps represented by photos and landmarks and they are encouraged to complete missing information through recognized context and logical constrains of their surroundings.

The designed prototypes were developed and tested according to User Centered Design methodology in order to create usable and accessible service. The design proved to be viable with overall positive feedback.

Future work and development should focus on the data sharing aspect and creation of user profiles. It may be appealing for users to create and share routes with friends via social networks such as Facebook or with Google. With higher amount of users and created routes, a categorization of routes according to city, city part and building should be implemented, possibly as a fusion with GPS service to locate the bulding and mark it on map, also a route search. Another improvements could be to incorporate pedometer to count footsteps in between the steps, possibility to switch to a backwards mode or implementing image recognition for automatic landmark categorization or creation.

The area we also need to look deeper into is motivation to contribute.

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Appendix A
Acronyms

AoA	Angle of Arrival
AR	Augmented Reality
GIS	Geographic Information System
GLONASS	Globalnaja Nawigazionnaja Sputnikowaja Sistema, a GNSS system
GNSS	Global Navigation Satellite System, any of the existing or proposed satellite—based positioning systems, such as GPS, GLONAS, Galileo and Beidou
GPS	Global Positioning System, a GNSS system
IR	Infrared
LoS	Line of Sight
NFC	Near Field Communication
RFID	Radio Frequency IDentification
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
TDoA	Time Difference of Arrival
ToA	Time of Arrival
ToF	Time of Flight
UCD	User Centered Design
UWB	Ultra-wideband
WLAN	Wireless Local Area Network
WSN	Wireless Sensor Network