Czech Technical University in Prague
Faculty of Electrical Engineering
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Orientation terminal for visually impaired older adults

Master thesis

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Master programme: Open Informatics
Branch of study: Human-Computer Interaction
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Studijní obor: **Interakce člověka s počítačem**

II. ÚDAJE K DIPLOMOVÉ PRÁCI

Název diplomové práce:

Orientační terminál pro seniory se zrakovou vadou

Název diplomové práce anglicky:

Orientation terminal for visually impaired older adults

Pokyny pro vypracování:

Senioři s vážnou zrakovou vadou často žijí v pobytových zařízeních, která jim poskytují specializovanou péči. Tato uživatelská skupina má specifické potřeby, schopnosti a preference, zejména z hlediska orientace v prostoru a interakce s technologiemi. Proveďte analýzu dosavadních výsledků výzkumu zaměřeného na téma orientace vážně zrakově postižených v prostoru se zřetelem na osoby vyššího věku. Navažte na dosavadní výsledky výzkumu provedeného na DCGI [1-3]. Pomocí metodologie User Centered Design [4] navrhněte a realizujte sadu prototypů terminálu orientačního systému pro interiéry budov. Tento terminál bude vhodnou formou poskytovat informace důležité zejména pro orientaci v prostoru a v čase. Přizpůsobte interakční metodu schopnostem a preferencím cílové uživatelské skupiny. Realizované prototypy otestujte se zástupci cílové uživatelské skupiny.

Seznam doporučené literatury:

[1] M. Macik, I. Maly, E. Lorencova, T. Flek, and Z. Mikovec. Smartphoneless context-aware indoor navigation. In Cognitive Infocommunications (CogInfoCom), 2016 7th IEEE International Conference on, pages 000163–000168. IEEE, 2016.
[2] M. Macik, I. Maly, J. Balata, and Z. Mikovec. How can ict help the visually impaired older adults in residential care institutions: The everyday needs survey. In Cognitive Infocommunications (CogInfoCom), 2017 8th IEEE International Conference on, pages 000157–000164. IEEE, 2017.
[3] M. Macik, V. Gintner, D. Palivcova, and I. Maly, “Tactile symbols for visually impaired older adults,” in Cognitive Infocommunications (CogInfoCom), 2018 9th IEEE International Conference. IEEE, 2018.
[4] DIS, ISO. (2009). 9241-210: 2010. Ergonomics of human system interaction-Part 210: Human-centred design for interactive systems.

Jméno a pracoviště vedoucí(ho) diplomové práce:

Ing. Miroslav Macík, Ph.D., Katedra počítačové grafiky a interakce

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

Datum zadání diplomové práce: **14.02.2019** Termín odevzdání diplomové práce: **24.05.2019**

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III. PŘEVZETÍ ZADÁNÍ

Diplomant bere na vědomí, že je povinen vypracovat diplomovou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací.
Seznam použité literatury, jiných pramenů a jmen konzultantů je třeba uvést v diplomové práci.

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Datum převzetí zadání

Podpis studenta

Declaration

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

In Prague, May 2019

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Bc. Vojtěch Gintner

Acknowledgements

I would like to thank my supervisor, Ing. Miroslav Macík, Ph.D., for his guidance and my consultant Mgr. Lukáš Treml, DiS. for valuable help and insights. I also want to thank everyone involved in the evaluation process in Home Palata. Finally, I would like to thank my close ones and friends for their support.

Abstract

Diskutuji proces návrhu hmatových symbolů pro seniory se zrakovým postižením. Při návrhu využívám metodologie User-Centered Design pomocí které vytvořím tři low-fidelity prototypy a jeden high-fidelity prototyp. Všechny iterace návrhu jsou v součtu vyhodnoceny 26 krát během čtyř různých experimentů s 23 unikátními účastníky testu z cílové skupiny zrakově postižených seniorů. 18 žen a 6 mužů se účastnilo experimentů, přičemž jejich průměrný věk byl 84.9 let ($MED = 86$, $MIN = 52$, $MAX = 98$, $\sigma = 9,7$). Výstupem této práce je návrh a prototyp indoorového terminálu orientačního systému, který podává hlasové pokyny a informace zlepšující prostorovou orientaci, časové a situační povědomí stejnětak jako nabízí navigaci zpět na bezpečné místo a možnost zavolání pomoci. Tato práce ukazuje způsob jak navrhnout hmatové symboly jejichž význam je srozumitelný zrakově postiženým seniorům. Hmatové symboly slouží k interakci mezi uživatelem a terminálem.

Klíčová slova: zrakově postižení senioři, hmatové symboly, hmatová rozhraní, prostorová orientace, orientační systém, orientační terminál, User-Centered Design

This thesis discusses the design process of tactile symbols for visually impaired older adults. During the design process, I employ User-Centered Design methodology and create three iterations of the low-fidelity prototype and one iteration of the high-fidelity prototype. All iterations were evaluated in total 26 times in four different experiments with 23 unique participants from the target user group. 18 women and five men participated in experiments, mean age 84.9 ($MED = 86$, $MIN = 52$, $MAX = 98$, $SD = 9,7$). The result of this thesis is a design and prototype of indoor orientation system terminal which provides voice information enhancing spatial orientation, time and situational awareness as well as provides navigation back to safety and call for help option. This thesis shows a way how to design tactile symbols whose meaning is understandable by visually impaired older adults. The tactile symbols are the main interaction between the user and the orientation terminal.

Keywords: visually impaired older adults, tactile symbols, tactile interface, spatial orientation, orientation system, orientation terminal, User-Centered Design

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Chapter 1

Introduction

Visually impaired people challenged with severe impairment or even blindness (according to WHO classification [1]) appear mostly among older adults. According to [2], 86.3 % of blind people are older than 50 years and 52.8 % older than 70 years. Unfortunately, the research attention on visually impaired older adults is limited.

In our previous research, we were aiming at the problems of the orientation of visually impaired older adults. The research produced a concept of complex indoor orientation system (more in section 2.1). We also focused on the design of tactile symbols used for buttons of an interactive indoor orientation system, helping visually impaired older adults with orientation and navigation inside a large complex building (more in section 2.2). The previous research [3] shows that visually impaired older adults experience severe problems with understanding the meaning of abstract tactile symbols. This thesis shows a way how to design tactile symbols whose meaning is understandable by visually impaired older adults.

Result of this thesis is a design of an OT (part of the mentioned orientation system) integrated into the whole complex of indoor orientation system. This OT should help with time and indoor spatial orientation of visually impaired people. The main part of the OT is tactile symbols that provide understandable interaction for visually impaired older adults.

1.1 Motivation

There are currently around 102 000 people with visual impairment living in the Czech Republic [4] (data from the year 2012). With higher age rapidly raises the chance of developing some visual impairment [5]. Therefore 68 000 of these people are at least 60 years old (Table 1.1).

More than 18 % of visual impairments are caused by elderly polymorbidity, and up

Age category	Number of people
0-14	6 715
15-29	4 501
30-44	7 892
45-59	14 851
60-74	**19 796**
75 +	**48 440**
Total	**102 195**

Table 1.1: Age categories of visually impaired [4]

Cause of visual impairment	Number of people
Birth	17 354
Injury	6 984
Disease	**50 694**
Elderly polymorbidity	**18 954**
Other	2 245
Unknown	5 964
Total	102 195

Table 1.2: Cause of visual impairment [4]

to 50 % are caused by a disease (Table 1.2). According to [6], depicted in Table 1.3, at least a third of the diseases result in severe visual impairment. These eye diseases develop into category 3-5 [7] of visual impairment. Those are severe impairments, including severe purblindness (category 3), practical blindness (category 4) and total blindness (category 5). People with such severe impairments lose their primary cognition input and remain dependent on hearing and touch. According to the World Health Organization's Report on Disability [8], the risk of disability occurrence rises with higher age. This can result in multiple disabilities for older adults. Thus dependence on hearing and touch is not ideal as those can be affected by lower acuity too.

People that lose their sight in old age have a hard time learning new habits and using compensatory aids. A lot of these people resign to learning the new way of living and remain reliant on the help of family members or elderly care center [9]. The vast majority of them does not actively use a white cane, a guide dog, or beacons. The same applies to Braille of which is knowledge sparse. This all hinders in the way of living an active life. People with sight loss also often lose their hobbies and friends; therefore, suffer from isolation, anxiety, dependence, and inferiority.

As visual impairment limits mainly a person's mobility and reduces travel-related activities [10], solutions helping visually impaired people with spatial orientation and navigation are of high importance. When asked, visually impaired mark problems with

Severeness of impairment	**Percentage of people**
Slight	28 %
Moderate	36 %
Severe	22.8 %
Very severe	12.6 %
Unknown	0.6 %

Table 1.3: Severeness of impairment percentage [7]

Problems with	**Number of people answered**
Mobility	5 931
Orientation	12 031
Independence	6 600
Household management	7 398
Receiving information	6 344
Communication	3 911
Catering	803
Legal capacity	511
Other	3 183

Table 1.4: Consequences of visual impairment (multiple choice, mean=2.9 problems per person) [4]

orientation as the most common problem (see Table 1.4). According to [4], visually impaired marked orientation in general twice as much as the second most answered problem (household management). This was also confirmed from personal experience during 21 interviews (subsection 4.1.1) with visually impaired older adults I made with my colleagues in the year 2017, where 13 people marked orientation as a severe problem. From all that data, we can depict that orientation of visually impaired older adults is the most common problem.

1.2 Thesis goals

This section describes the general objectives of this thesis. The goals are based on previous research (see chapter 2). The fulfillment of the goals is discussed in section 8.1. The goals are listed below:

- **G1:** Analysis of all previous work, progress, and associated research documents.
  - *Discussed in chapter 2*
- **G2:** Analysis of related work and other orientation systems.

- *Discussed in chapter 3*

- **G3:** Analysis of user group.
  - *Discussed in section 1.1, chapter 3 and section 4.1*
- **G4:** Choice of functional and non-functional requirements. Including a set of provided functions.
  - *Discussed in section 4.2*
- **G5:** Design of suitable interaction method.
  - *Discussed in chapter 4*
- **G6:** Creation of high-fidelity prototype implementing all previous results.
  - *Discussed in section 4.7*
- **G7:** Evaluation of the design.
  - *Discussed in chapter 6*

Chapter 2

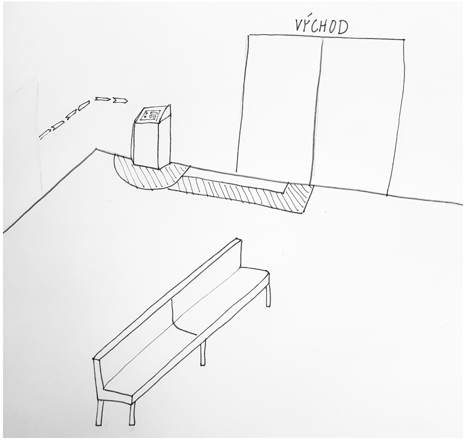
Previous work

In this chapter is discussed all our previous work and research preceding this thesis. Analysis of related work by other authors is discussed in chapter 3.

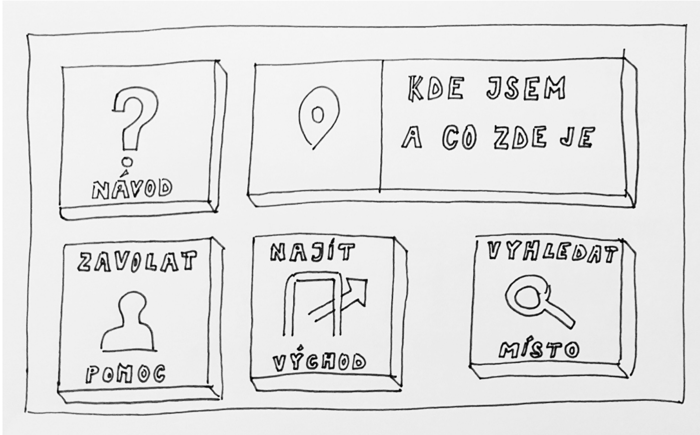
There is currently active research aimed at indoor orientation problems of older adults [11]. This research is being held at the Department of Computer Graphics and Interaction of Faculty of Electrical Engineering. The current branch of research started as a school project of a course Psychology in HCI. During that course were conducted 21 semi-structured interviews with visually impaired older adults. These semi-structured interviews revealed several serious problems. The most common key finding being an indoor orientation. More in subsection 4.1.1.

Following this project was a project during the course Design of User Interfaces. This project was run by me and my colleague. A complex orientation system was designed and tested during the course. More information about the orientation system in section 2.1. This orientation system was designed with User-Centered Design technique [12]–[14] in several iterations. Techniques like scenarios, Hierarchical task analysis [15], storyboards, and design studio [16] were employed during the designing phases. Techniques of low-fidelity prototype and Wizard of Oz method [17] were used during the evaluation phases.

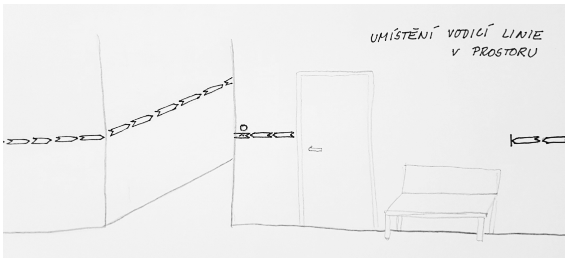
Following the end of this course was the project transferred into standalone research. A high-fidelity prototype of two of three parts of the orientation system was then created by cooperation with a visually impaired consultant, under supervision of Ing. Miroslav Macík, Ph.D. Focus was then changed on the design of OT (part of the orientation system). This resulted in research and an experiment on designing tactile symbols for visually impaired. This topic is discussed in detail in section 2.2.



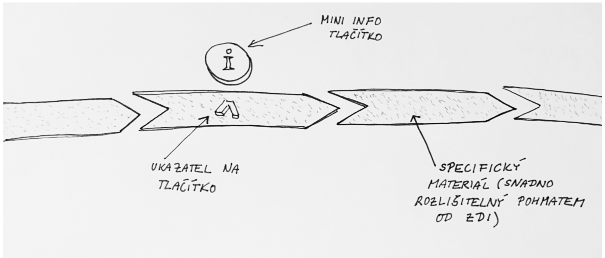
(a) Concept of OT location near elevator or exit and guiding line indicating presence of the OT



(b) Concept of OT



(c) Concept of guiding line on the walls indicating direction to closest OT



(d) Concept mini-info button on the wall indicated by a mark on guiding line

Figure 2.1: Concept of indoor orientation system

2.1 Indoor orientation system

Mentioned research resulted in a concept of indoor orientation system for larger buildings, concretely for Home Palata – residential home for visually impaired older adults (more in section 3.1). This orientation system does not serve the purpose of navigation but mainly orientation (the difference is discussed in section 3.6). This prevents users from getting lost or confused or help them recover from a situation when they got lost. The orientation system consists of three parts: the OT, mini-info buttons, and guiding line.

2.1.1 OT

The OT is a small device that should provide information to users. Information that OT provides should help users with time, situational, and spatial orientation. This OT should also help the user recover from a situation of getting lost.

The OT will always be placed nearby significant and frequent places like the main entrance/exit, elevator, etc. These OTs can differ depending on the characteristics of the location.

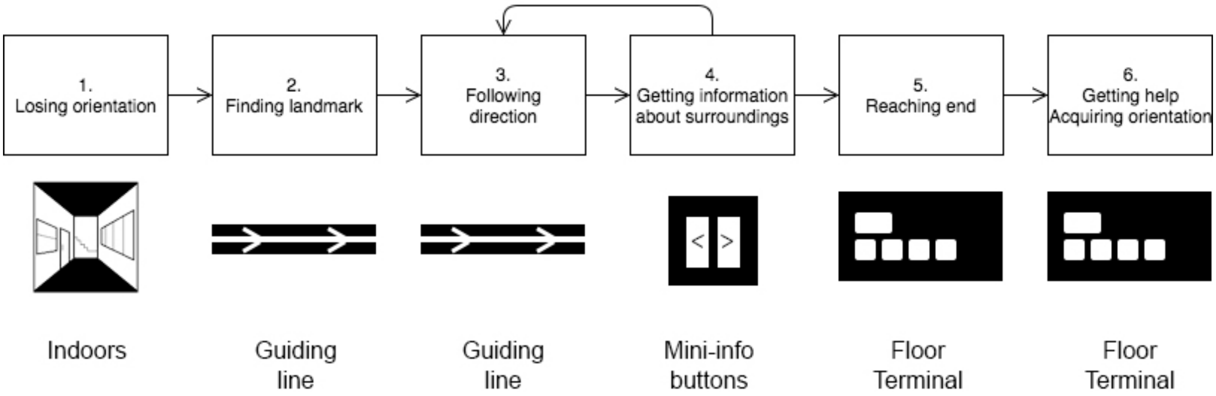


Figure 2.2: Diagram of the orientation system usage

The OT could hypothetically provide information like: Current location, directions to some other significant place, how to interact with the orientation system, call for assistance, what time is it, what is the schedule of the user/building, etc. The set of provided functionality is partly a subject of this thesis and is discussed in section 4.1 and section 4.2.

(a) Concept of OT with several buttons representing various functions of the OT

(b) Concept of a speaker module placed above the OT. This speaker would provide text to speech response to user requests.

Figure 2.3: OT of the orientation system

2.1.2 Guiding line

Guiding line is an oriented tactile line placed on the walls of the interior. The orientation of the guiding line always points at the nearest OT, which is placed at some important location. Guiding line is always present on at least one wall.

The guiding line can be shortly discontinued in case of a small obstacle (e. g. door) being present. If the guiding line cannot be present, there is placed mini-info button on both sides of the interruption that resolves this situation. Marks on the guiding line indicate the presence of a mini-info button or OT.

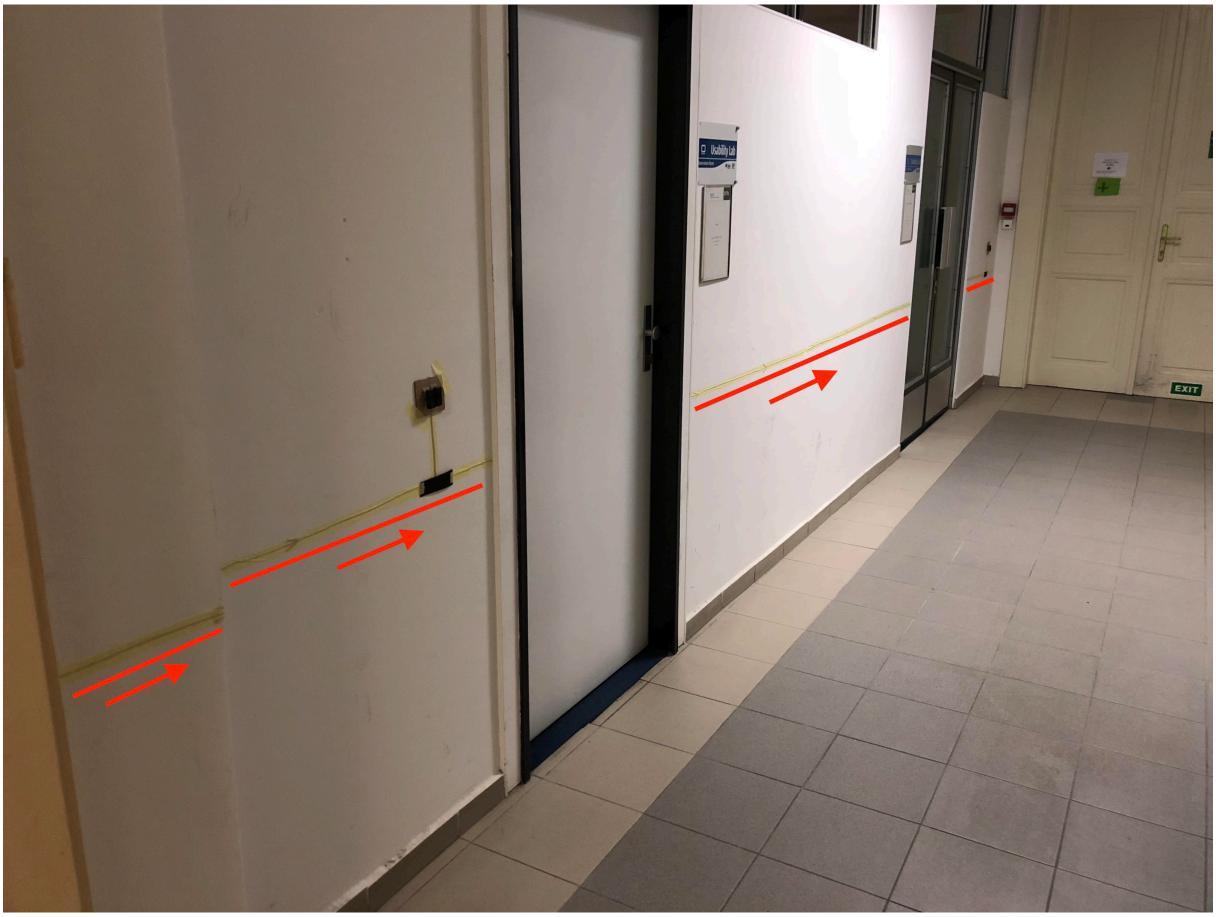


Figure 2.4: Concept of a guiding line, two mini-info buttons also visible above the line

2.1.3 Mini-info button

Mini-info button is a small device placed above the guiding line. The guiding line indicates the presence of the mini-info button. It serves the purpose of providing additional context information in places with complicated structure or situation. It can also provide time-place related contextual information. In the short term, it can either warn the user of some obstacle or inform of an important landmark. The mini-info button can be a set of two directional buttons. Both are providing the information in the context of the direction it points at.

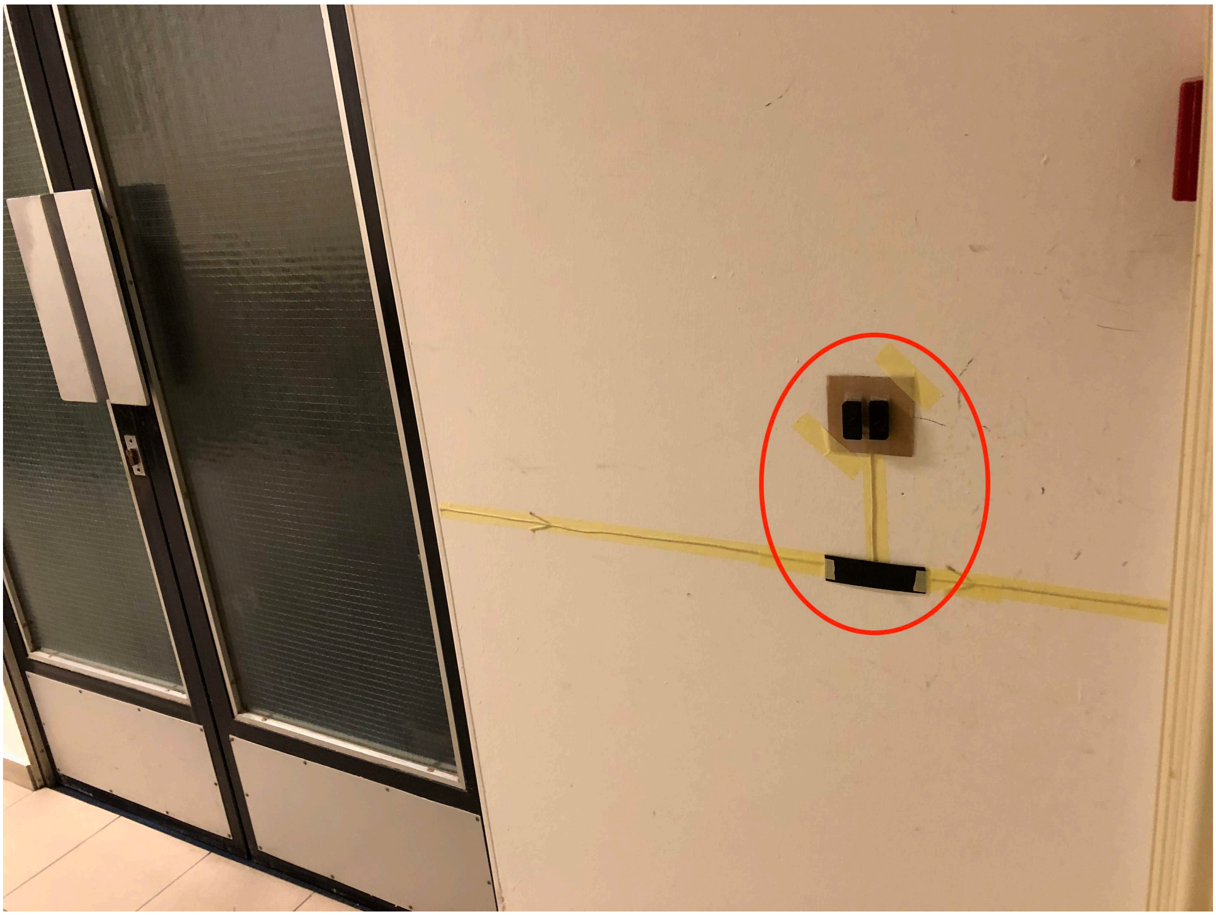


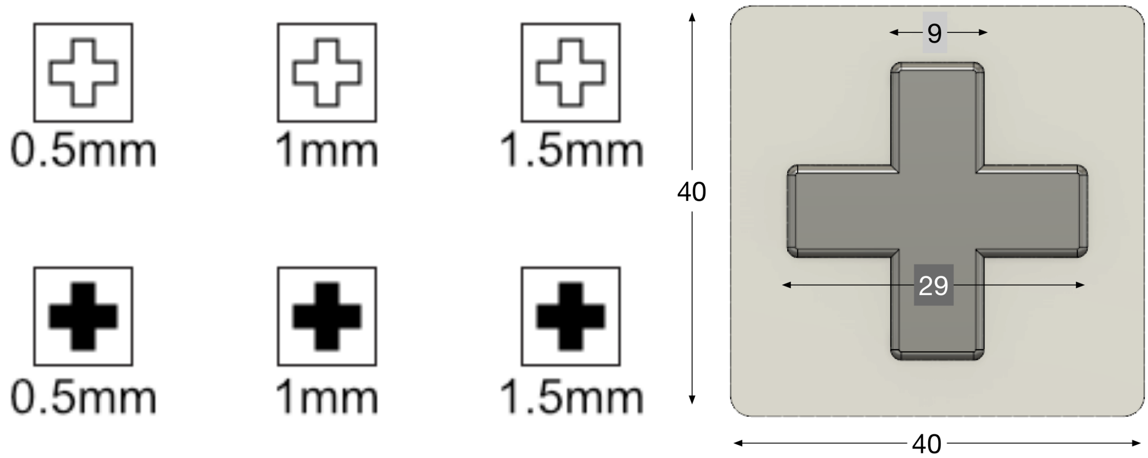
Figure 2.5: Concept of a mini-info button

2.2 Tactile symbols for orientation system

In [3], I and my colleagues focused on tactile symbols for visually impaired older adults. Our goal was to design great buttons for the OT (section 2.1). The work investigates the performance of older adults in tasks related to the recognition of tactile symbols. We conducted experiments to evaluate different tactile symbols with varying elevation, shape form (outline, fill), and symbol preference in general. We used both qualitative and quantitative methods to evaluate the experiments. We conducted two experiments with visually impaired individuals. The first experiment focused on the assessment of their preferences and performance regarding tactile symbols shape form and elevation. In the second experiment, we put a particular focus on performance and preferences of older adults with vision impairment while interacting with a set of tactile symbols.

Experiment 1 - form and elevation

The first experiment was with a general population of visually impaired (N = 6, age mean = 46.3). Two objectives were to find out the preferred shape form (fill, outline) and symbol elevation (0.5mm, 1.0mm, 1.5mm).



(a) Symbols layout from experiment 1; rows from top: outline, fill

(b) Tactile symbol model used for experiment 1

Figure 2.6: Experiment 1 apparatus - Tactile symbols for visually impaired older adults from [3]

Participants were free to explore separate rows of symbols, half of the participants started with outline row, the other half with fill row. They then filled in a Likert's scale of likeability and distinguishability. In the end, had a participant to choose the best symbol from a row and overall.

All participants correctly recognized the shape of the symbol (a cross). The Likert's scale showed that all of the symbols are distinct and likable. The best variation of shape elevation from outline symbols was chosen $1.0mm$ symbol (four times). The same applied to filled symbols. Again $1.0mm$ was picked four times. $0.5mm$ and $1.5mm$ were chosen equally often. When participants had to choose the best symbol overall, four of them had chosen filled $1.0mm$ symbol. One of the participants made a notable statement: "I think for blind users, it is much easier to recognize the filled-in symbol because he or she does not need to explore the empty part inside the outline." Results show that even $0.5mm$ elevation is sufficient for intelligibility, but higher elevation does not compromise it. Chosen variation of shape form was filled symbol.

Experiment 2 - identification, meaning and confusion

The second experiment was with visually impaired older adults (N = 9, age mean = 76.8) all late blind (mean = 15.88 years) age ranged from 51 to 98 (mean = 76.8, $SD = 17.3$) and two of them had dexterity issues caused by diabetes or burns. The experiment was divided into three standalone parts. Part A: Symbol intelligibility (identification). Participants were asked to identify real-world objects (or abstract terms) represented by symbols. Part B: Symbol preference (assign meaning). Participants were asked to connect symbols (A) to a function of hypothetical OT. Part C: Symbol recognizability (confusion). Participants were asked to recognize already learned symbols sequentially.

Experiment 2, part A - symbol identification

In part A of the experiment, we focus on symbol identification. There were six tactile symbols with 1.0mm elevation and three with fill and three with outline shape form. These six symbols correspond to hypothetical OT functions. The main research question here was: "Will participants identify tactile symbols as real-world objects or abstract terms?" Results show that symbol identification favored the simplest and also fill symbols.

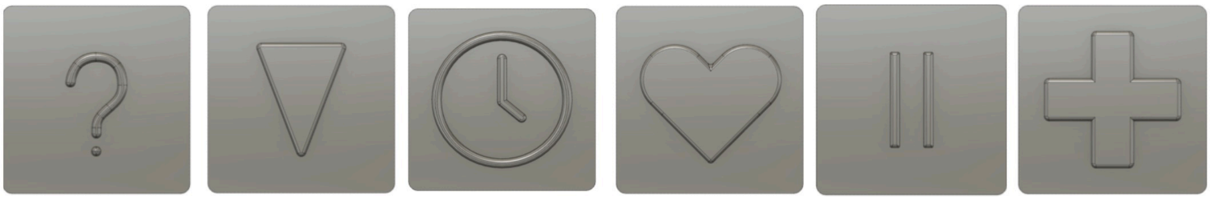


Figure 2.7: Experiment 2, used symbols: question mark, down arrow (triangle), a clock, hearth, two lines, cross

- down arrow (8 of 9 identified)
- hearth (6 of 9 identified)
- cross (5 of 9 identified)
- two lines (four of 9 identified)
- question mark (2 of 9 identified)
- clock (0 of 9 identified)

Experiment 2, part B - assign meaning to symbols

After that were the shapes said to the participants so they can later refer to those. We designed six functions of a hypothetical OT, and the task for the participants was to connect the symbols to the functions. The functions were read aloud one by one, and participants chose the corresponding symbol they felt like fits the best. The research question in this part of the experiment was: "Will participants connect the symbol with functions of the OT?" Unfortunately, the results are extremely bad as only 16.7 % of initial assignments matched the intended function and usually only one person per symbol

recognized	actual					
	question mark	**down arrow**	**clock**	**hearth**	**two lines**	**cross**
question mark	64	-	2	-	-	-
down arrow	-	62	-	1	-	1
clock	1	-	64	-	1	-
hearth	-	2	-	65	-	-
two lines	-	-	-	-	64	-
cross	-	2	-	-	-	64

Table 2.1: Confusion matrix [18] of symbol recognition, no confusion between fill and outline groups

assigned as intended. Also, participants were not able to confidently assign symbols to functions. One crucial observation had happened during this part. Five participants assigned clock to daily schedule.

In combination with part A, it is quite an exciting insight. Although none of the participants identified a symbol of a clock and this symbol performed the worst during the part A. Most of them correctly assigned the corresponding function to it in part B, and it performed the best. There is a reasonable suspicion that more complicated and abstract symbols compromise the identification but improve assignment of meaning or connection to real-world object or term. This could be later used as an assumption that if we teach somehow the symbols on the OT to our users, they may correctly connect them to intended functionality.

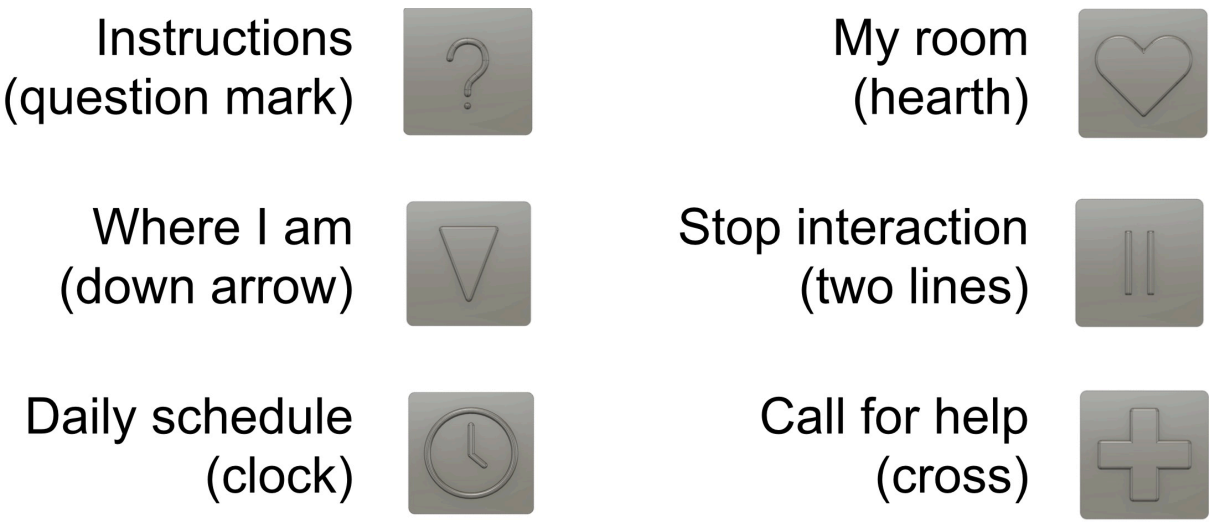


Figure 2.8: Experiment 2, symbols according to functions of hypothetical OT

Experiment 2, part C - symbol recognition and confusion

The last part sorely focused on symbol recognition and confusions between symbols. We taught participants all the symbols so we can be sure they can recognize them. Then we gave them cards with repeating lines of those six symbols in pseudo-random order. There were a total of three rows on four cards with six symbols in each row. That is 72 symbols to recognize per participant. Participants were asked to go one by one and recognize the symbols as fast as possible. Recognition of a single symbol usually took under one second. The research question of this part of the experiment was: "Will participants be able to recognize symbols and will not confuse symbols?"

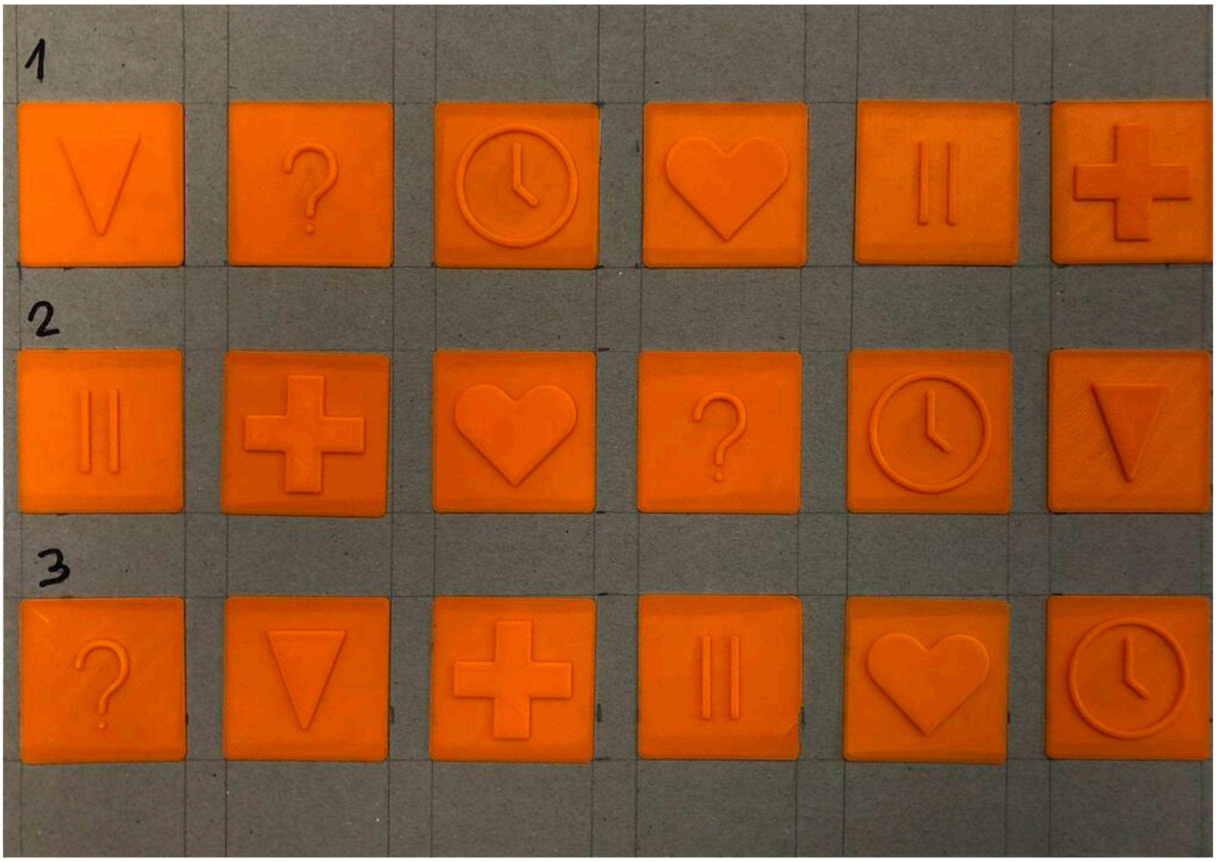


Figure 2.9: Experiment 2, one of four cards with three rows of six symbols in pseudo random order used for symbol recognition

Although two participants could not proceed with the experiment (because of fatigue) and one finished only half of it. Results are surprisingly outstanding. Three hundred ninety-six symbols were recognized in total, and three were not recognized (False Negative Rate of 0.76 %). Three hundred eighty-six symbols were positively recognized (True Positive Rate of 96.72 %) and ten mistaken (False Positive Rate of 2.53 %). There were no confusions between fill and outline groups.

Conclusion

The results indicate that even older adults are capable of distinguishing between six different tactile symbols. No confusions between fill and outline symbols had been recorded, and confusions were sparse. Participates frequently failed to connect meanings of abstract symbols with functions of a hypothetical OT. Shape form favors the simplest and fill symbols, and elevation is not a deciding factor in likeability and intelligibility.

Chapter 3

Analysis

In this chapter is the analysis of related work, other orientation systems, related terminology, the user group, and characteristic attributes of the user group.

3.1 Home Palata – residential home

Home Palata [19] is a specialized residential home for visually impaired older adults in Prague. It is an elderly nursing home with specialization for visually impaired individuals. The employees are trained for care of blind and visually impaired, and also the environment is adapted for those needs. Home Palata was established in 1888 and first opened on 25.11. 1893. Since the very beginning was the purpose the same, nursing home for visually impaired. It is to date of this publication 125 years of Home Palata being active, including both world wars.

The building is vast and historical; it is a neo-renaissance palace with a shape of rectified number eight. There are three floors where clients live and also a basement with laundry. Home Palata includes a spacious park with pavements, benches, trees, and a pond in front of the building.

Those three floors are together having a capacity of 40 double rooms and 45 single room with a total of 125 clients. The capacity is fulfilled most of the time. Most of the clients in Home Palata are women, and the mean age is around 83 years old. In total 107 employees with various competence take care of the clients. All the client rooms are based on the main hallway, which goes around the building. There are also some common rooms, dining room, chapel, et cetera. The hallways across floors are connected by stairways and three elevators, two elevators in the back side of each tower and one in the middle. Most of the clients prefer those elevators. Elevators are also sounded and tell aloud the floor and direction of lifting.

There is a handrail on the main hallway, which is the primary tool for navigation and orientation of the clients. This handrail spans around the whole building on all floors, and there are also small dots placed on the handrail where the client rooms are. Clients can touch these buttons and remember, for example, that room within three dots on the handrail nearby is their room.

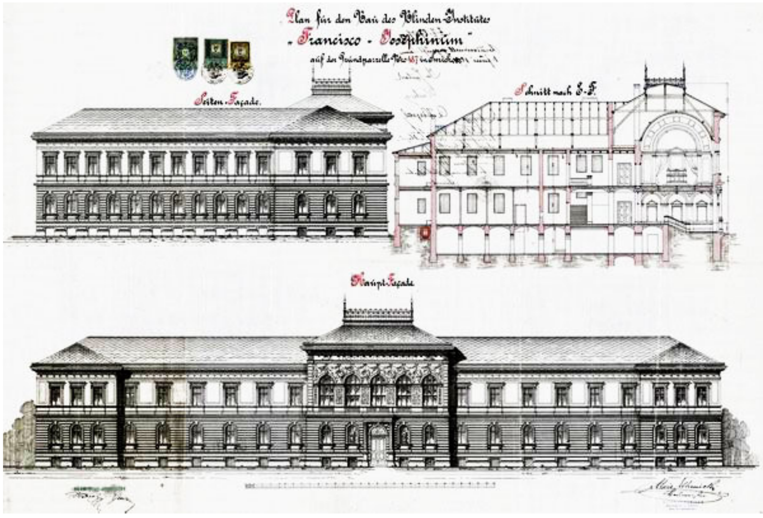
Also, all rooms are labeled by large numbers or text and also braille. However residents, except for a few, do not know Braille and use only large tactile lettering. Other main orientation landmarks are decorations placed on the hallway. Each block of the building and thus the hallway has a different type of decoration including plants, pictures, benches, chairs, a cage with parrots, teddy bear, et cetera. Clients use these landmarks for easier orientation in this vast building.

Unfortunately, the building is large, and architecture is extremely symmetric, which confuses even sighted people, and it takes a few days even for sighted people (like employees) to fully orientate. All newcomers are taught the basics of orientation and go through these landmarks with a lecturer.

Some clients are not only challenged by visual impairments, but also diseases like Alzheimer's disease, dementia, and other.

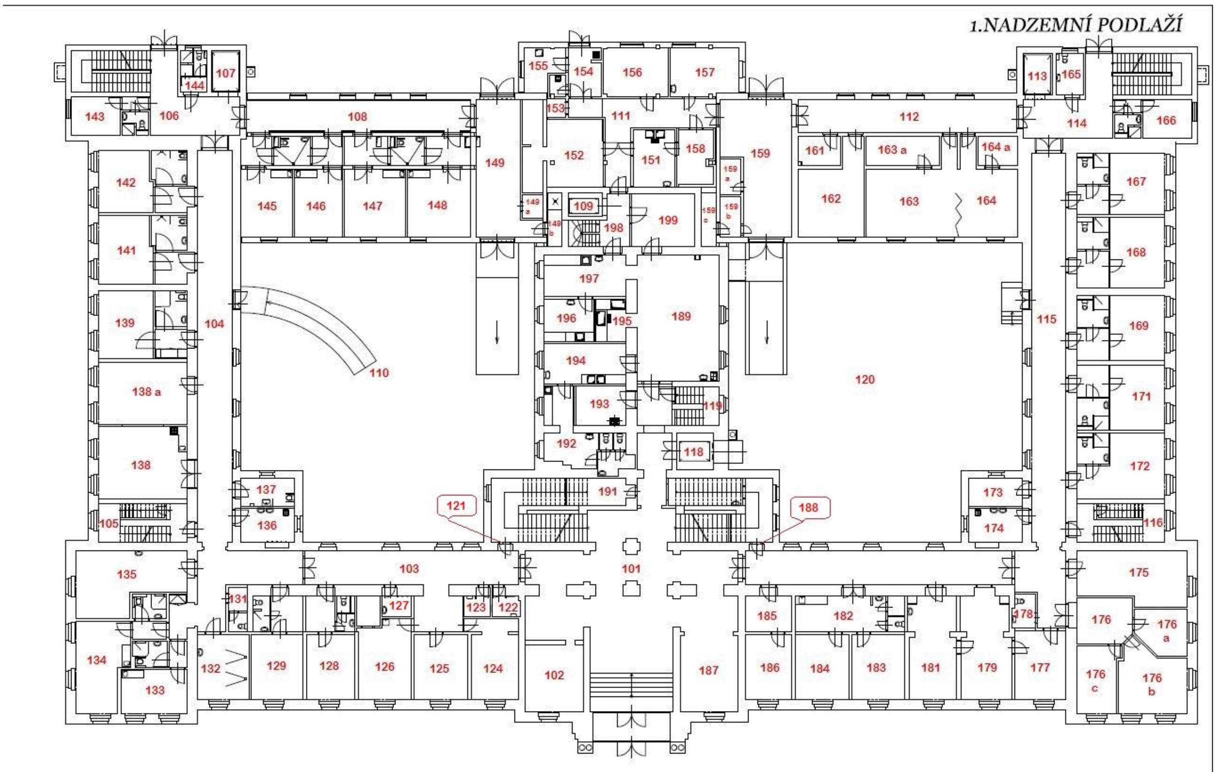
Home Palata also holds many cultural, medical, and other activities and events during the week. For which purpose is every morning a local radio being broadcasted announcing the date, lunch menu, and all the upcoming activities.

Authors in [20] also present options of ICT, helping visually impaired older adults after interviewing Palata residents.



(a) Original plans of the Francisco Josephinum palace, which is now called Home Palata

(b) Photo of one of the hallways inside Home Palata, you can see the brown handrail on the right



(c) Current ground plan of the ground floor of the building

Figure 3.1: Francisco Josephinum palace – Home Palata building, figures downloaded from [19] gallery

3.2 Demographics

As discussed in section 1.1. The most numerous group of visually impaired people is a group of people above 75 years old (almost half of all visually impaired). With the inclusion of people 60 years old and older, we receive a group of visually impaired older adults which consists of around 67 % of all visually impaired people according to data provided by Czech Statistical Office.

User group of older, visually impaired adults is expected to consist of more women than men [21]. Derived from the data provided by the Czech Statistical Office for the year 2013 is the life expectancy of men 75.23 years and for women 81.13 years. During the age of 60-64, 15 % of women are widowed, 25 % for age of 65-69, 39 % in age 70-74, 55 % for 75-79, 71 % during 80-84, 85-89 a 90+ belongs to 82 % and 88 %. While more than 55 % of men are married during the age of 55-89. Only 39 % of men in category 85-89 are widowers.

In [22] author points out that 70 to 75 % of all visual impairments is emerging after 65 years of life and around 80 % of all people 75 years old or older has severe eye disease. The most common eye disease is age-related macular degeneration, which weakens particularly central vision. As a result, the ability to read and thus the ability to retrieve information gradually deteriorates. Other frequent visual impairments of seniors include diabetic retinopathy and glaucoma. The range of visual impairments is extensive, and the consequences are varied. The most common consequences are reduced visual acuity, visual field outages, various types of color blindness, light-fastness, reduced ability to perceive contrasts, practical blindness and other.

3.3 Consequences of visual impairments

People that happen to develop eye disease and severe visual impairment tend to suffer from sudden isolation. Isolated from the outer world, friends, family, and information [22]. These people then face a situation in which they cannot acquire general information nor information about their surrounding as they did before. They cannot read a newspaper or books. This condition creates a tendency to develop fast deterioration of a person's self-esteem and interest in any activities. These conditions are even worse for older adults for which it is way harder to learn new techniques and acquire so much needed skills with compensatory aids. In a lot of these cases, are those people also alone and become depressed. Their family does not have time to take care of them, and their partner is not able or unfortunately not non-existent. There are unfortunately many cases when especially older adults receive compensatory aids but resist to use them. They keep them in their closet and argue, that they are not good enough with those or that nobody explained everything clearly and repeatedly so they could not learn [22]. This clearly shows how specific this user group is and how important it is to help users learn everything new in their life by clear explanation and numerous repetition. This indicates the need to help users of the orientation system gather the skill to use it first. Teach them how to use and what it can do. Then they could potentially perform well.

In [23] author analyzes the consequences of losing sight, especially in older age. The emotional response of older adults to loss of sight is individual and unique. However, research suggests that frequent responses include a sense of loss, isolation, and dependence, loneliness and depression, low morale, lessened satisfaction with life, a tendency to lower scores on a mental status exam, and a sense of incompetence. This all leads to bad socializing and resignation. The author discusses how important is the morale of people that lose their sight and how much emotions affect the well-being tendency to fight with their impairment. There is a special program that helps family members see better how life changed for their loved ones and encourages to help them find their will again. This also includes much time spent training new techniques and repetition in assuring their loved ones, that every little progress counts.

Wahl et al. [24] investigated the psycho-social consequences of visual impairment by comparing the visually impaired older adults to healthy older adults or mobility impaired older adults. Comparisons confirmed the hypothesis that age-related visual impairment is associated with negative effects in the behavioral as well as emotional domain.

Findings from analyses [25] confirm that depression is a prevalent and often persistent problem among older adults with age-related vision impairments. Results show that 33 % of interviewed participants reported clinically significant depressive symptoms at baseline. Further, more 25 % of them reported so at the two-year follow-up interview, and 21 % reported depression at both points in time. These rates are as high, or higher than those documented among medically ill elders and those with other age-related disabilities. Analyses focused on older adults with recent age-related vision impairment. It revealed that counseling services, low vision clinical services (i.e., assessment of residual vision, and prescription of optical devices) helped to a significant decline in depressive symptoms over time.

On the other hand, skills training and use of adaptive devices did not. This could also be reasoned that people who used adaptive devices or needed extensive training were in severe condition and thus way worse than people that found help in prescription of optical devices — resulting in way lower improvement in their lifestyle and well being.

3.4 Orientation

According to [26] is space orientation natural and routine activity for people that employ sight. Sighted people primarily use their sight in order to gather information from the environment for physical or mental manipulation and interaction with objects belonging to the environment. Sight is also used primarily for scheduling of movement and paths in the environment. People with visual impairments cannot do any of this without the help of others (sighted people) or employing special techniques that allow compensating this handicap.

Visually impaired people usually suffer from a lack of needed information about their surroundings [27], the most important being the lack of information about their current location, what objects are nearby, which direction leads where, what is ahead of them and complementary information about any dangers, critical situations, and essential objects or rooms. In the case of indoor orientation, the purpose of every door and room behind is also essential knowledge that visually people do not receive in any way.

While sighted people choose their route in the environment in order to minimize the travel distance and avoid dangerous obstacles, visually impaired on the other hand, minimize exposure to possibly dangerous or confusing routes. Thus use walls as a safe routing path. If there is an obstacle in front, they try to walk around it in a small radius as possible in order immediately come back to the wall. In case of need to walk through an open space, visually impaired people try to hold one direction until they reach their destination or opposite wall. This minimizes the risk of losing orientation and allows easy and safe route back [28] in case of a problem.

3.5 Compensatory aid

In [29], authors discuss the two most widely used travel aids in the United States. These are the same for the Czech Republic. It is a white cane and guide dog. The most successful being purely mechanical device is a white cane, that can be easily folded and kept in a pocket. It provides short-range scanning of the surrounding ground in the walk direction. Unfortunately, it comes with a hidden cost of up to 100 hours of training upfront needed. Most of the older adults that lose their sight do not go through this extensive training and thus do not use the white cane. In the special housing (section 3.1), only a few residents are equipped with a white cane.

Guide dogs are competent guides for visually impaired, but they require extensive training. Fully trained guide dogs are very expensive, and they are only useful for a limited time (the dog's lifespan). Also, most of the elderly with visual impairment find it too difficult to care for another living being. Thus the very little amount of visually impaired people use a guide dog. None of the residents in special housing (section 3.1) uses a guide dog.

There are also many devices that use sensors and electronics to improve the mobility of visually impaired in terms of safety speed and guidance. These devices are collectively called Electronic Travel Aids (ETAs). These devices are based on various technologies and approaches to the problem like laser distance measuring white cane [30] or a white cane with sonars that detect objects, object detecting ultrasonic handheld device [31], wearable ultrasonic belt device [32] or even collision avoiding guiding robots [33]. However, none of these devices [30]–[37] had been successfully adopted by visually impaired users yet, even though the mentioned research papers span from 1973 to 2006 and there was a plenty of time to adopt it. Also, none of these electronic devices are being used by any of the special housing residents.

3.6 Orientation vs Navigation

Orientation. According to the article published by Right-Hear [38] orientation is the knowledge of ”where you are” and ”what is around you.” By Montello [39], the detail of this knowledge can vary across different situations and people. Two other terms often associated with orientation are recognition of external features or landmarks and dead reckoning. Recognition of external features and landmarks serves as a key to access in internal model representation and cognitive maps and allows access to spatial knowledge while dead reckoning is a process of recalling additional attributes associated to a speed of movement, corner angle, number of steps without association to recognized landmarks.

Navigation. According to Montello, [40] navigation is coordinated and goal-oriented movement through the environment. It involves the execution of movements and planning. It consists of two components: wayfinding and locomotion. Locomotion is body movement coordinated to the nearby surroundings. It depends on immediate sensory information, and it does not depend on any cognitive map or internal model. Wayfinding is the decision making and planning process coordinated to the distant as well as nearby surroundings. It allows a human being to reach destinations that are not in the immediate sensory field. It involves usage and generation of cognitive maps and internal models. Locomotion and wayfinding vary in demand for attention and cognitive load. Navigation through known route is way less demanding than navigation through an unknown environment.

3.7 Tactile user interfaces

A tactile user interface is one of the efficient ways of interaction for visually impaired people as their passive tactile acuity is superior [41]. There exist extensive research in the field of tactile symbols used, especially in the framework of tactile maps like [42], [43]. Besides 2D symbols researchers experiment also with 3D (volumetric) tactile symbols [44], [45]. Moreover, the tactile perception of visually impaired people is superior [41].

3.7.1 Tactile vs Haptic

Words "tactile" and "haptic" are often used as synonyms in literature, but there is a difference between those two. The first difference was recorded by Gibson [46], [47] by defining the distinction between active and passive touch. Gibson also used terms like "tactile scanning," "kinesthesis" and "haptics." Later were terms "tactile perception", "haptic perception" and "kinesthetic perception" defined by Loomis [48]. Loomis describes tactile perception as a passive sensory perception mediated solely by variations in cutaneous stimulation. An example could be a sensory of pressure on fingertips while exploring a surface material or Braille. Tactile perception is always a passive process, and it can vary based on posture and other active attributes of the exploratory process. Loomis defines kinesthetic perception as perception mediated exclusively or nearly so by variations in kinesthetic stimulation. This means the individual's perception of their posture, joint position, speed of movement, the weight of their body or object in hand. Haptic perception is then defined as a combination of tactile and kinesthetic perception. Other authors [49], [50] often define tactile perception as a passive process and haptic perception as an active process.

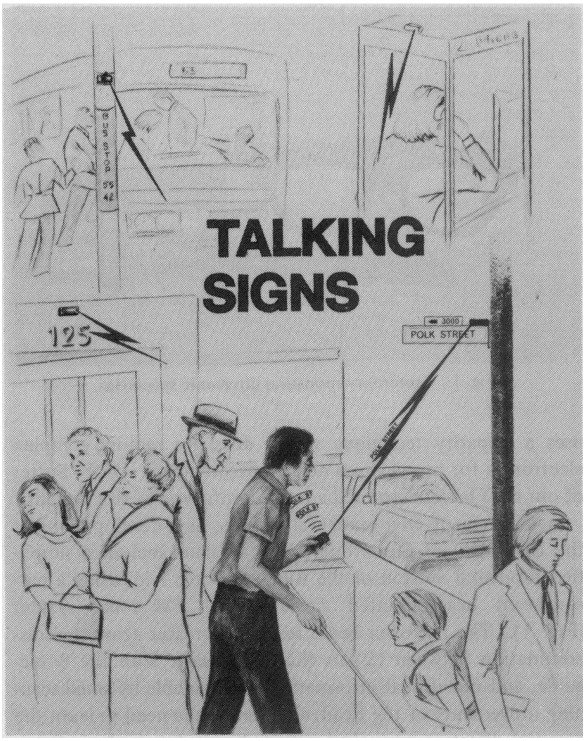
3.8 Other orientation systems

Most of the found orientation and navigation systems that are currently available e. g. [51], [52] focus on outdoor orientation based on GPS and smartphone app. This is unfortunately inappropriate for the sake of an indoor orientation system for visually impaired older adults from two main reasons. The first reason is that GPS use is practically impossible indoors. The second reason is that almost every potential user from the user group does not own a smartphone and is not even skilled with using mobile phones let alone any smartphones at all.

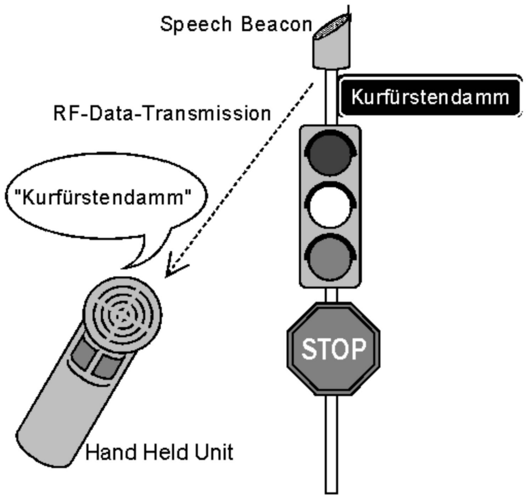
3.8.1 Radio frequency speech beacons

One of the most widely used solutions for orientation of visually impaired is a public system of radio frequency speech beacons [53], [54] placed nearby important landmarks. The visually impaired individual carries an RF transmitter. If the portable transmitter is activated in the proximity of a speech beacon, the speech beacon itself or the portable transmitter (depends on the implementation) starts talking. It usually informs about the location and describes the place or provides any other related information.

For example, in the Czech Republic is this system widely used for public transport signalization or public buildings. The correct and mandatory usage of RF beacons is stated by law, an act [55] consists all directives. For example, if the user of the system activates the transmitter near a tram stop platform (it needs to be electrified tram stop), the tram stop itself starts talking. It tells the visually impaired individual name of the tram stop, and what trams are commuting there. The RF transmitter has a set of six buttons that correspond to different groups of interaction and landmarks. So by another button can be signalized an RF receiver on the incoming tram itself to tell aloud its number and direction and inform the driver that visually impaired person may need to enter the tram. These beacons are also placed above entrances to public buildings, on escalators, or metro platforms. The act [55] also states many other uses.



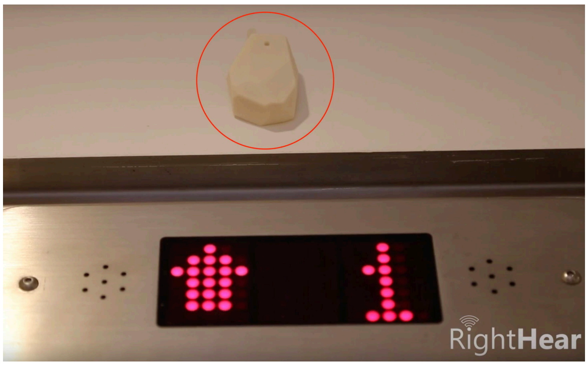
(a) Public space landmark signalizing radio frequency speech beacons, figure taken from [53]



(b) German implementation of RF speech beacons in public space, figure taken from [54]

Figure 3.2: Radio frequency speech beacons

3.8.2 Right-Hear



(a) Right-Hear beacon placed above elevator

(b) Right-Hear beacon placed outdoors

Figure 3.3: Right-Hear beacons, figures exported from [56] video

Right-Hear is a smartphone application [57] that provides spatial orientation information with the help of static Bluetooth beacons placed in the environment. It is capable of use indoor and outdoor. The system is very similar to a system of radio transmitter speech beacons placed in public space. Beacons are placed on important locations (intersection, entrance, stairs, etc.) when the user (and his/her smartphone) get into proximity of that beacon; the smartphone reads aloud the text or instructions set in the beacon. It can warn users about stairs, inform about doors and entrances or read aloud any other information or instruction. It also records the last met beacons so the application can induce direction of walking from the previous beacon (beacons). This can be taken in advance and divide the beacon information into direction based. Instructions on the beacon can be easily changed if needed by the administrator of that beacon. A suggestion of instruction change can be submitted by users. Beacons are supposed to be bought by store owners and other individuals managing any public space in order to embrace the user experience of visually impaired individuals. There are currently hundreds of indoor and outdoor beacons across Israel (as it is the homeland of this project), about a hundred in the United States of America and a few in France and the Czech Republic.

3.8.3 PERCEPT

PERCEPT is indoor navigation and orientation system [58] for visually impaired that uses a combination of passive and active elements in conjunction to provide an interface that embraces indoor spatial orientation in public buildings and allows for more straightforward navigation. The navigation system consists of five parts. The first part is passive Radio Frequency Identification technology [59] (RFID) tags that are located in all important places. These tags have a shape and form of classic labels with large tactile lettering and Braille just like any other labels for visually impaired placed indoors to indicated and label rooms and hallways. Inside those labels are the passive RFID tags.

Figure 3.4: Overview of the PERCEPT system, figure taken from [58]

The second part of the system is a PERCEPT glove. This glove contains RFID reader, a battery, and Bluetooth module. When the user finds the tactile label and reads the tactile label text or Braille by touch (fingers), it can then use the palm of a hand with the glove which needs the proximity of 2-3cm in order to read the RFID tag. The RFID tag contains additional information about directions, surroundings, etc. accompanying the tactile label.

The third part of that system is PERCEPT Kiosks. These are boards (similar to the OT of our orientation system) that contain multiple labels with RFID tags. So the Kiosks serves the purpose of a signpost. The user reaches the Kiosk, finds the label that corresponds to the place that the user wants to reach and then let the glove read instructions and directions on how to reach that location. There is always one label in the Kiosk for any label on the current floor and one label for any other floor. Kiosks are located in strategic places.

The fourth part of this system is a PERCEPT server that contains and stores all the instructions that are given by the RFID tags. So these instructions can be easily manipulated.

The last part of the system is an android phone of the user allowing Bluetooth connection with the glove and internet connection with the server and thus allowing to gather all the required data in order to read aloud the instructions given by those RFID labels.

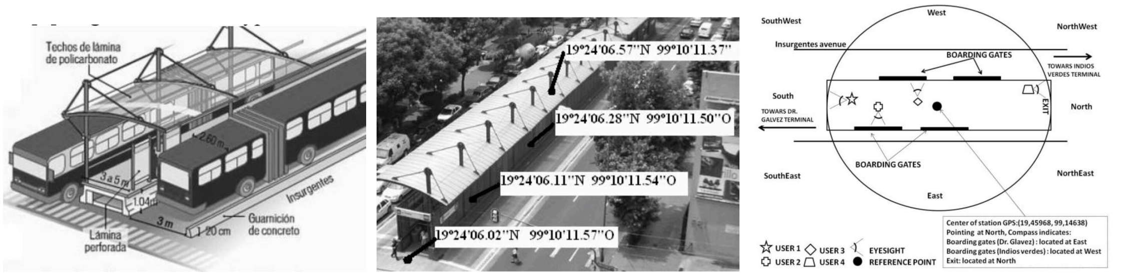
3.8.4 Automated Mobility and Orientation System for Blind

In [60] authors created an enhancement for the white cane. They added laser and ultrasonic sensors to the cane so it can detect obstacles that would generally be too far from the reach of the white cane. Signals from these sensors are then propagated to the user by beeping of different frequencies based on the distance from the obstacle. They also added GPS and accelerometer module to the system, so current location and orientation of the user can be detected and additional information provided. This, unfortunately, does not noticeably enhance indoor orientation of the user.

Figure 3.5: White cane with laser and ultrasonic sensors detecting obstacles, figures taken from [60]

3.8.5 A mobile navigation and orientation system for blind users in a Metrobus environment

A mobile navigation and orientation system for blind users in a Metrobus environment [61] is a research of outdoor navigation and orientation based on GPS signal a compass. The system runs on a third generation mobile phone with Symbian operating system and heavily relies on the premise that the Metrobus system of the Mexico city, where was the system implemented, is always placed outdoors on a clean plane without any obstructions that would otherwise block the GPS signal. The mobile phone makes requests to a web server based on the GPS location and compass and receives the instructions it should provide to the visually impaired user. The directions are simple; it consists only of naming a few nearest Metrobus landmarks like platform, sign, crosswalk, and the corresponding distance from the current location and the direction which leads to that landmark. What is interesting is that authors suggest using a clockwise direction system instead of a "right, left, top-down" system as it allows for way more accurate directions. The clockwise system is an exciting idea, but it may be too complicated for the user domain of visually impaired older adults.



(a) A Metrobus station (b) GPS coordinates in a Metrobus station (c) Testing scenery in a Metrobus station

Figure 3.6: Metrobus system experiment, figures taken from [61]

3.8.6 RFID floor grid

RFID information grid for blind navigation and wayfinding [62] is a concept project proposed by the University of Florida - Computer & Information Science & Engineering Department as an answer for a need of orientation and positioning system for visually impaired individuals in public buildings. The project sorely emphasizes a need for a low-cost solution in public space. Their proposal relies on the installation of RFID tag grid in the indoor environment of a building. These RFID tags should be placed on the floor. Concretely under the floor, meaning placement under a carpet or linoleum as such. RFID tags are incredibly cheap in mass production and completely passive with minimal maintenance.

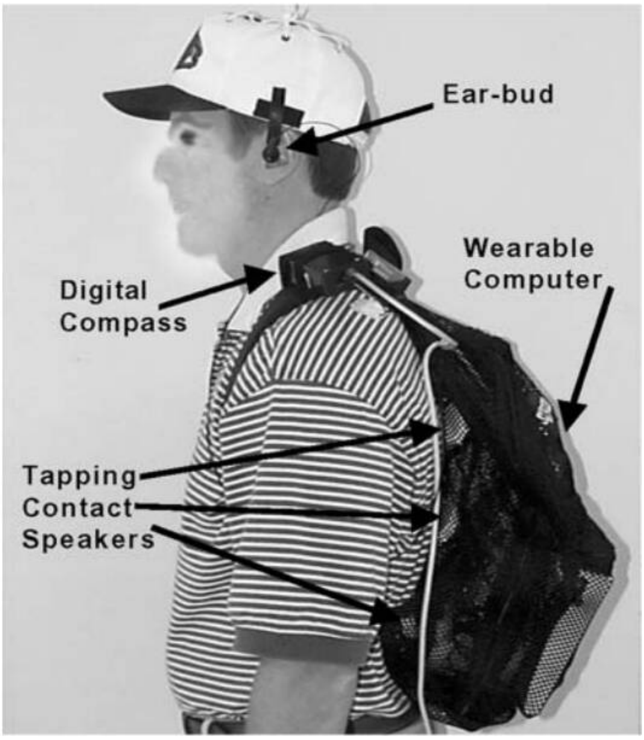
These RFID tags would form a grid of important places, crossings, doorsteps, etc. Each RFID tag would include an absolute location based on the geopositioning system but adapted for indoor usage by including room numbers, floor numbers, and so on. The type of RFID tags they propose allows 75-150 mm read distance and 140ms needed for setup time + around 500ms read time. This should allow usage of a simple RFID reader + speaker placed on the bottom of a white cane, wheelchair or shoe. In wider areas is an array of identical tags needed to ensure contact with the reader antenna.

The High-Density RFID Tag Space

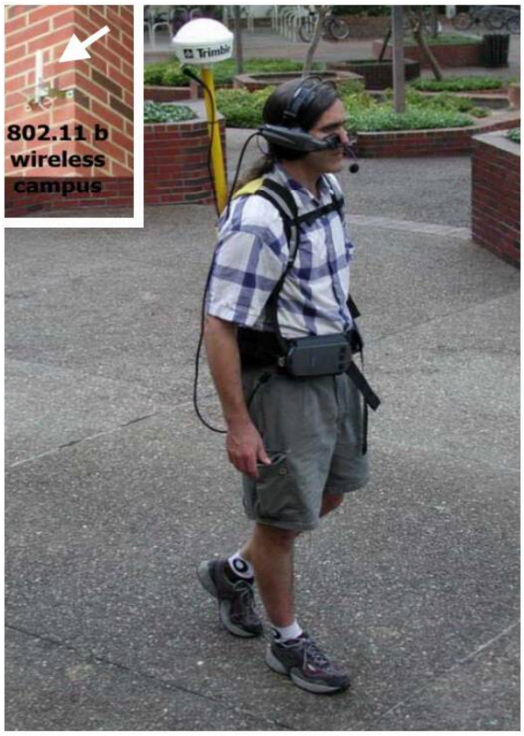
The idea is not new as the High-Density RFID Tag Space [63] uses active RFID Tags and relies on a grid density of 1.2 meters. Active RFID tags have a battery power source which allows for a stronger transmission signal but at a higher unit cost and long term maintenance.

3.8.7 Wearable computer positioning systems

In [37], [64] and [65] authors focused on usage of wearable computer in combination with placing active devices like ultrasound beacons, IR sensors etc. Just from the photos, it is clear that this is unfortunately unusable for the needs of visually impaired older adults as the devices needed to wear are too large and highly impractical.

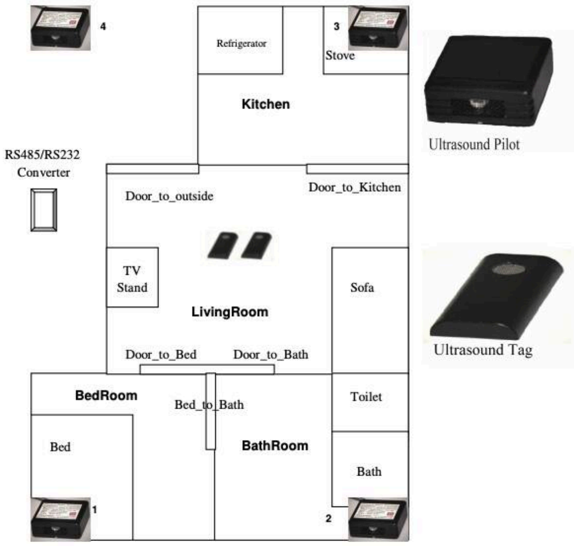


(a) Picture of person wearing the prototype interfaces from [37], figure taken from [37]



(b) Person wearing device from [65] including GPS, WIFI and IR sensors, figure taken from [65]

(c) Wearable computer with ultrasound sensors from [64], figure taken from [64]



(d) Ultrasound location system coverage of indoor environment [64], figure taken from [64]

Figure 3.7: Wearable computer positioning systems in conjunction with active sensors

3.8.8 Use of acoustic devices for orientation

In [66], the authors implemented a prototype of indoor navigation and orientation system. The system was tested with one participant and within two indoor environments (participant's house and work). The system consists of two components. The first one is a small portable box with a radio receiver, set of buttons a speaker. The other component is radio signal transmitters placed in the indoor environment. The user chooses the destination using the buttons on the portable receiver. The receiver then switches its inner schema to listen to an only specific radio transmitter that the user had chosen. If the user walks towards the chosen transmitter, the portable box remains silent. If the user gets off the course, the portable box starts buzzing and producing sounds based on the severity of direction change. The portable box gets silent once the user starts getting closer to the chosen transmitter. Unfortunately, this study was evaluated only with one participant after a training session, and technical implementation details also remain very sparse.

A similar design was used in another set of experiments in [67]. These experiments were conducted with two blind individuals that had been classified in the profound range of mental retardation. The orientation system used the same setup as the previous one. The only change was that the chosen transmitter (destination of user navigation process) itself made the sound. Thus acoustically giving away its location. Participants did undergo basic training with the orientation system. Results showed improvements in spatial orientation of the experiment participants.

3.9 Conclusion on other orientation systems

Some of the mentioned orientation systems above are already implemented and deployed in the real environment with success. This is a sign that orientation systems are possible and can be effectively used visually impaired people. Unfortunately, none of the mentioned systems was designed especially for the user group of visually impaired older adults nor even evaluated with this user group. This means that any given results may not be valid or applicable for the specific user group of visually impaired older adults. I did not manage to find any single research or project of orientation or navigation system designed or applied to that user group. Even though the amount of distinct orientation systems for visually impaired is not negligible, the need for a design for the specific group seems now even more necessary. Despite all this could be some parts and ideas of these orientation systems used for the design.

All mentioned systems have one thing in common, and that is a prerequisite to carry or wear some part of the system. It can be sensors, mobile phone, RFID reader glove or

RF transmitter. The very first and main idea of the orientation system I am enhancing was the absence of the need to carry anything with you in order to use the system. That is what is all of the mentioned systems currently missing. We want to avoid that as our user group can often include people with mobility issues [68] or mental illness (approximately 20 % of adults aged 60 and over suffer from a mental disorder) [69]. Visually impaired older adults are not only specific by their needs of simplicity but also by their motoric, cognitive, and mental capabilities. So this excludes any large or cumbersome devices like wearable computers or sensors from use. As Home Palata (section 3.1) is a home for the clients. They cannot be forced to carry anything with them all the time. That would have to be their free will to carry something with usage in mind. For example, when they would leave their room, they would need to keep in mind they cannot forget to carry the device with them in case of losing orientation or need for directions. That does not even cover the case when they forget to carry the device, and that older adults suffer from diseases like Alzheimer's disease. This does not go well with the idea of a carrying device.

The only option there would be to use something item that becomes part of their life, habits, and day to day routine. If the carrying device could be disguised as some jewelry or part of the clothing, that could be the way. People are used to carrying their amulets, bracelets, watch, rings, and so on all the time. So using that into advantage could solve the problem with forgetting and also with the need of omnipresence of the device.

The mentioned systems employ great ideas in order to achieve a similar goal from a different point of view. My favorite idea here is the placement of beacons and their activation. This could, in combination with the auditory feedback, make a robust system of artificial landmarks that tell the directions. We already employ artificial landmarks with the use of the Mini-info buttons (section 2.1). Remote activation and auditory feedback seem like nice enhancement of the Guiding line. Unfortunately, older adults tend to have a worse hearing, and a lot of Palata clients use a hearing aid. So the idea of auditory orientation is not fail-proof. Also, this does not even solve the primary concern of this thesis, and that is the OT.

The most suitable similar project for the case is project PERCEPT (subsection 3.8.3). PERCEPT allows the user to get the information about their surroundings, what is in each direction and also to plan their route by selecting their destination in the Kiosk. The Kiosk is very similar to the idea of the OT, and labels are similar to the idea of Mini-info buttons. Usage of the system is again very similar. The only difference is that we use direct buttons instead of a RFID tag reader glove and mobile phone. Our system employs the same ideas, but without the need to carry anything around. The carrying device of PERCEPT systems allows one luxury, that our system can not at the moment, a process of guided navigation. User can choose the destination, and the system guides the user between landmarks. This may be a considerable addition to the system, and the OT could serve the very same function of the PERCEPT Kiosk.

Chapter 4

Design

I employed participatory design methodology [70] and created four separate designs which involved all stakeholders during the whole process. The stakeholders include residents (users) of the residential home (see section 3.1), employees of the residential home, visually impaired expert, and the research group. All designs were also evaluated with participants from the user group. I started the design by conducting a workshop with employees and analyzing 21 interviews with residents. Design requirements were then stated, and the initial design was made. The initial design was transformed into a prototype which was qualitatively evaluated with participants recruited from the residential home. Insights from the evaluation were then used in the creation of the next design iteration. More on that process is in section 4.3.

4.1 User study

During the pre-phase of the design process, it was necessary to get even closer to the user group. Although I had extensive insights from previous research (chapter 2) and user analysis by itself, interviews with visually impaired older adults (subsection 4.1.1) and workshop with employees (subsection 4.1.2) of Home Palata (section 3.1) was conducted to enhance the knowledge of the user domain, their knowledge, needs, habits and routines. Workshop with employees was a great way to get indirect information and insights about the clients, that could otherwise remain untouched.

4.1.1 Interviews

During the course, Psychology in HCI were conducted 21 semi-structured interviews (by five colleagues and me) with visually impaired older adults. These semi-structured interviews revealed various key findings and valuable information, including several serious problems. The most frequent key finding is a problem with indoor orientation.

A lot of the participants have residual sight and thus use sight as their primary orientation modality. They mostly use visual landmarks and ambient colors for orientation. On the other hand, participants with severe visual impairment or blindness use tactile landmarks and compensatory tools like the handrail in Home Palata (section 3.1). Sometimes are those landmarks rather ambient than tactile. Some examples could be the smoking room. "If I smell cigarettes, I know I am nearby the main entrance because that is where the smoking room is." The same applies to the dining room. Ambient landmarks do not have to be always olfactory but also auditory. This applies for example for a cage with parrots in the middle tower, second floor in Home Palata. "I know I am reaching the middle elevator when I hear the birds sing louder." Other landmarks include pictures on the wall, plants and other decoration.

Some clients of Home Palata use a white cane, but most of the clients do not use any compensatory aids for orientation. A large number of clients suffer from motoric problems and thus use special pushcarts or supporting wheelchairs. A lot of people there are having problems with hearing. For that, they use a hearing aid.

The diversity across clients is extensive. While some clients can walk outdoors and go shopping in the center of Prague or nearby shops, other clients do not leave their rooms either caused by motoric problems or fear of getting lost in the environment of the large building.

Some participants reported using the special electric magnifying glass for reading or sewing. Others use television for amusement. However, the most frequent item in the participants day to day routine is a radio. Participants reported listening to the radio for most of the day. Some clients of Home Palata have a collection of CDs or cassettes while others fear of switching the channels on the radio or using any other buttons other than on/off because they fear they'll set the radio into a state that would render it useless or broken and they wouldn't know how to set it back.

Clients of Home Palata are usually good at the orientation of the nearby surrounding around their room and essential routes to and from their room (for example to the dining room). Some also reported that they sometimes conduct exploratory journeys around the building, but that is rather rare.

Usually, clients of Palata do not want to disturb the personnel and try to solve any problems by themselves at first. After that, they call the employee by pressing a button placed nearby their bed in the room or reach the employee room to ask for help.

The most problematic places for clients of Home Palata are corners of the hallways and complicated places like intersections. Clients reported that they would use help in these places, but that is report only from the clients that do walk around the building which is by the measure of the sample we encountered merely 40 %.

There are also some reported incidents of clients entering the wrong room. This is somewhat rare and not caused by the orientation than being busy in thoughts or conversation with another client.

What makes problems more often are elevators. Clients reported that elevators are the main orientation landmarks for any cross-floor journey. However, also reported that they or someone else pushes a wrong button and due to inattention leave the elevator on the wrong floor or even the basement where the laundry is. These incidents are quite common and also stressful for some clients that now refuse to use the elevator alone because they fear of reaching a wrong floor and getting lost.

All around most of the problems reported by participants were based on orientation and lack of orientation in the environment of Home Palata.

4.1.2 Workshop with employees

Blind expert, my supervisor and I were conducting a workshop with employees of Home Palata (section 3.1) in order to receive insights about the facility from another point of view. The goal of this workshop was to get in touch with more people from the inside and discover more valuable information about the user domain that might got lsot during the interviews with participants. We focus on daily routines, needs, and problems of clients.

We managed to get in touch with four employees (three women, one man) for about 80 minutes. All of these employees were from different departments of Home Palata and from different personnel groups, including nurses, activisation employees (they take care of cultural and amusement activities that clients may participate in) and caregivers.

The workshop was divided into three phases. In the first phase, we introduced ourselves, telling them our background, experience, history of research of interfaces for visually impaired individuals — our current approach and state of our research and the goals we would like to reach.

The second phase was dedicated to open discussion about the project, clients, and other related topics. We gathered many interesting insights during this phase that otherwise would remain hidden because clients did not talk about those during the interviews.

The third phase was a design studio [16] based. Employees went through three short rounds of designing functions for the OT that they find useful or necessary for the residents. After the end of each round were those ideas and designs presented to others, and some of them were then also used in the next round regardless who came with the idea. Because employees were from different departments of the facility, their clients had a little bit different needs as different departments of the facility take care of different set of clients categorized by their motoric and mental capabilities. This diversity nicely revealed itself during the design studio phase.

There are many interesting findings, insights, ideas, and suggestions. Key insights and ideas were taken into consideration in the future User-Centered Design process [14]. One could say some of these are so trivial and obvious, that it is not possible that these were not discovered earlier. However, it is essential that employees shared those. The problems are listed below.

- Clients forget which side is left and which right and also freely interchange sides. This issue is more common within residents with more severe mental diseases and capabilities. However, it is not unusual that even the youngest and the most capable clients make such mistakes and assumptions.

- Most of the clients are confused about the distances. If it is either in meters or steps. Clients are not capable of correctly estimating the distances. Even during the learning phase of their spatial orientation during the newcomer's training are distances usually totally omitted and landmarks are used instead. So instead of "It is ten steps this direction from this room." are sentences like "It is the second door within the direction to the elevator from this room" used.

- Those with severe mental illness sometimes totally forget who they are, where are they and what is it they are currently doing. Self-awareness is a huge problem at the departments with clients having weak mental capabilities. Sometimes clients leave their rooms, the department and even the facility without any self-awareness. Clients cannot be forced to announce they are leaving as this is their home, not hospital or jail. Unfortunately, this leads in rare occasion to losing the client and then random people reporting the lost client in the city center. When clients come back, they do not even know they left or how they got there. So not only spatial and time orientation is needed, but probably even some kind of self-awareness and personality embracing features of the orientation system may be needed.

Employees also suggested more exciting and essential features and information that the orientation system should provide.

- Residents of the Home Palata often misunderstand or forget the morning local radio broadcast announcements. So they then ask employees about the date, weather, daily schedule, activities, lunch menu, etc.

- Instructions or information given by the orientation system should be as short as possible while still retaining the same value. Older people tend to lose attention and forget very fast what was said even just a few seconds ago.

Other than that were employees designing the OT with various exciting features and contexts in mind.

- Someone suggested dividing the system into spatial orientation, time orientation, lunch menu, weather, daily schedule, and activities.
- The OT could be used as a signpost on places where intersections are. The guiding line oriented into different directions could be made of different materials, and the OT could indicate the direction heading and the material to follow.
- The OT should be placed not only on the important routing places (main entrance, elevator) but also beside the most important landmarks in the building as almost everybody knows these places and even meetings between clients and arranged near those important landmarks. These landmarks are for example the bird's cage in the first floor of the central tower, or the teddy bear (third floor, central tower). Clients are even taught their routes in consideration of the important nearby landmark.
- Employee suggested taking in consideration the context of the part of the building the system is placed on (department) and use that as an advantage of knowing the subset of residents, that would use this part of the orientation system the most often. Orientation system, given information and instructions, and their simplicity and length could be adapted across various departments.
- As a follow-up idea on that previous one was an idea to use the context of the user by itself. If we could identify the client, we can provide tailored information and directions just for her/him. This could adapt the system to various types of residents based on their mental and motoric capabilities and also the known location of their room and activities.
- One exciting idea regarding the not so well working tactile symbols (section 2.2) was the use of metaphors to the topic or even real-world objects. So, for example, a date button on the OT could be accompanied by a real calendar object or lunch menu could be accompanied by a knife, fork, and a plate.

4.2 Design requirements

From the user study (see section 4.1) and analysis (see chapter 3) were determined and identified several functional and non-functional requirements for the OT. The set of functions of the OT (function requirements) are based on insights from interviews with clients (see subsection 4.1.1) and frequently asked questions by the clients reported during workshop with employees (see subsection 4.1.2). All requirements are listed below:

- **R1:** OT should be accessible for visually impaired and sighted. Visual impairment should not be a disadvantage nor advantage during interaction with OT.
- **R2:** User should be able to determine and predict the functionality before the functionality is invoked with no recall needed.
- **R3:** Interaction should not rely on knowledge of Braille.
- **R4:** OT interaction method and feedback should be easily understandable by any target user.
- **R5:** OT interaction method and feedback should be consistent throughout the whole system.
- **R6:** OT should not persist any state. Stateless interaction is less prone to unexpected behavior.
- **R7:** OT interaction should be repeatable without any restrictions.
- **R8:** Interaction should by invoked by the user, not by the OT.
- **R9:** OT design should prevent accidental interaction.
- **R10:** Accidental interaction should not set the system or user in an unexpected state or situation.
- **R11:** OT should divide the interaction parts into containers. Parts that belong together should be close together and contained. Parts that do not belong together should be in separate containers.
- **R12:** OT should provide a way to call for help or assistance.
- **R13:** OT should leave the user in the same or better mental state or orientation than before use.
- **R14:** OT needs to help users with spatial and situational orientation.
- **R15:** OT should work in synergy with other orientation system parts.
- **R16:** OT should work without other parts of the orientation system.
- **R17:** OT should not be prone to system errors and breakage.
- **R18:** OT should be made from safe, hygienic, washable, pleasant and durable materials.

- **R19:** OT should provide contextual information about the date, time, daily schedule, weather and meals
- **R20:** OT should provide navigation back to a safe place (client's room)

4.3 Design process

During the whole process, I employed the User-Centered Design technique [12]–[14]. The process is divided into separate iterations where I take into consideration the insights and results from the previous qualitative evaluation and design a new prototype (usually low-fidelity prototype) in order to be able to evaluate as soon as possible and do as many iterations as I can. All stakeholders are involved in the design process.

4.4 Design A

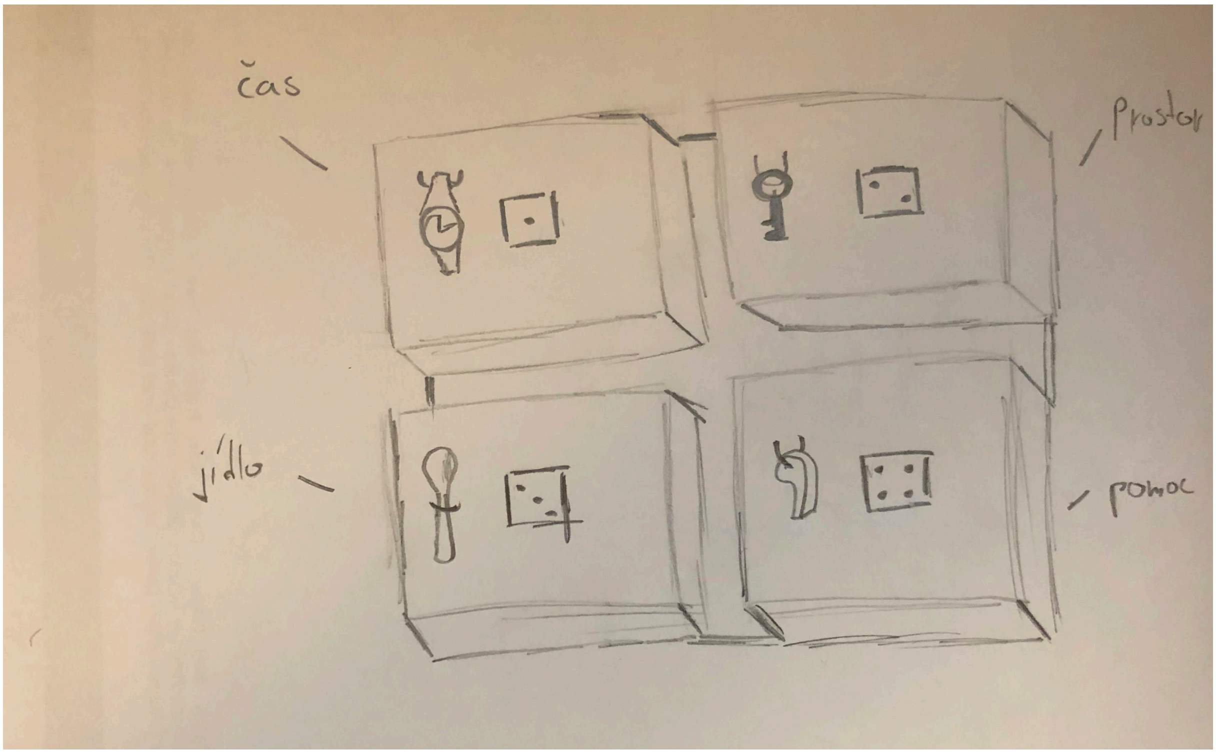


Figure 4.1: Design A: initial sketch of the OT

In the first design I focused mainly on the insights received from interviews (subsection 4.1.1), workshop with employees (subsection 4.1.2) and experiments in section 2.2. I chose four functions of the OT based on the frequent questions that clients of Home Palata (section 3.1) admitted to asking the employees. Those are questions about time, date, weather, and daily schedule, about lunch menu and spatial orientation. The last function serves the purpose of calling for help. As mentioned in subsection 4.1.2 someone suggested to divide the OT into sections in terms of the context of information the buttons provide. I think that is an excellent idea to strengthen the mental model of separated functions that the system provides and helps to separate the corresponding responses mentally.

Figure 4.2: Design A: low-fidelity prototype of the OT divided into four separate sections

From previous research (see section 2.2), we knew that people have a problem to match an abstract 2D button symbol with a real-world object, functionality, or abstract term. Part of that could be a problem of dimensionality reduction from the 3D world into a 2D symbol. So I tried to avoid this by thinking about a clever idea of different symbolic representation. An employee during the workshop (subsection 4.1.2) suggested using real-world metaphors in order to connect the functionality with the button mentally. So I came up with an idea of using real-world objects (including the actual size, material, etc.) and using those to depict the functionality. I have thought about numerous objects until I chose the final four. The main idea behind it was to try and arouse a similar set of thoughts and ideas behind the object that the user is familiar with and the functionality. So for example, when someone eats, there is always present a set of items like a plate, spoon and so on. I tried then to use these items as metaphors. Another advantage is that understanding of these objects is the same for people exploring visually and people exploring only by touch.

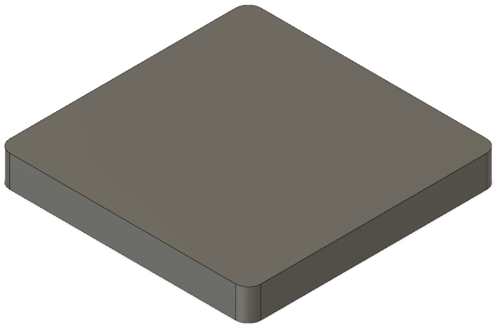


Figure 4.3: Design A: plastic rectangle representing a button. 4cm x 4cm x 5mm

Each section of the prototype is made of a cardboard square (15cm x 15cm) as depicted in Figure 4.2. In the center of each square is placed a rounded plastic rectangle (4cm x 4cm x 5mm) Figure 4.3, to the left of that rectangle, is placed the item using a metal wire or two. The items are always attached to the base so they can be explored from various directions (the key and whistle are hanging, the watch can be explored from the inside). Only the spoon is attached firmly because of technical reasons. The spoon is placed by the bowl upwards to simulate the position it has on the table during a meal. All objects are consistently placed on the left from the button. This is justified by designing for a culture which reads from left to right, including Braille. My idea here is that people will explore the OT from top left to bottom right in an ”F” pattern, just like it happens to be for sighted people on websites [71]. In the prototype, I used tactile separation (empty space) between the sections of the OT and also color separation for people who still partly use their sight to embrace recognition.

Used items were as follow:

- Wristwatch (yellow background) – represents time-related information. Button provides information about the current time and date, daily schedule, and weather.
- Spoon (green background) – represents eating. Button provides information about lunch time and lunch menu.
- Key (blue background) – represents going in/out of the room, walking. Button provides spatial information about the nearby surroundings and directions.
- Whistle (red background) – represents loud noise, draw attention to yourself. Button provides a way to call for help.

Every item has its set of attributes, that could be adjusted in future iterations to embrace the identification or mental connection.

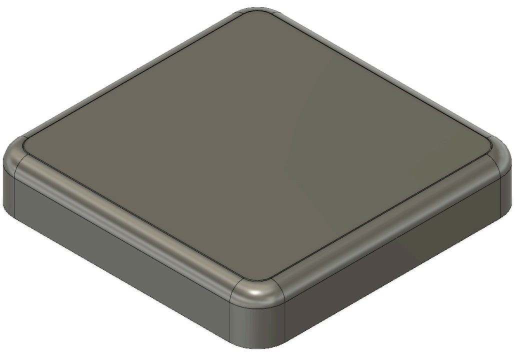
- Wristwatch - A larger, shiny, silver metal one with a metal band made of the same material, more likely men's wristwatch because of the size. I chose men's wristwatch because it is a larger object and should be easier to identify.
- Spoon - Shiny silver (iron) teaspoon with more pronounced deflection and deeper bowl. Teaspoon was chosen because of the size restrictions. More pronounced deflection and deeper bowl were chosen for easier identification.
- Key - An old large metal key, that was widely used in the past before FAB keys took over. Size and type were chosen for easier identification and recognition from the past (when people used way more keys like this one daily).
- Whistle - Small black plastic whistle. I chose this plastic whistle over a metal one as it has a larger and louder ball inside and I think people will tend to touch it. Moving the whistle makes more noise than the metal one, and I think it could help with identification.

The colored backgrounds are there to help people who primarily use a sight with separation and recognition. The only intended color is the red one under whistle to arouse the idea of help as emergency, ambulance, and help is usually depicted with red color as the main theme. The other colors are arbitrary.

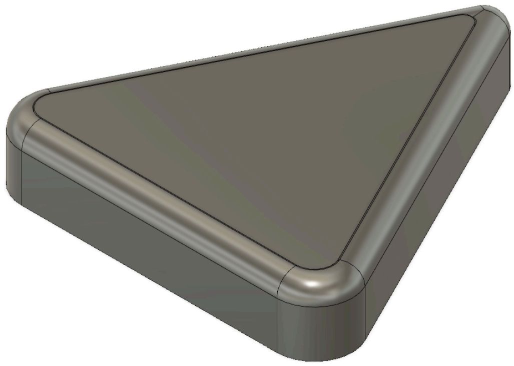
Evaluation of this design is available in section 6.1.

4.5 Design B

Use of real-world objects as symbols in the previous design produced good results. The only problematic part was the spatial orientation (the key). So in this iteration, I am trying to improve the section of the OT dedicated to spatial orientation while keeping the other parts untouched. There is a concurrently ongoing project of a haptic model of the Home Palata including haptic maps. So I decided to try and merge with the ideas of haptic maps. I got provided a prototype of a 3D haptic map reviewed by a blind expert for orientation. So I took the prototype and chose a concrete place in the building to model the haptic map at. I chose a place next to the elevator on the second floor (see in Figure 4.6) as this corresponds to a real usage scenario, and the place is not trivial for an experiment. The OT consists of two sides. On the right side are placed three sections from the previous design (excluding the key) section 4.4 vertically aligned in a row. On the left is placed a new part of the OT – haptic map. The haptic map consists of 4 parts (as depicted in Figure 4.4).

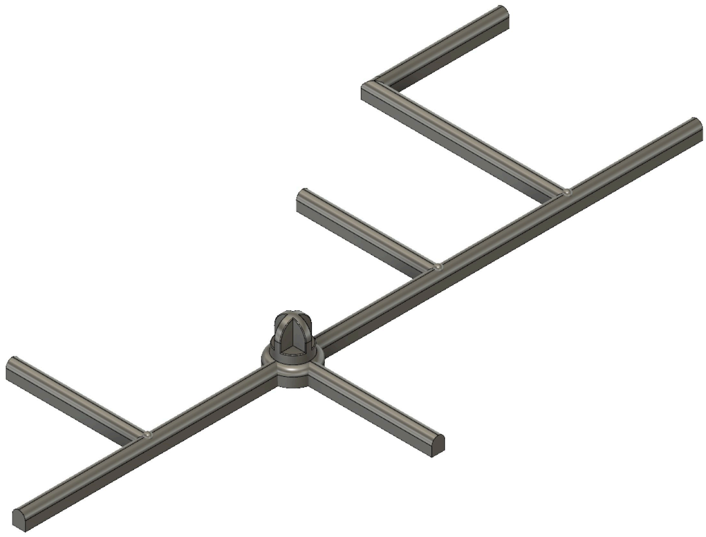


(a) rectangular button that represents a room (4cm x 4cm x 6mm)



(b) arrow button that represents a hallway or direction (4cm x 4.5cm x 6mm)

(c) circular knob that represents current location (1cm diameter, 2cm height)



(d) map made of elevated lines (5mm high, 4mm or 2mm wide)

Figure 4.4: Design B - haptic map components

The first part is a circular knob (1cm diameter, 2cm height) that represents the current location. On top is the circular knob rounded and contains ridges to emphasize a singularity and differentiability on the haptic map (as it is the only one present). It can be pushed like a button, and then the OT tells aloud the current location and describes the closest surroundings. The second part is rectangular 4cm x 4cm x 6mm buttons that represent a singular room. Name and direction of the room are read aloud by the OT upon button push. The third part is an arrow button (4cm x 4.5cm x 6mm). This one works almost the same as rectangular buttons except that these do not represent a singular room, but a direction to department or group of rooms, stairs and so on. The last part is the passive elevated line (5mm high) that connects the buttons and represents the hallways made of two types. Wide (4mm) representing the hall and narrow (2mm) representing the existence of a room (a button).

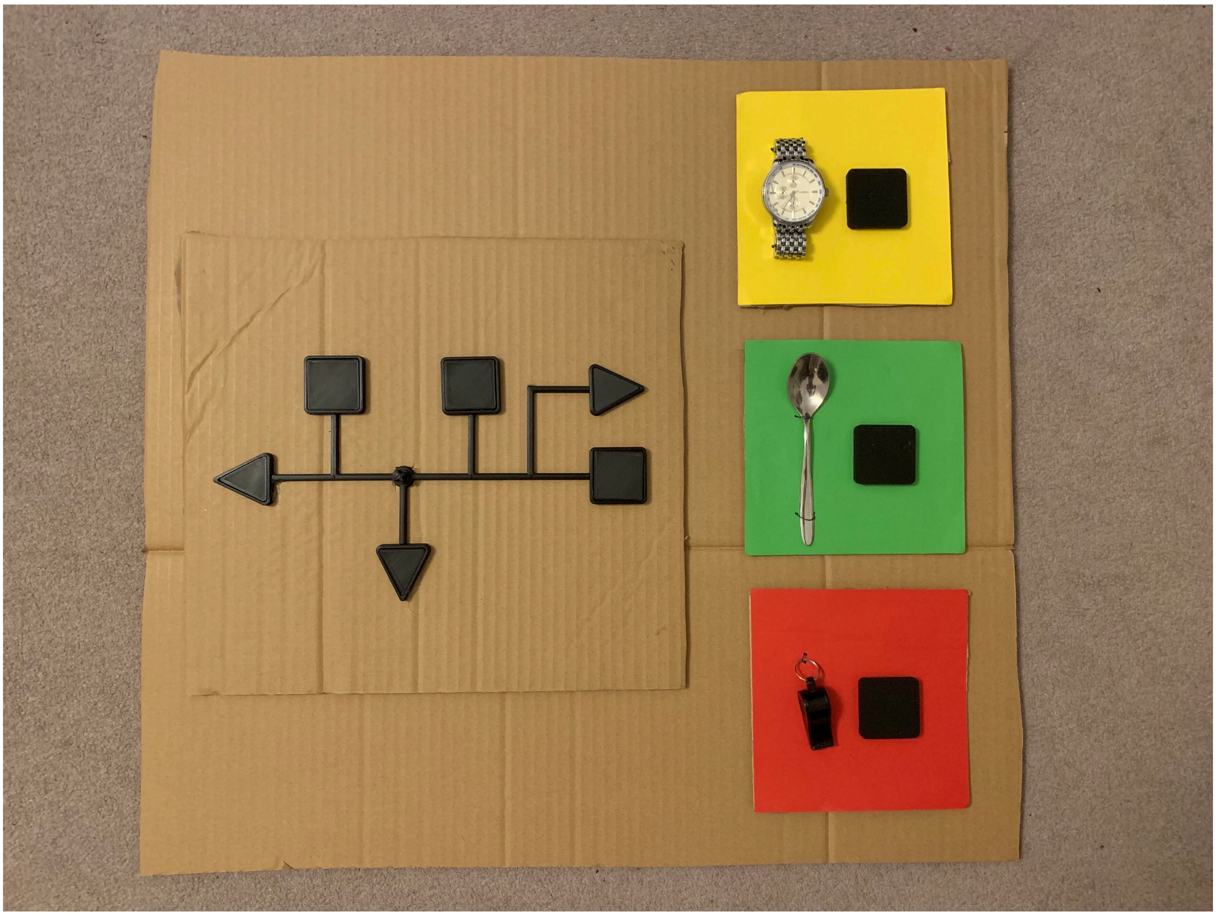


Figure 4.5: Design B: low-fidelity prototype of the OT divided into two dominant parts, one dedicated to spatial orientation and the other one to other functions

The intended usage is that the user touches the haptic map and finds the raised circular knob which tells current location. Based on the desired direction (or whole surroundings) can then user explore the corresponding rooms, directions, and hallways.

The instructions and information given by the Text To Speech synthesis software [72] (TTS) upon button press are as follows.

- Wristwatch – It is half past nine in the morning of Friday, the fourteenth of December 2018. It is Lydia's name-day. Outside there are three degrees below zero and calm. Canistherapy will be held in the common room on the second floor at four o'clock in the afternoon

- Spoon – For lunch, there will be cauliflower soup and goulash with bread dumplings, a diet lunch is a chicken slice with mashed potatoes. The dining room is open from 11:30.

- Whistle – If you need help or any assistance, push this button longer until you hear the tone.

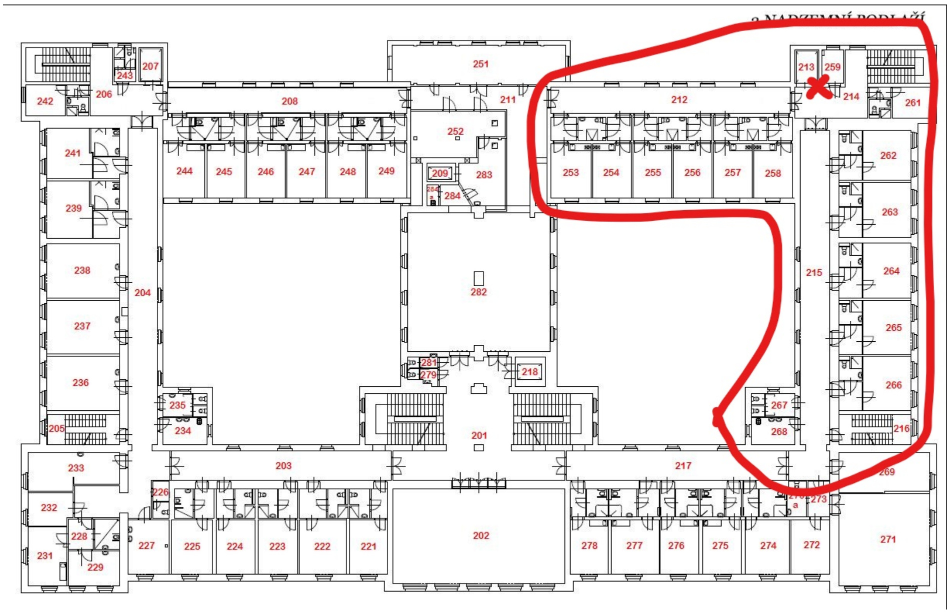


Figure 4.6: Design B: ground plan of Home Palata, second floor. The red marked part is the part that have been modelled by the haptic map and a red cross is exact location of placement of the OT.

- Whistle (long push) – Peep, an employee is on its way to you. Please stay here; an employee will help you soon.
- Circular knob – You are on the second floor one meter right from elevator A.
- Arrow back – Back to you is a corridor with rooms 262 to 266. At the end of the corridor is a nurse room and cultural room.
- Arrow left – In the left direction from you is a corridor with rooms 258 to 253. At the end of this corridor is a back entrance to the dining room.
- Arrow over the corner – Six meters right is a wall, two meters to the left from that point is a staircase upwards, to the left from it staircase downwards.
- Left room (elevator) – One meter left in this wall is elevator A.
- Right room – One meter to the right in this wall is a cleaning room. The cleaning room is inaccessible.
- Room 261 – Six meters to the right is a room 261.

4.6 Design C

I had two different options to choose from after evaluation of prototype B. Either I could try to improve the haptic map, make it cleaner and easier, make the circular knob stand out way more and try to make it usable for the user group or come up with a different solution and evaluate it. From the qualitative evaluation of design B, I decided to come up with a different approach as there were indications that the haptic map will not work for the user group as it requires too large cognitive load to be involved. Multiple projections need to be done by the haptic map. My current position, to position on the map, map projection to my surroundings, and a virtual map walk-through while projecting back to a real world. It was quite evident that this was too much for the user group, especially the people with cognitive issues. Nevertheless, I got some hints and ideas about the next design during the evaluation.

P1 from subsection 6.2.2 ignored all buttons above the horizontal line. Using only the left, right, and bottom one. She later answered that she thought that it is buttons for directions left, right and back from her. P4 reported: "The lines, hierarchy and all that around is too much for an old man. Too confusing. Keep just the buttons, please, make it simpler.". This, along with the fact that two people (P3, P7) reported they thought it is a sideways projection instead of a floor plan, brought me an idea of creating a simple cursor.

I chose four buttons for orientation consisting of one (central) for "Where I am" and three arrows (left, down, right) for directions to the left, back to them and right. I then also decided to take back the key section of the OT as it could serve a purpose of navigation back to safety (back to their room). The idea behind this was that the orientation cursor would transform the mental association of the key from "going somewhere out" to "going back home" as the cursor already serves the purpose of receiving information about orientation on going somewhere and receiving the same from the key is redundant. My idea is that the presence of those two parts nearby will modulate each other's purpose and will shift the opinion of users about the purpose and expected provided instructions. The only thing that could affect this is the order of exploration. I need to assure that spatial orientation section is observed first. I try to ensure that by the idea of synergy between the other parts of the orientation system — namely the guiding line. The guiding line should connect with the OT right beneath the cursor section, so the user is guided directly to the spatial orientation first. The order of the sections is designed, so it gradually spans from the most needed and frequently used to the occasional emergency.

It was also evident during the evaluation of design B (section 6.2) that there is only limited vertical space on the wall while horizontal space is almost infinite. So I decided to stretch out the OT horizontally and keep a minimal height. The OT is now having a shape of oblong rectangle consisting of 5 separate sections. See Figure 4.7 for better understanding.

With five distinct sections serves the OT four purposes. There is also concurrently

Figure 4.7: Design C: low-fidelity prototype of the OT divided into 5 sections, spatial orientation, navigation back to safety, time-related information, food related information and call for help

ongoing research of contextual user model designed for the same user group. I take this in advance and assume that the OT can identify the user and provide personally adjusted and contextual information for the specific user, e.g., navigation back to their room.

- Spatial orientation – the OT provides information about the current location, nearby surroundings, and directions.
- Navigation back to safety – the OT provides an itinerary of steps needed to take in order to get back to safety (participants room).
- Contextual information – the OT provides contextual information about the date, time, user's and building's schedule (e.g., therapies, lunch).
- Call for help – the OT provides an easy way to call for help in case of emergency or just a need of assistance.

The five sections are sorted from right to left like this.

1. Spatial orientation – white background, arrows (directions, surroundings) and central square button (where I am)
2. Navigation to room – blue background, metal key
3. Time related information – yellow background, metal men's wristwatch
4. Food related information – green background, a metal teaspoon
5. Call for help – red background, metal whistle

The metal wristwatch changed slightly from the previous iteration. That is due to a breakage done during transportation of the prototype; there is no other reason. I tried to find wristwatch to be as similar as possible to the previous one. The whistle changed too, and I intended that. The only problematic item for identification during the evaluation subsection 6.2.2 was the plastic whistle. I previously used the plastic one as it was noisier while being manipulated by a hand (larger ball inside). However, I may have been wrong about this, and people of the target age usually came across a metal whistle during their life, so I decided to change it for a metallic one and try if it makes some difference.

The first section of the OT (spatial orientation, arrows) needed to be reworked a little as it does not match the original theme of one button and one item side by side. I had to expand the width of the section to 20cm in order to place all buttons inside of it while keeping the negative space distances equal. The first section is then 15cm x 20cm. I chose a white color as an arbitrary color. The factors for choosing white were three. The first factor was that it was not already taken, and it differs much more from other colors. Brown could be confused with red, purple with blue, etc. The other factor is that those black buttons can be easily identified and recognized on the white background. It is the most contrasting one, and that comes hand in hand with the need to recognize arrow directions and two different types of buttons. The third factor is that white color could represent empty space, arousing the idea of spatial orientation.

I also made all distances and dimensions consistent across the OT. I chose two different lengths, a width of a single average human finger (about 13.5mm) and two fingers width side by side (about 30mm). These are consistently repeated on the OT. This is depicted in Figure 4.8.

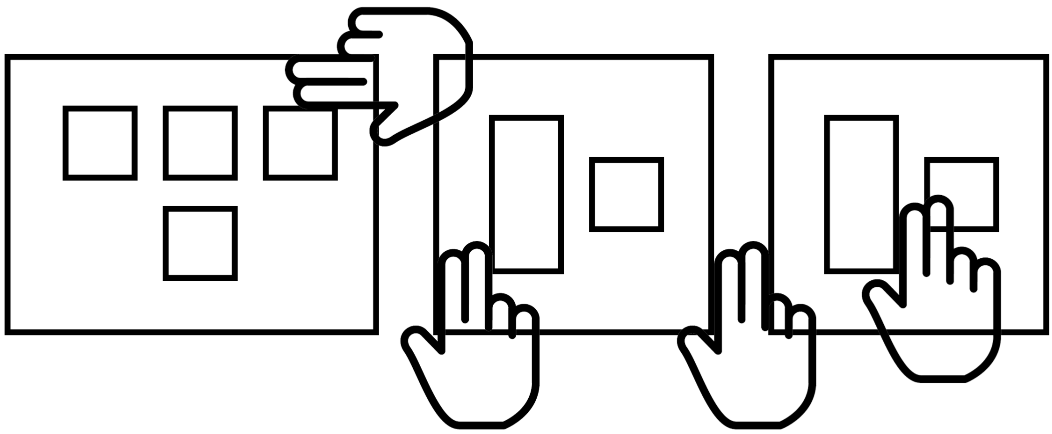


Figure 4.8: Design C: dimensions of the prototype depicted as finger widths

Distance between item and button – one finger width, this ensures that every time a person touches the object attached next to the button, it also touches the button itself accidentally. This allows for easy discovery of the buttons, items attached, and their relation.

Distance between buttons (spatial orientation section) – one finger with; the reason is the same as the distance between item and button.

Distance between sections – two fingers; this ensures clear separation of the sections not only by the edge but also by the negative space between.

Distance between item/button and the edge of section – two fingers; this allows comfort exploration of the sections and ensures no connection between buttons and items from different sections are made.

The instructions and information given by the TTS upon button press are as follows.

- Where I am – You are on the second floor one meter right from elevator A.
- Arrow left – In the left direction from you is a corridor with rooms 258 to 253. At the end of this corridor is a back entrance to the dining room.
- Arrow back – Five meters back to you starts a corridor with rooms 262 to 266. At the end of the corridor is a nurse room and cultural room.
- Arrow right – Six meters right is a wall, two meters to the left from that point is a staircase upwards, to the left from it staircase downwards.
- Key – Your room number 225 is on this floor. The way to it leads down the corridor behind you, at the end of this corridor, turn right and find the third room.
- Wristwatch – It is half-past eleven in the morning of Tuesday, the fourth of March, 2019. It is Casimir's name-day. Outside it is eight degrees, cloudy and calm. Canistherapy will be held in the common room on the second floor at four o'clock in the afternoon
- Spoon – For lunch, there will be cauliflower soup and goulash with bread dumplings, diet lunch is chicken slice with mashed potatoes. The dining room is open from 11:30.
- Whistle – If you need help or any assistance, push this button longer until you hear the tone.
- Whistle (long push) – Peep, an employee is on its way to you. Please stay here; an employee will help you soon.

4.7 Design D (High-fidelity prototype)

Evaluation of previous design (section 6.3) showed excellent results, so a high-fidelity prototype of this design was created and evaluated. The design is identical with the previous design (see section 4.6). There is only one change in the design. An addition of bonus or extended information was added to the functionality of a key, wristwatch, and spoon buttons.

In the previous experiment section 6.3 was mentioned by a few people that they would like to have a special action available to invoke extended or bonus information from the OT. Thus I decided to add this feature experimentally. On the key, wristwatch and spoon buttons can be invoked special information by a long push (for at least 2.5 seconds). The key provides a detailed navigational itinerary of the route back to the client's room. The wristwatch provides name-day, weather forecast, and schedule for tomorrow. The spoon provides the whole menu for the current day and also diet versions of the meals.

Creation, hardware, and software details and deployment of the high-fidelity prototype are discussed in chapter 5 (Implementation).

The instructions and information given by the TTS upon button press during evaluation of design D (section 6.4) are as follows.

- Where I am – You are on the second floor one meter right from elevator A.
- Arrow left – One meter to the left of you is an elevator, then a corridor with rooms 258 to 253. At the end of the corridor is the back entrance to the dining room.
- Arrow back – Five meters behind you begins the corridor to rooms 262 to 266. At its end are a nursery and a small cultural room.
- Arrow right – Six meters to the right of you with free space is a wall. Two meters on the left along this wall is a staircase up, and the staircase down to the left.
- Key – Your room number 237 is located on this floor. The way to it leads down the corridor behind you; the corridor turns right at the end, your room is the third on your left in this corridor.
- Key (long push) – Turn your back on this OT. Go through the six-meter free space and look down the left side of the corridor wall. Walk along this wall thirty meters. At the seventh door, the nursery, turn right, go four meters through the open space, and find the hallway wall on the left. Walk along the wall ten meters; the third door is the entrance to your room number 237.
- Wristwatch – It is half-past eleven in the morning, Friday the third of May 2019. It is Alexei's name-day. Outside is eleven degrees, cloudy and gentle wind. Canistherapy will be held in the common room at four o'clock in the afternoon.
- Wristwatch (long push) – Tomorrow is Květoslav's name-day. Outside, there will be 13 degrees and rain. Tomorrow at three o'clock there will be art therapy in a small cultural room.

- Spoon – For lunch, there will be cauliflower soup and beef goulash with bread dumplings. The dining room is open from 11:30. The back entrance to the dining room is fifteen meters at the end of the corridor, which starts three meters to the left of you.

- Spoon (long push) – Diet lunch is a chicken slice with mashed potatoes. For dinner, there will be a potato pancake with smoked meat and sauerkraut. Diet dinners are pancakes with cottage cheese.

- Whistle – If you need help or any assistance, push this button longer until you hear the tone.

- Whistle (long push) – Peep, an employee is on its way. Please stay here; an employee will help you soon.

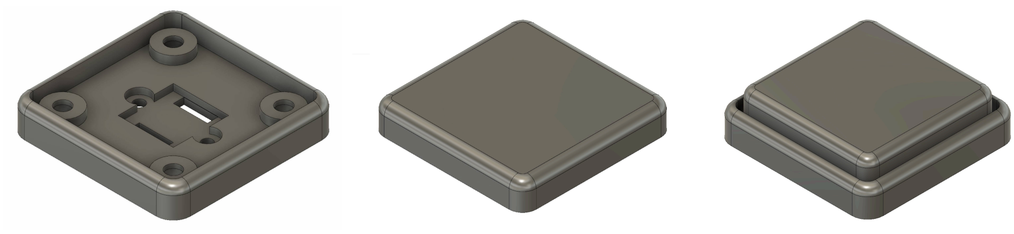
Chapter 5

Implementation

As mentioned in design C section (section 4.7), design C was a success, and I decided to fulfill the final goals of this thesis by implementation and evaluation of the high-fidelity prototype.

5.1 Hardware

In order to create the high-fidelity prototype, I chose 3D prints as the most suitable method of creation. It is fast, cheap, easy to employ, and the material suits the needs of an orientation system terminal. 3D printed plastics are harmless, washable, light enough to be mounted on a wall but still strong enough to withstand regular use of touch exploration and button pressing. Also, there are many colors of 3D printer materials to choose from so I can keep the color separation of sections straightforward.



(a) Square button base (4cm x 4cm) (b) Square button cap (c) Square button

Figure 5.1: High-fidelity prototype - square button assembly

I started by 3D modeling of all buttons. Every button, square or arrow is made of two parts. Button base and button cap. See Figure 5.1 & Figure 5.3 to observe the models in detail. The button base will also consist of microswitch (see Figure 5.2) that sits in the center and provides the tactile button feedback, clicking sound as well as the circuit input. The button base is mounted to a section base by two M1.6 screws. The second part of all buttons is the button cap. It sits directly on the microswitch, and it is mounted by four (three in case of an arrow) M1.6 locking screws in the corners. These screws not only ensure that the button cap does not fall off, but also consistent clickiness all around the button cap and also limits the wobbliness of the button cap.

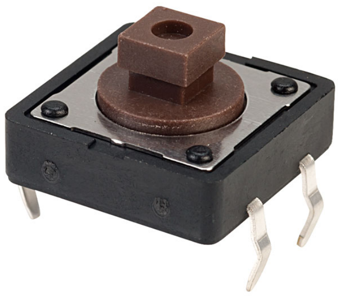
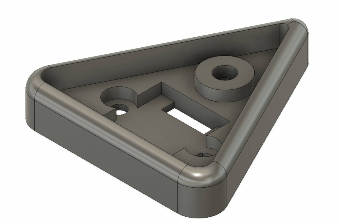
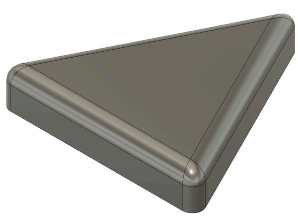


Figure 5.2: High-fidelity prototype: DTS-24N tactile switch 12mm x 12mm, figure taken from [73]

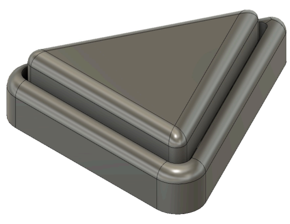
I also 3D modeled the section bases. See Figure 5.4 for a detail. The sections are 2cm high, and the thickness of the plastic is 2mm. All edges had been rounded. This also applies for the buttons as sharp edges could cause harm to users, and that is unacceptable as the users will explore the OT by touch. The sections bases include cutouts for the buttons, but no cutouts for the attached items as those were precisely drilled later on. There is also support underneath the base, which prevents bending while the button is being pushed. Sections bases should be attached to a foundation plate by either screws or a snap-on mechanism. Both of the options are modeled into the button base as it was not already decided on what to use during the prototyping phase.



(a) Arrow button base (4cm x 4.5cm)



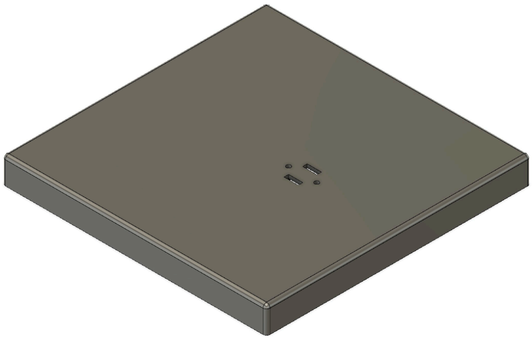
(b) Arrow button cap



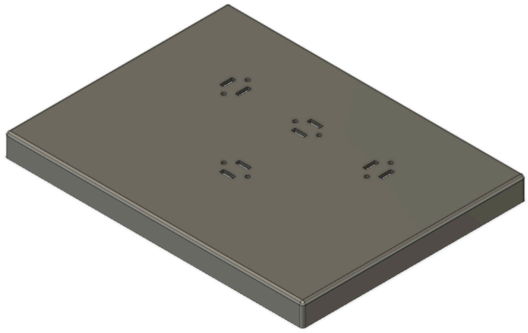
(c) Arrow arrow

Figure 5.3: High-fidelity prototype - arrow button assembly

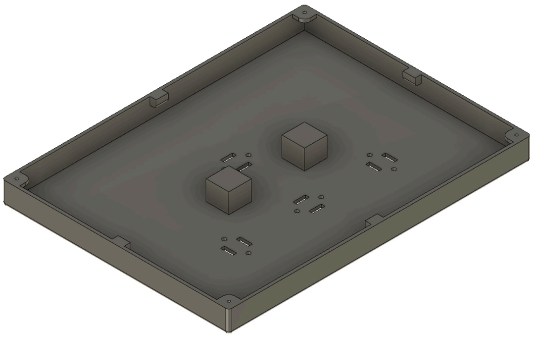
The parts were printed on a 3D printer Prusa i3 MK2 [74]. The material used was PLA in four different colors (white, blue, green, yellow) and one PETG in bright orange color due to lack of red and orange PLA material. Those two materials are almost indistinguishable, so it does not take any effect during the experiment.



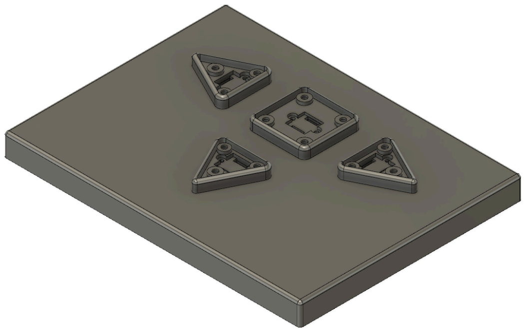
(a) Section support (15cm x 15cm)



(b) Cursor section support (15cm x 20cm)



(c) Cursor section support bottom



(d) Cursor section support with button supports in place

Figure 5.4: High-fidelity prototype - sections assembly

5.2 Software and deployment

The deployment of the prototype consists of two distinct parts. The first part is the OT with buttons by itself. The electronics inside are made of microswitches, resistors, wires, and microcontroller Arduino Pro Micro (by SparkFun) [75], [76]. The diagram can be seen here Figure 5.5. It runs a simple code that detects possible actions on any of the buttons. Those actions are "push down," "release," "long push" (being pushed for 2500ms) and "release after the long push." If any of these actions are registered, a simple string is sent on the serial port. The string format is as follows: "ACTION_BNUMBER," where ACTION can be of types "ON," "OFF," "LONG" and "OFFLONG" and BNUMBER denotes simply a number of the button. Code snippet of the firmware is available at section A.1.

The second part of the deployment is a TTS server written in python. It listens to commands which are being sent by the OT on the serial port and then it plays a corresponding sound to the command. Code snippet of the TTS server is available at section A.2.

A schema of the deployment can be seen on Figure 5.5.

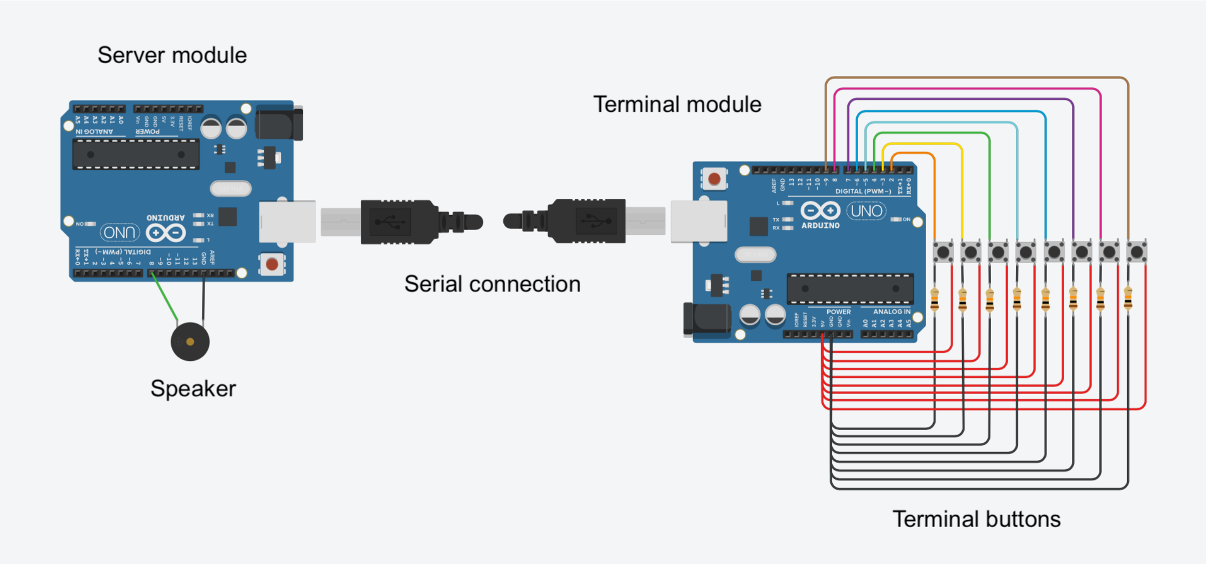


Figure 5.5: High-fidelity prototype: deployment schema, generated from tinkercad [77]

The python server was running on my laptop during the evaluation as it also provided power to the OT, while I used Bluetooth speaker mounted above the OT for voice output. The python server could be running on a small computer like Raspberry Pi Zero W [78] with a speaker hidden inside the OT.

Software used for 3D modeling was Autodesk's Fusion 360, cloud CAD software [79]. Software used for 3D printing options and gcode generating was Ultimaker Cura [80].

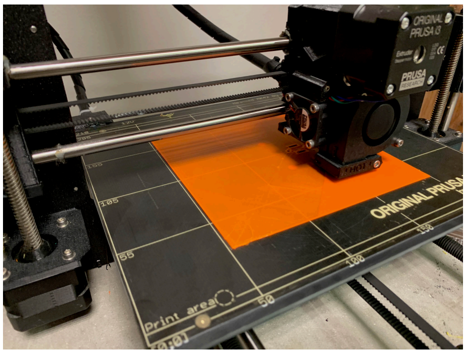


Figure 5.6: High-fidelity prototype: 3D printing process

The whole prototype mounted on a wall at Home Palata section 3.1 can be seen here Figure 5.7. Above the OT is placed a Bluetooth speaker connected to a laptop which runs the TTS server. Underneath the OT can be seen USB cable providing power and a serial connection to the TTS server.

The TTS server does provide not only TTS voice output but also audio feedback upon button push. There are two sets of sounds played for corresponding actions. A short beep is played upon button push to provide feedback for the user to know the button is being pressed. Also, a short high pitch tone is being played after invoking a long push action.

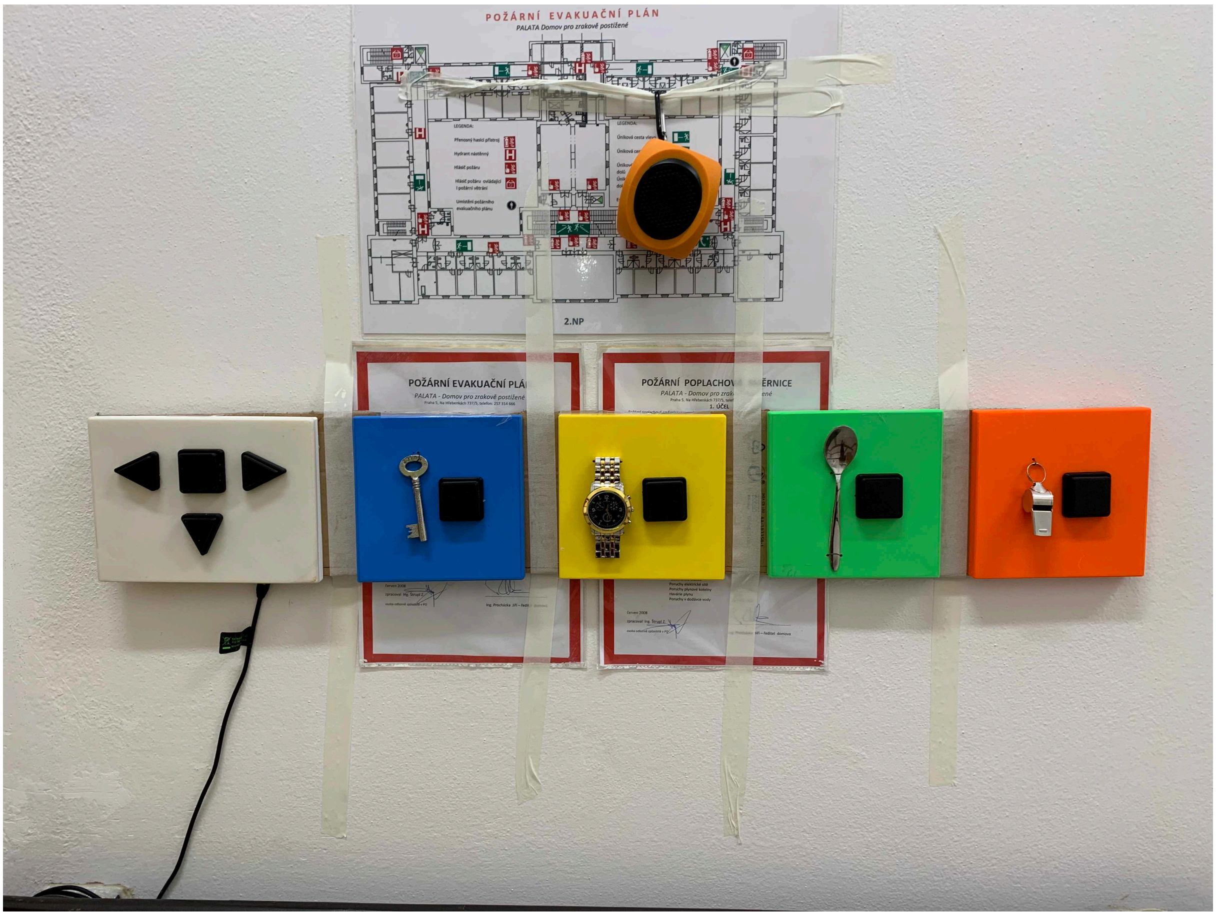


Figure 5.7: High-fidelity prototype: prototype mounted on a wall

The TTS output is always played after these sounds. These requirements are stated by authors in [20].

Evaluation of the high-fidelity prototype is discussed in section 6.4.

Chapter 6

Evaluation

All four designs (see chapter 4) were evaluated with participants recruited from residential home (see section 3.1). The evaluation is chronologically sorted from the earliest design (design A, see section 4.4) to the latest (design D, see section 4.7).

6.1 Design A evaluation

Evaluation of Design A (section 4.4) was conducted with six participants from Home Palata (section 3.1), five women and one man, mean age 87.7 ($MED = 86$, $MIN = 81$, $MAX = 98$, $SD = 5.8$), see table 6.1. Two participants had bad sight, and four were blind. The evaluation was separated into four phases. The first three phases were conducted to get more insights on the future design, and the last phase was the actual evaluation experiment. The whole experiment took on average about 35 minutes.

Participant	**Sex**	**Age**	**Impairment**	**Impairment duration**
P1	F	90	severe	5+Y
P2	M	86	blind	70Y
P3	F	86	severe	70Y
P4	F	85	blind	8Y
P5 ($P3_C, P3_D$)	F	81	blind (light perception)	10Y
P6	F	98	blind (light perception)	5+Y

Table 6.1: Table of participants for evaluation of design A, P5 is also P3 from evaluation of design C, D

6.1.1 Phase 1 - association of ideas

In phase 1 were participants said words, and their task was to answer the first thing that came to their mind. The meaning behind this process is getting more ideas of various objects and metaphors for the system functions representation. This part confirmed that watch is usually the first thing that comes to mind when thinking about something time-related. Ideas associated with food were concrete meals or chef. A spoon was not mentioned. Call for help was associated with medical help, doctors, etc. Also, spatial orientation words were very inconsistent, subjective, or abstract, so no valuable information was observed. Results are depicted in Table 6.2.

	Words and associated ideas							
P#	**Food**	**Time**	**Weather**	**Orientation**	**Space**	**Surroundings**	**Where I am**	**Call for help**
P1	potato pancakes	growing tree	cloud	map	the universe	forest	tree	stretcher
P2	vegetable sauce	age	sun	white cane	-	wall	someones help	nurse
P3	chef	wrist watch	sun, countryside	white cane	-	furniture	-	doctor
P4		clock	cloud, outdoors	-	-	-	-	-
P5	taste	watch	rain, sun	scouting	shining light in space	forest	-	fire
P6	hunger	seasons	rain, cloud	-	-	-	-	-

Table 6.2: Phase 1: table of idea associations with words

6.1.2 Phase 2 - the association of items

In phase 2 were participants said words, and their task was to answer the first concrete object that came to their mind. The meaning behind this process is getting more ideas of various objects and metaphors for the system functions representation. Five of six people's first item on mind associated with time was a wristwatch or clock. This perfectly matches the design. Food associations are now separated into a concrete meal or a fork, knife, and spoon. Half of the ideas match the design too. Help remains a little bit more divergent as associated items vary. However, all of the items signalize some urge of a call for help or getting attention. Regarding the orientation are words clustered into tools for orientation (map, white cane), items regarding orientation (landmark) and phenomenon connected with the orientation process like traffic noise. No one mentioned a key which may signalize that the key may not work with the intended design. Results are depicted in Table 6.3.

	Words and associated items			
Participant	**Time**	**Orientation**	**Food**	**Help**
P1	growing tree	map	potato pancakes	stretcher
P2	wrist watch	white cane	vegetable sauce	phone
P3	wrist watch	white cane	favorite meal	ambulance
P4	clock	landmark	spoon, dumplings	dog
P5	wrist watch	-	knife and fork	fire
P6	clock	traffic noise	fork	-

Table 6.3: Phase 2: table of item associations with words

6.1.3 Phase 3 - association of materials

In phase 3 were participants told the same words as in phase 2, and their task was to answer the first material that came to their mind. The meaning behind this process is getting more ideas of various materials for the distinct sections of the OT for easier intelligibility. Unfortunately, associations to materials are too abstract, and there is no observed general connection of a material to the words. The material results are very divergent or even too abstract to depict, as shown in Table 6.4. Only potatoes as a material resembling food and bandage or fabric resembling help were common. Fabric may be used, but nothing else usable was observed in this phase.

6.1.4 Phase 4 - the association of functions to items

In phase 4 were participants given a prototype of the OT containing the four sections with buttons (mentioned in section 4.4). They were allowed to explore the OT freely. Participants were only told that pushing the buttons would do some action. Their task was to say aloud what they think the button would do. Concrete answers are depicted in Table 6.5.

Participants correctly identified all the objects. That is a great success and concludes that this seems like working design of understandable symbols. The results of the associations seem very promising for watch, spoon, and whistle. The whistle is especially great with a 100 % identical associations as the intended functionality. The key is little more complicated as it recalls an action of movement. It does not only resemble movement back home or back to the room, to safety or known location (two occasions, P3, P4) it also resembles of leaving (three occasions, P1, P2, P5). Participants are expecting the intended functionality of movement, that is great. Unfortunately, these are two separate ideas and overloading of the button with multiple functions (spatial orientation, getting back) could result in ambiguous results. As spatial orientation and getting back to safety

	Words and associated materials			
Participant	**Time**	**Orientation**	**Food**	**Help**
P1	wood	-	potatoes	bandage
P2	-	wall	potatoes	fabric
P3	-	-	bread	bandage
P4	-	-	-	
P5	-	-	mashed potatoes	
P6	-	-	-	

Table 6.4: Phase 3: table of material associations with words

	Words and associated items			
Participant	**Watch**	**Key**	**Spoon**	**Whistle**
P1	time	gatehouse	coffee time	call someone
P2	-	leaving house	go eat	call someone
P3	schedule	getting to flat	go eat	call help
P4	time, date	go to room	go eat	call someone
P5	time, schedule	leaving house	go eat, lunch menu	call someone
P6	time, date, daily schedule	go there	stir coffee	call help

Table 6.5: Phase 4: table of associated functions to OT section

is the most critical functionality of the OT, this result is not convincing enough, and I am going to try and find different design ideas to separate these two functions.

6.1.5 Conclusion

Results show that association of functionality and chosen set of symbols works great. All participants correctly identified the used objects. That concludes my idea of using concrete real-world objects instead of 2D symbols. Unfortunately, the association of functionality to the key object is diverging between moving back to the room and leaving the room, that could result in ambiguous expectations and usage, and more work needs to be done on that topic.

6.2 Design B evaluation

Evaluation of Design B (section 4.5) was conducted with seven participants from Home Palata (section 3.1), six women and one man, mean age 83 ($MED = 81$, $MIN = 70$, $MAX = 94$, $SD = 7,9$), see table 6.6. four participants had very bad sigh and three were blind.

Participant	**Age**	**Sex**	**Impairment**	**Impairment duration**
P1	81	F	blind (light perception)	13Y
P2	94	F	severe	5Y
P3	81	F	severe	23Y
P4 ($P5_C$)	70	M	severe	10Y
P5	79	F	blind (light perception)	1Y
P6	90	F	severe	30Y
P7	86	F	blind (light perception)	5Y

Table 6.6: Table of participants for evaluation of design B, P4 is P5 from evaluation of design C

6.2.1 Procedure

The placement of the OT prototype was on the second floor, next to the elevator A as this is a non-trivial location and also a real usage scenario. You can observe a floor plan with a marked location on Figure 4.6. The disadvantage of this place was that it is on quite busy corridor with many people going around, usually talking or even talking to us on some occasions. The place was crowded by people waiting for the elevator with voice feedback, which was talking the whole time during the experiment, during lunchtime. I think this is a perfect place for experiment even though it is not quiet a laboratory environment as people using the OT in the real world would face those issues too.

I placed the prototype at the corresponding location on the wall centered at the eye level of an approximately 165cm high person and brought the participant in. I told them that there is a prototype of the OT that can talk and possibly help them. I also mentioned that the OT could tell them what is around, what time is it or what is for lunch. I let the participants explore the OT and use the think-aloud protocol to get into their point of view. I encouraged them to tell me what they found, what those items represent, and what function could they serve.

The voice feedback of the OT was simulated by using a Wizard of Oz technique. I was activating the TTS on my tablet upon button press during the evaluation.

After free exploration, I explained to participants that the OT is divided into two separate parts and that there are buttons which can talk upon pushing. In the end, I ask participants the following set of questions for them to answer.

1. Can this OT tell you what time it is?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?
2. Can this OT tell you where you are? What is your current location?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?
3. Can this OT tell you what is for lunch today?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?
4. Can you tell me what is around you using the OT?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?
5. Which direction would you go to get to a cultural room on this floor?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?

6. Which direction would you go to get to a nearby staircase?
    (a) What would you do to make the OT tell you?
    (b) Which button would you push?

6.2.2 Results

I will discuss the results participant by participant always starting with the information part of the OT (wristwatch, spoon, whistle) then reporting on interaction with the haptic map. A shortened overview is depicted in Table 6.7. The whole experiment took on average about 25 minutes.

Participant	Item identification	Function prediction	Haptic map usage
P1	All	All	Failed
P2	2/3	All	Failed
P3	2/3	All	Sideways projection
P4	All	All	Failed
P5	All	All	Yes
P6	2/3	All	Failed
P7	2/3	1/3	Sideways projection, later yes

Table 6.7: Overview of the most important experiment B results

Participant P1

She correctly identified wristwatch, spoon, and whistle. Also, correctly predicting their functionality. She very liked this part of the OT. Unfortunately, the other part (haptic map) remained unnoticed. I had to step in and encourage her to explore more and notice the haptic map. She later answered that she ignored it because she did not understand it. While using the haptic map, she missed the circular knob (”where I am” button). Even after encouraging her to use it, she kept on ignoring this button. She also ignored all buttons above the horizontal line. She was using only the left, right, and bottom one. She later answered that she thought that it is buttons for directions left, right and back from her. Then I explained the haptic map idea and how it should work. I tried again if she will be available to use it with this knowledge. However, she remained too confused and kept on pushing the elevator button. She could not even answer where she is and what is around. Thus she could not use the haptic map. The participant said it was too much for her — ”too many buttons and too confusing”.

Participant P2

Participant correctly identified wristwatch and spoon. She could not identify whistle for a long time. A small hint helped her identify later on. She predicted all functions correctly. She did not realize it is a map and did not understand the concept even after some time spent explaining and teaching. She ignored the circular knob and all of the lines. Her strategy was to press all buttons in random order and listen to the feedback. She caught the information from the TTS instructions, but could not reliably answer, because she could not map the instructions to the map and surroundings. The experiment was later terminated without any noticeable improvement in understanding of the concept of a map.

Participant P3

Even though P3 used mainly sight for exploration, she did not identify whistle at first glance. She had to spend some time exploring it in order to identify correctly. All other items were identified correctly. Functions were also correctly assigned. Only for the whistle, she said: "It is something to call in people, for example, call for lunch or an event.". She ignored "where I am" during the usage of the haptic map. At first, she used only rectangular buttons. She then reported that she thought arrows only show directions and cannot also be pushed. Her idea of the haptic map was a sideways projection instead of a floor plan. Thus she understood the horizontal line as this floor, and all above is on the upper floor, while all below being on the ground floor. I explained to her that the idea here is a floor plan, not a sideways projection. After gaining this knowledge was she able to finish all the tasks successfully. She also asked if parts of the haptic map could be distinguished by colors as her main perception was eyesight. In the end, she reported that more clear declaration on "what can be pushed and what can not, would definitely help too."

Participant P4

Participant correctly identified all objects and predicted all functions. When using the haptic map did not notice the circular knob and later answered that the down arrow signalizes "where I am" function for him. After explaining the circular knob, he was able to use it later on successfully. Unfortunately, he did not understand the hierarchy and relation between buttons and lines. He used only the buttons and later reported. "The lines, hierarchy and all that around is too much for an old man. Too confusing. Keep just the buttons, please, make it simpler." He was able to finish the tasks, but did not like the concept and would welcome something way simpler without any map, lines — only buttons and directions.

Participant P5

P5 correctly identified the whistle and spoon. At first glance, she thought the wristwatch was a toy car. She was later changing mind after grabbing the watch into her hand. All functions were predicted correctly. She understood that it is a haptic plan and thought at first; it depicts a different location in the same building. She corrected her opinions swiftly after using the circular knob. She even correctly answered simple questions about spatial orientation and which directions are the mentioned rooms gathered from the OT. Unfortunately, the OT layout was too large for her. She always stuck at exploring a small neighborhood of buttons being afraid to leave it. I had to instruct her on finding other buttons. Her interaction with the OT was far from confident. However, she clearly showed she understands the concept.

Participant P6

She could not identify the wristwatch. All other objects were correctly identified, and all functions assigned. It was quite noticeable that she can not hold a large cognitive load. She always understood a first few and last few words from the instructions. Only the short instructions (like an elevator) were clear for her. She did not get the idea of a haptic map, and it also seemed impossible to explain it to her. She pushed the buttons in random order, not understanding the concept and hierarchy and not even using the lines. Nevertheless, was she smiling the whole time and repeatedly reported she likes it and needs some time to learn using it. She even asked if I could "borrow her that box," so she can exercise.

Participant P7

P7 identified all apart from the whistle. She thought it is a key chain. She expected the spoon to tell her the way to the dining room instead of a lunch and wristwatch to tell her which way to go to a currently ongoing event or therapy. She realized it is a map but did not use the circular knob as a button but rather as a passive landmark or flag of her current location. At first, she thought it is a sideways projection instead of a floor plan later correcting herself. She even correctly answered that buttons are for rooms, arrows for halls, and directions. She was struggling but could use the haptic plan to some extent.

6.2.3 Conclusion

Results show that information part of the OT works very well with a small exception for the whistle. People tend to have a harder time identifying it, and this could be improved in the next iteration. There was also a nice discovery of all 7 participants being able to correctly use the long push of the ”call for help” button. Some even tried to use this button during the experiment trying to get some hints from me. The haptic map, on the other hand, was a total disaster. The circular knob on the map was always ignored and will need a rework. Only 3 (P4, P5, P7) participants realized it is a map, 2 (P3, P7) even thinking it is a sideways projection instead of a floor plan. Only one participant (P5) being quite reliably able to use the map and another one able to use it with a little help (P7) is not a convincing result. This is indicating that the haptic map may not be the right design.

6.3 Design C evaluation

Evaluation of Design C (section 4.6) was conducted with six participants from Home Palata (section 3.1), four women and two men, mean age 79.5 ($MED = 86$, $MIN = 52$, $MAX = 93$, $SD = 15.8$), see table 6.8. four participants had very bad sigh and two were blind. The whole experiment took on average about 20 minutes.

Participant	**Age**	**Sex**	**Impairment**	**Impairment duration**
P1	90	F	severe	20Y
P2	93	F	blind	15Y
P3 ($P5_A, P3_D$)	82	F	blind (light perception)	10Y
P4	90	F	moderate	2Y
P5 ($P4_B$)	70	M	severe	10Y
P6	52	M	blind	27Y

Table 6.8: Table of participants for evaluation of design C, P3 is P5 from evaluation of design A and P3 from D, P5 is P4 from design B

6.3.1 Procedure

I placed the prototype on the wall on the second floor, next to the elevator (see placement Figure 6.1) and brought the participant in. The location is the same as in experiment B (see Figure 4.6). I told participants there is a prototype of terminal that can talk and possibly help them. I let the participants explore the OT and use the think-aloud protocol to get into their point of view. I encouraged them to tell me what they found, what those items represent, and what function could they serve.

The voice feedback of the OT was simulated by using a Wizard of Oz technique. I was activating the TTS on my tablet upon button press during the evaluation.

Figure 6.1: Placement of prototype C in Home Palata (section 3.1) during evaluation

After free exploration, I explained to participants that the OT is divided into sections, and each section serves a different purpose and provides some functionality. I also mentioned that buttons found on the OT could be pushed and upon that will the OT do something. Participants were then given a set of questions and tasks to answer or finish.

1. Can this OT tell you what **time or date** is it?

    (a) What would you do to make the OT tell you?

    (b) Which button would you push?

    (c) What is the date today?

    (d) Whos name-day is it today?

    (e) What therapy is going to be held in the afternoon and where?

2. Can this OT tell you **where you are**?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?
   (c) What is your current location?
3. Can this OT tell you **what's for lunch** today?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?
   (c) What is for lunch today?
4. Can this OT tell you **what is around** you?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?
   (c) What is on the left from you?
5. Can this OT call you a **help or assistance**?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?
   (c) Please, show me how you would do it.
6. Can this OT tell you how to **get back to your room**?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?
   (c) Which way would you go?
7. Which direction would you go to **get to a cultural room on this floor**?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?
   (c) What other places would you go around?
8. Which direction would you go to **get to a nearby staircase**?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?

6.3.2 Results

I will discuss the results participant by participant. The results I evaluate are item identification (including cursor), function prediction for all eight buttons, and given tasks and questions. A shortened overview is depicted in Table 6.9.

Participant	**Item identification**	**Function prediction**	**Tasks done**
P1	All	All	All
P2	All	6/8	All
P3	All	All	All
P4	All	7/8	All
P5	All	7/8	All
P6	All	All	All

Table 6.9: Overview of the most important experiment C results

Participant P1

The participant looked overall confused and absentminded. Nevertheless, was she able to identify all items. She correctly answered that the cursor was something like a signpost with buttons. She then even correctly predicted functions of all nine buttons and was able to finish all tasks with minor hick-ups. She was, unfortunately, interchanging sides and for example, answering ”left” and waving her hand to the right. Overall took the experiment around 30 minutes as she took her actions slowly and needed some time to think for longer time.

Participant P2

She identified every item and answered about the cursor, that it is some arrows with one more button in the center. She predicted all functions except for two. She mentioned that the down arrow tells directions about a lower floor. This could be caused by the experiment taking place nearby an elevator with voice feedback, which was being used during the whole duration of the experiment by the residents. She also answered that the central button of the spatial orientation section serves the purpose of explaining what the other buttons and arrows are. She self-corrected after trying out these buttons resulting in successfully finishing of all given tasks later on.

Participant P3

This participant had already evaluated design A, thus mentioned that she remembers some of the items and functions. Nevertheless, could she identify all items, including those that were not present in design A. She was also able to predict all functions and finish all the tasks correctly. She encountered only a single problem during the evaluation when button "Where I am" told her she is standing one meter to the right from elevator A. But when she activated the left arrow, it told her directions to the left corridor only. She was expecting to get the information about the elevator on her left (1 meter) and then the corridor. This confused her for a while, and she needed to push those buttons repeatedly and ensure by walking the direction that her assumption is correct. I agree with that. A next prototype should also mention the elevator on the left arrow. She also complained that upon activating the spoon button she received only information about lunch and time when the dining room is open, but not the direction which should she go to reach the dining room. She also asked if it is possible to press the spoon button again to get extended information, including the navigation to the dining room. That is an interesting proposal, and I will consider that.

Participant P4

P4 was using her eyesight as her primary perception, and she explored the OT just by looking at it. She used her hands only to push the buttons. The participant successfully identified all sections and made one mistake during the function prediction. She thought that the down arrow was telling information about the lower floor. I asked her to push the button and restate her opinion. She then correctly said it describes the directions to her back instead. She was able to finish all the tasks. The participant liked the prototype very much and asked if the colors are going to stay like that as it felt very natural for her and help her a lot while using.

Participant P5

P5 successfully identified all items while using his eyesight primarily. He predicted all functions except for the key. He said, it will probably be navigation somewhere, but he could not figure out where. He was able to finish all tasks but reported even though he liked it, and it was pleasant to use, he would not use it as it is not necessary for him. He only suggested he would welcome a functionality on the watch button that would tell him when does the next bus to the city center arrive at the bus stop outside. He also suggested it could be some hidden function that only some people could invoke by some advanced action.

Participant P6

The participant successfully identified all objects, assigned all functions, and finished all tasks. He also liked it very much and reported that he would use it. He only complained that the spoon button told him only the next upcoming meal. He suffers from a severe state of diabetes and needs to plan out his dosage of insulin injections based on the food he is going to eat the whole day. He suggested there could be some bonus functionality on that button, which would tell him all day meal plan.

6.3.3 Conclusion

The results overall seem very promising. Participants were using the prototype very confidently and mostly found it useful. They also usually made only a minor mistake(s) and were able to finish all given tasks. What was also surprising is that there was not a single failed identification of the whistle after changing it for a metal one. When observed the participants, the whistle identification changed from questionable to the fastest recognized item overall. That is a great success. Interesting is also that all items now are metallic and identification is error-free.

There was a problem for P3 with missing information about the elevator being present on the left arrow as it read aloud only the upcoming corridor, but not the closest landmark in that direction. I agree the arrows should mention all important landmarks, not only the distant ones.

Two participants (P2, P4) encountered a problem while predicting the functionality of the down arrow. As they thought, it will tell them directions about the lower floor instead of what is behind them. I don't think this is any major problem as participants always corrected their opinion after pushing the button and also this problem could be caused by the location chosen for the experiment as it was taking place right next to the busy elevator with voice feedback which was talking; saying things like "The elevator is going down.", "Second floor.", "The elevator is going up." during the whole experiment. I think the presence of this background noise made it, so they thought it is going to be related to the elevator.

Three participants (P3, P5, P6) requested if there could be any action they could do to receive a bonus or extended information from the OT. I think this is an interesting idea, and the request showing up in three of six sessions means this is not an uncommon request. However, this should not interfere with the regular usage as it had been shown even during the previous experiments that some people cannot handle as much cognitive load and require shorter simpler information.

Overall was the prototype working very well, and I find this design as well working;

thus the next step will be a high-fidelity prototype of this design with minor changes to address the recorded issues and requests.

6.4 Design D evaluation

Evaluation of Design D (section 4.7) was conducted with seven participants from Home Palata (section 3.1), five women and two men, mean age 86 ($MED = 86$, $MIN = 75$, $MAX = 95$, $SD = 6.9$), see table 6.10. three participants had very bad sigh and four were blind. The experiment took on average 25 minutes.

Participant	**Age**	**Sex**	**Impairment**	**Impairment duration**	**Time in Palata**
P1	86	F	severe	80Y	6M
P2	87	M	blind	80Y	6M
P3 ($P5_A, P3_C$)	82	F	blind (light p.)	10Y	9Y
P4	75	M	blind (light p.)	7Y	1M
P5	94	F	severe	6Y	2Y
P6	83	F	blind (light p.)	16Y	2M
P7	95	F	severe	6Y	5Y

Table 6.10: Table of participants for evaluation of design D, P3 is also P5 from evaluation of design A and P3 from C

6.4.1 Procedure

I placed the prototype on the wall on the second floor, next to the elevator (see placement Figure 6.2) and brought the participant in. The location is the same as in experiment B (see Figure 4.6) and experiment C (see Figure 6.1). I told participants there is a prototype of terminal that can talk and possibly help them. I let the participants explore the OT and use the think-aloud protocol to get into their point of view. I encouraged them to tell me what they found, what those items represent, and what function could they serve.

After free exploration, I explained to participants that the OT is divided into sections, and each section serves a different purpose and provides some functionality. I also mentioned that buttons found on the OT could be pushed and upon that will terminal do something. Participants were then given a set of questions and tasks to answer or finish.

1. Can this OT tell you what **time or date** is it?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?

Figure 6.2: Placement of prototype D in Home Palata (section 3.1) during evaluation

  (c) What is the date today?
  (d) Whos name-day is it today?
  (e) What therapy is going to be held in the afternoon and where?

2. Can this OT tell you **where you are**?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?
   (c) What is your current location?

3. Can this OT tell you **what's for lunch** today?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?
   (c) What is for lunch today?

4. Can this OT tell you **what is around** you?
   (a) What would you do to make the OT tell you?

   (b) Which button would you push?
   (c) What is on the left from you?

5. Can this OT call you a **help or assistance**?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?
   (c) Please, show me how you would do it.

6. Can this OT tell you how to **get back to your room**?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?
   (c) Which way would you go?

7. Which direction would you go to **get to a cultural room on this floor**?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?
   (c) What other places would you go around?

8. Which direction would you go to **get to a nearby staircase**?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?

9. Can this OT tell you **who's name-day is tomorrow** or what **schedule is tomorrow**?
   (a) What would you do to make the OT tell you?
   (b) Which button would you push?

10. Can this OT tell you **what's for dinner** today?
    (a) What would you do to make the OT tell you?
    (b) Which button would you push?

6.4.2 Results

I will discuss the results participant by participant. The results I evaluate are item identification (including cursor), function prediction for all eight buttons, and given tasks and questions. A shortened overview is depicted in Table 6.11. I also asked participants in the end, which part of the design they liked and if there is anything they would change.

Participant	Item identification	Function prediction	Tasks done	Long push
P1	4/5	All	All	Yes
P2	4/5	7/8	All	Yes
P3	All	All	8/10	Failed
P4	All	7/8	All	Failed at first trial
P5	All	7/8	All	Yes
P6	All	6/8	9/10	Failed at first trial
P7	All	4/8	8/10	Failed at first trial

Table 6.11: Overview of the most important experiment D results

Participant P1

P1 did not identify whistle. All other items were identified. She predicted all functions correctly. Unfortunately, she started using a long push from the very beginning, so the information received did not make much sense to her. I had to offer her an option of short push and from that moment was everything OK. She was then able to use the long push for bonus and extended information without any problem as she already experienced this feature accidentally before. She reported that it was pleasant to use, and except for the long push felt very easy and natural.

Participant P2

Participant P2 started by accidentally pushing spoon. He then immediately got an idea about what to expect and how it behaves. All items except for wristwatch were successfully identified. He was hesitating between a wristwatch and car toy during the identification of wristwatch. During prediction of functions were all buttons assigned except for down arrow. He had no idea what to expect there although he assumed that arrows to the left and right tell directions. The participant started ignoring the items later on and kept pushing buttons, always listening to the beginning of the information and then pushing another one until he received the required information. It is an unexpected behavior, but it leads to a successfully finishing first eight tasks despite this. He even successfully tried to use long push when asked to receive the bonus information somehow during task 9 & 10 — thus finishing all tasks perfectly. P2 even reported he liked it very much and would use the spatial orientation and navigation back to the room as he finds it very useful and clever.

Participant P3

She successfully identified all items and predicted all functions. Unfortunately started pushing everything for a long time thus resulting in receiving of bonus information instead. This certainly leads to some confusion even though I explained her to use a short push after two long pushes. She mixed the information gathered and thought that short push tells her time and schedule on a wristwatch while long push tells her date and weather. I asked her to try the buttons again in order to correct her later on. Despite this wasn't she able to figure out what the long push does and thus failing at tasks 9 & 10. She repeatedly tried to push the button twice for the bonus information instead of long push. Even later reporting this during post-test questioning that she would prefer double click instead. She also encountered one more problem during the evaluation. "Where I am," button said that she is one meter to the right from elevator A while arrow left says that elevator A is one meter to the left. She kept pushing those buttons and reporting this information is inconsistent and wrong. I agree that this requires some mental rotation, and egocentric information shall be used on all buttons. Despite the encountered problems was she very happy about the prototype and reported she would use it if those problems get solved.

Participant P4

P4 was very confident since the very beginning of the evaluation. He even actively went on his way to verify the directions received and then coming back. He successfully identified all items and even predicted all functions except for down arrow. He thought it is information about the lower floor. His usage of the OT could be described as rash and imprudent. He mostly ignored the items and just pushed the buttons until discovering the right one. Nevertheless he was able to finish all task until task 9. He tried to push the button twice in order to receive the bonus information. I had to help him with the long push. He would later repeat the strategy during task 10 without any problem. He said he likes it and would use the spatial orientation and spoon buttons.

Participant P5

P5 mainly used her sight as perception and touched the OT only for button pushes. She correctly identified all the items and liked colorful backgrounds very much. She failed to predict function only for the key. She failed to use the long push on the whistle (because holding too short duration), later correcting herself. When asked tasks 9 & 10, she reported that she would use double push, but remembering the long push on the whistle, thus using it successfully. She finished all tasks only with minor hick-ups. She liked the OT and reported she would use the spatial orientation and navigation back to the room.

Participant P6

P6 used the OT a little fearfully and cautiously. Nevertheless, she was able to identify all items. Functions assignment was quite successful as she said that the key would be navigation somewhere, but not figuring out where, and also reporting about the arrows that they describe the floors, which means down arrow describing lower floor while left and right arrow describes current floor. All other function predictions were successful. She repeatedly failed to remember which button did what during tasks but always found it by exploring the items. She could not finish task 9, as she doubted, there is any way to receive this information. After explaining the long push for the bonus information she was able to use it during task 10. She said she likes the spatial orientation section and navigation back to the room.

Participant P7

Participant P7 succeeded during item identification but failed with function prediction. She reported that whistle is something with sport and could not find usage in her environment. She also said that the key would lead her somewhere, but she thought it would be a public toilet or locker room. During the arrow prediction, she first reported that the right arrow describes all the other buttons of the OT because it points at them and down arrow points to the handrail and describes how to leave the OT safely. She then reported that the left arrow points to the elevator and left corridor. This got her to the right mental state and figuring out naturally that central button tells her current location. She was then able to finish seven of eight first tasks. She reported that way back to her room is described by the spatial orientation part and could not figure out that the key is navigation back to her room. She also failed to get the bonus information trying to push the button twice. I explained to her the long push, and she was then able to repeat that during task 10. She liked the sizes, the items, and reported it is very natural to use. Unfortunately, she also reported that she does not want to think about things and explore. She would use just the whistle for calling help, and someone would help her as that is the easiest way for her.

6.4.3 Conclusion

The evaluation of high-fidelity prototype confirmed the same results from the low-fidelity prototype. The only problem discovered was the only added feature. Bonus or extended information did not work as intended. Most of the participants (four of seven) were not able to use it correctly. For some, it even interfered with normal usage and prevented the basic functions when participants used long push at first instead of the short push (P1, P3). Four participants (P3, P4, P5, P7) tried to use double push as their first idea for bonus information. This indicates that long push is not by far the best possible option, and there may be better more natural and more often occurring solutions within the user group. However, this hypothesis needs further evaluation to be proven or disproved.

Overall was the OT accepted very well, and even four people (P2, P4, P5, P6) reported they would use the spatial orientation part. Three participants (P2, P5, P6) reported they would use navigation back to their room. There were also some singular occasions of different sections usage like a whistle for P7 or a spoon for P4. The OT seems almost finished with only further minor adjustments to be made. More on that in section 8.2.

An additional observation was an attempt of several participants to look up the current time or date from the wristwatch attached to the OT or actual usage of the attached whistle. This would be a nice subject for further evaluation as the primary function of the real world objects was being utilized by the users and even prioritized in some occasions.

Chapter 7

Discussion

The qualitative evaluation proved how even subtle details affect the interaction and the whole functionality of the system. In the previous experiments, we learned that people are great at recognizing known symbols and assigning concrete functions to abstract symbols and representations of concrete objects, like the assignment of time information to an abstract symbol of a clock. We also learned how bad could be an identification of abstract symbols. None of nine people identified the symbol of a clock while eight of nine identified the simple geometric symbol of the down arrow (down triangle), but unfortunately not being able to assign a function to it.

In the evaluation of design A (section 6.1) was proven that the obstacle of abstract symbol identification could be solved by using the real object and mimicking the real world. This allows the combination of almost perfect identification with accurate function assignment as a core of the interaction with OT. An observation during evaluation (chapter 6) showed how crucial could be the ability to observe the real object from all sides including inside of the object and holding it in hand, experiencing not only the shape but also the weight and movement characteristics of the object. A quarter of all wristwatch identifications resulted in thinking it is a small toy car. Only when participants started to explore the wristwatch from the inside and observed the characteristics of the watchband movement, they corrected themselves into answering it is a wristwatch. This also offers an option of follow-up research exploring the attributes of the objects, which attributes are crucial for successful identification and which are redundant. Maybe a change of the metal wristwatch band for a leather band could eliminate the idea of it being a toy car and restrict the need to observe the inside of the wristwatch.

During the evaluation of design B (section 6.2) was clear how functionality and meaning must not compromise simplicity, consistency, and clear design. The haptic map proved to be unusable by the participants for various reasons. Some thought it is a sideways projection; others failed to understand it is a map at all. All participants struggled with the usage of the hierarchy model and the abstraction of hallways and rooms represented by lines and buttons. People could not orient themselves using the map and even failed at discovering the whole map, usually staying on just one line (hallway) or a set of two nearby buttons. Although these participants failed at using the haptic map, reporting they would like to make it simpler, easier and even suggesting the usage of a simple cursor, they were very successful using the OT part with the objects.

Evaluation of design C (section 6.3) showed that simple detail like the material of the object could make a huge difference in identification. Some participants struggled to identify a plastic whistle in previous designs. All of them were able to identify a metal whistle immediately even though it was the same size and shape, and no other attribute changed. We also observed how the proximity of OT sections or objects could modify the meaning and expected functionality. In design A (section 4.4), half of the participants expected the key is telling them something about going to their room, and the other half expected instructions on going out (of the building). In design C (section 6.3), the key was placed right after the orientation section with the cursor. When participants explored the whole OT, they expected the key is telling them way back to their room in all occurrences. Some people were also thinking aloud and saying: "The key will show me some way, maybe back to my room or somewhere out. However, for going around the building are there those arrows, so the key should take me back home as this is the only information I am currently missing". In the evaluation of design C (section 6.3) was also evident how consistent sizing and carefully tuned dimensions can prevent misunderstanding of relations between the objects and the buttons. Choosing the right sizes prevented people from connecting a button and object from different sections as well thinking about the OT as a whole and more as individual closed sections with different function and meaning.

Evaluation of high-fidelity prototype proved that people could easily understand, repeat, and use instructions (using long push on a whistle to call for help). While not being able to replicate this knowledge in the discovery of hidden functions. Participants did not try the long press on other buttons and were not able to discover the additional functions. They were able to use it when instructed to during the evaluation, but they reported their first thought would be pressing it again or twice instead of a long press. The evaluation indicates how an exploration of user expectations is also a crucial aspect of Participatory design and that this invocation should have been used rather than the long press. Double press needs and evaluation in future work, but most of the users trying it first or even reporting they would expect that indicates a better method.

Chapter 8

Conclusion

I have conducted four iterations of User-Centered Design methodology, including four qualitative evaluations of separate designs. The design was evaluated in total 26 times in four different experiments with 23 unique participants from the target user group. 18 women and five men, mean age 84.9 ($MED = 86$, $MIN = 52$, $MAX = 98$, $SD = 9,7$) participated during the evaluation process. The last iteration was a design, implementation, and evaluation of a high-fidelity prototype of the OT, which indicated the design is usable by the participants of the qualitative evaluation from within the target user group. Both blind users and people with severe visual impairment were able to use the OT without noticeable differences in performance. The final design of the OT consists of five sections providing information about spatial orientation, navigation back to a safe place, time and context-related information, and call for help. The OT interaction is based on buttons, voice feedback (provided by TTS), color and negative space separation, and real-world objects attached to sections of the OT. The OT was designed to work in synergy with the rest of the orientation system. There is still need for minor adjustments of the span of information provided for individual users based on user identification and context model or evaluation of other methods for invocation of bonus or extended information as long push has been proven as insufficient action. The final design was well accepted by most of the participants during the evaluation process. Participants even reported they would use it regularly. The concrete information and voice feedback is a subject to individual adjustment based on the location and context of the OT placement.

8.1 Fulfillment of thesis goals

In this section is discussed fulfillment of thesis goals. The goals and corresponding fulfillments are listed below:

- **G1:** Analysis of all previous work, progress, and associated research documents.

- *Discussed in chapter 2*
- A complex analysis of all previous work was made, and this thesis is a continuation of the previous work. All aspects of the previous work are incorporated during the design and evaluation phases.

- **G2:** Analysis of related work and other orientation systems.
  - *Discussed in chapter 3*
  - Analysis of related work and other orientation systems was made, and some insights were incorporated during the design. In comparison with other mentioned orientation systems (and terminals), there is no need for carrying any artifact around in order to use the system or interact with it. This is the best advantage that no other compared system can not provide.
- **G3:** Analysis of user group.
  - *Discussed in section 1.1, chapter 3 and section 4.1*
  - Analysis of user group including demographics, special characteristics, needs, behaviour, habits and daily routine was made with usage of available statistics (section 1.1), literature (chapter 3) and documents from previous research. There was also workshop (subsection 4.1.2) with employees who take care of those users and also numerous interviews subsection 4.1.1 with potential users were made and analysed.
- **G4:** Choice of functional and non-functional requirements. Including a set of provided functions.
  - *Discussed in section 4.2*
  - There are 20 functional and non functional requirements chosen with respect of analysis of previous work, related research and user study.
- **G5:** Design of suitable interaction method.
  - *Discussed in chapter 4*
  - With usage of User-Centered Design methodology were made three iterations of design, and consequent low-fidelity prototypes.
- **G6:** Creation of high-fidelity prototype implementing all previous results.
  - *Discussed in section 4.7*

  - High-fidelity prototype was created in response to three iterations of design, low-fidelity prototypes and evaluation.

- **G7:** Evaluation of the design.
  - *Discussed in chapter 6*
  - All four iterations of design, low-fidelity and high-fidelity prototypes were separately qualitatively evaluated during total of 26 sessions with 23 unique participants from the target user group.

8.2 Future work

A subject for further research are alternative methods for bonus or extended information invocation as long push proved insufficient, and participants suggested the usage of double click as their preference. The need for bonus or extended information invocation can be even omitted by the usage of user identification (by a token or camera with face recognition) and employment of user context model which would decide what level of information to provide to individual users and could even adapt to the current situation. Integration with the context model is a whole step up in possibilities that the OT could serve. Production in more significant quantities also remains a subject for future work as manual soldering and assembly of 3D printed parts is inaccurate and labor intensive. With that of course comes the need for evaluation in different facilities and buildings with different user group as well as adjustments for purposes of other facilities. One more interesting observation was an attempt of several participants to look up the current time or date from the wristwatch attached to the OT or attempt of actual usage of the attached whistle. Research on primary functions of the attached objects would be an excellent subject for further evaluation as the primary function of the real world objects was being utilized by the users and even prioritized in some occasions. Fine tuning of the object attributes like leather or metal band on the wristwatch, a tactile wristwatch for the visually impaired or usual wristwatch, whistle on a roll-up string may produce even better results.

Appendix A

High-fidelity prototype source codes

A.1 Arduino buttons firmware

```
// used here to set pin numbers:
const int numbuttons = 8;

// the current reading from the input pin
int buttonState[numbuttons];

// the previous reading from the input pin
int lastButtonState[numbuttons];

// the current long press state
int longPressState[numbuttons];

// the last time the output pin was toggled
unsigned long lastDebounceTime = 0;

// the debounce time; increase if the output flickers
const unsigned long debounceDelay = 50;

// long press delay time
const unsigned long longpressDelay = 2500;

void setup() {
  Serial.begin(115200);

  for (int i = 2; i < numbuttons + 2; ++i) {
    pinMode(i, INPUT_PULLUP);
  }
}

```

```
void loop() {
  for (int i = 0; i < numbuttons; ++i) {
    // read the state of the switch into a local variable:
    int reading = digitalRead(i + 2);

    // If the switch changed, due to noise or pressing:
    if (reading != lastButtonState[i]) {
      // reset the debouncing timer
      lastDebounceTime = millis();
    }

    if ((millis() - lastDebounceTime) > debounceDelay) {
      // whatever the reading, it's longer than the debounce delay

      // if the button state has changed:
      if (reading != buttonState[i]) {
        buttonState[i] = reading;
        if (buttonState[i] == HIGH) {
          Serial.println("ON_"+String(i+2));
        } else {
          if (longPressState[i] == LOW) {
            Serial.println("OFFLONG_"+String(i+2));
          } else {
            Serial.println("OFF_"+String(i+2));
          }
        }
        longPressState[i] = HIGH;
      } else {
        if (
          (millis() - lastDebounceTime) > longpressDelay
          && reading == HIGH
          && longPressState[i] == HIGH
        ) {
          Serial.println("LONG_"+String(i+2));
          longPressState[i] = LOW;
        }
      }
    }

    // Next time through the loop, it'll be the lastButtonState:
    lastButtonState[i] = reading;
  }
}
```

Listing A.1: Arduino buttons firmware

A.2 Python TTS server

```
import serial
from os import system, remove
from time import sleep
from gtts import gTTS
from pygame import mixer
from tempfile import TemporaryFile
import serial.tools.list_ports

speed = 1.0

tts = {}

for i in range(2, 10):
  tts[str(i)] = {}

tts['2']['OFF'] = gTTS('TTS text', lang='en')
tts['2']['LONG'] = None

tts['3']['OFF'] = gTTS('TTS text', lang='en')
tts['3']['LONG'] = None

tts['4']['OFF'] = gTTS('TTS text', lang='en')
tts['4']['LONG'] = None

tts['5']['OFF'] = gTTS('TTS text', lang='en')
tts['5']['LONG'] = None

tts['6']['OFF'] = gTTS('TTS text', lang='en')
tts['6']['LONG'] = gTTS('TTS text', lang='en')

tts['7']['OFF'] = gTTS('TTS text', lang='en')
tts['7']['LONG'] = gTTS('TTS text', lang='en')

tts['8']['OFF'] = gTTS('TTS text', lang='en')
tts['8']['LONG'] = gTTS('TTS text', lang='en')

tts['9']['OFF'] = gTTS('TTS text', lang='en')
tts['9']['LONG'] = gTTS('TTS text', lang='en')
```

```python
def playTTS(tts):
  if (tts == None): return
  f = TemporaryFile()
  tts.write_to_fp(f)
  mixer.init()
  mixer.init(int(22050 * speed))
  mixer.music.set_volume(1)
  f.seek(0.9)
  mixer.music.load(f)
  mixer.music.play()

def play(pin, command):
  mixer.init()
  if (command == "ON"):
    mixer.music.load('sounds/robot_blip.wav')
    mixer.music.play()
    return
  if (command == "LONG"):
    mixer.music.load('sounds/peep.mp3')
    mixer.music.play()
  return playTTS(tts[pin][command])

ports = serial.tools.list_ports.comports(include_links=False)
port = None

for p in ports:
  if (p.product and 'SparkFun Pro Micro' in p.product):
    port = p
    break

portInfo = serial.tools.list_ports_common.ListPortInfo
if (not isinstance(port, portInfo)):
  exit(1)

with serial.Serial(port.device, 115200) as serialport:
  while serialport.isOpen():
    line = serialport.readline()
    line = line.replace("\n", "").replace("\r", "")
    if (line != ""):
      print(line)
      command, pin = line.split("_")
      if (command != "OFFLONG"):
        play(pin, command)
```

Listing A.2: Python TTS server

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