Master Thesis

Czech Technical University in Prague

F3

Faculty of Electrical Engineering
Department of Computer Graphics and Interaction

Tactile models for older adults with vision impairments

Dina Chernova

Supervisor: Ing. Miroslav Macík, Ph.D.
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ZADĆNĉ DIPLOMOVĖ PRĆCE

I. OSOBNĉ A STUDIJNĉ ĐDAJE

Pŝ²jmen²:	**Chernova**	Jm®no: **Dina**	Osobn² ļ²slo: **420050**

Fakulta/¼stav: **Fakulta elektrotechnick§**

Zad§vaj²c² katedra/¼stav: **Katedra poļ²taļov® grafiky a interakce**

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II. ĐDAJE K DIPLOMOVĖ PRĆCI

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Hmatov® modely pro seniory se zrakovĨm postiģen²m

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Tactile models for older adults with vision impairments

Pokyny pro vypracov§n²:

Older adults with severe vision impairments often live in residential care institutions that provide specialized care. This user group has specific needs, abilities, and preferences, primarily from the perspective of orientation in space, interaction with technologies, and free-time activities. Analyze the outcomes of current research on the spatial orientation of severely visually impaired with a particular focus on older adults. Follow up the results of research conducted at the DCGI [1,2] and on solution described in the patent titled 'Three-dimensional model of a building primarily for visually impaired older adults' [3]. Specify information to be represented by geographical models of the interior as input. Design and implement a method to transform geographical models of the interior environment to (interactive) tactile models usable by visually impaired older adults. Follow the User-centered design method [4]. Evaluate the outcomes with participants representing the target user audience.

Seznam doporuļen® literatury:

[1] 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 000157ï000164. IEEE, 2017.
[2] Gintner, V., Macik, M. and Mikovec, Z., 2019, September. Perception of Tactile Symbols by Visually Impaired Older Adults. In IFIP Conference on Human-Computer Interaction (pp. 325-334). Springer, Cham.
[3] Mac²k M., MalĨ I., Balata J., M²kovec Z, Treml L. TrojrozmŊrnĨ model budovy urļenĨ pŝedevģ²m pro zrakovŊ postiģen® uģivatele, Aug 2019. Patent. Dostupn® z: https://isdv.upv.cz/doc/FullFiles/Patents/FullDocuments/307/307912.pdf
[4] DIS, ISO. (2009). 9241-210: 2010. Ergonomics of human system interaction-Part 210: Human-centred design for interactive systems.

Jm®no a pracoviģtŊ vedouc²(ho) diplomov® pr§ce:

Ing. Miroslav Mac²k, Ph.D., Katedra poļ²taļov® grafiky a interakce

Jm®no a pracoviģtŊ druh®(ho) vedouc²(ho) nebo konzultanta(ky) diplomov® pr§ce:

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Ing. Miroslav Mac²k, Ph.D. podpis vedouc²(ho) pr§ce	podpis vedouc²(ho) ¼stavu/katedry	prof. Mgr. Petr P§ta, Ph.D. podpis dŊkana(ky)

III. PřEVZETĉ ZADĆNĉ

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Podpis studentky

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Thank you.

Declaration

I hereby declare that the presented work was made independently, and that I have listed all the sources of information used within it, in accordance with the methodical instructions for observing the ethical principles in the preparation of the university thesis.

Prague, August 2020

Abstract

Older adults with severe vision impairments often live in residential care institutions that provide specialized care. This user group has specific needs, abilities, and preferences, primarily from the perspective of orientation in space, interaction with technologies, and free-time activities. In this thesis I have proposed a pipeline for reconstruction of a building from images that satisfies the requirements of the patent 'Three-dimensional model of a building primarily for visually impaired older adults' [33] for creation of a tactile 3D map for the visually impaired older adults. The pipeline was designed, implemented and tested with a target user group using the User-centered design method. The results of the evaluation show that there's still a lot to be improved. Furthermore, I have designed and 3D printed an exterior part of the Home Palata building. The printed 3D model was then glued to a wooden model created by Ing. Miroslav Macík, Ph.D. as part of the implementation of the patent mentioned before. I have evaluated the model that I have created with a visually impaired expert. He has shared a lot of valuable insights to improve the model.

Keywords: visually impaired, blind, low vision, older adults, residential care institution, palata, navigation, orientation, indoor, outdoor, inside, outside, 3D model, 3D printed, 3D printer, external building part, facade, 3D building, tactile map, interactive

Supervisor: Ing. Miroslav Macík, Ph.D.

Abstrakt

Starší lidé s těžkým poškozením zraku často žijí v ústavních zařízeních poskytujících specializovanou péči. Tato skupina uživatelů má specifické potřeby, schopnosti a preference, především z hlediska orientace v prostoru, interakce s technologiemi a volnočasových aktivit. V této práci jsem navrhla pipeline pro rekonstrukci budovy z obrazů, které splňují požadavky patentu „Trojrozměrný model budovy primárně pro zrakově postižené starší dospělé" pro vytvoření taktilní 3D mapy pro zrakově postižené starší dospělé. Pipeline byla navržena, implementována a testována s cílovou skupinou uživatelů pomocí metody User-centered design. Výsledky hodnocení ukazují, že je stále co zlepšovat. Dále jsem navrhla a vytiskla vnější část budovy domova Palata. Tištěný 3D model byl poté přilepen na dřevěný model vytvořený vedoucím mé práce v rámci implementace výše uvedeného patentu. Vyhodnotila jsem model, který jsem vytvořila, s nevidomým odborníkem. Odorník sdílil spoustu cenných poznatků, jak model vylepšit.

Klíčová slova: nevidomé, slepý, slabý zrak, starší dospělí, palata, navigace, orientace, vnitřní, venkovní, 3D model, 3D tisk, 3D tiskárna, vnější stavební část, fasáda, 3D budova, hmatová mapa, interaktivní

Překlad názvu: Interaktivní hmatové plány pro seniory se zrakovou vadou

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Chapter 1

Introduction

According to the report of the World Health Organization from 2010 there are 285 million people in the world diagnosed with different types of visual impairment, 39 million of which are blind. The majority - around 82% - of people suffering from vision impairment are over the age of 50. The main reasons for this are uncorrected refractive errors (43%) and cataract (33%). [40] In Europe there are over 30 million blind and partially sighted persons. Based on data from the Sample Survey of Disabled People [62] conducted by the Czech Statistical Office in 2013, there are approximately 65000 people with severe visual impairments in the Czech Republic.

Having visual impairment increases the risk of mobility disability especially for the older people. According to the paper [53], among people aged 65+ around 32% have a difficulty with walking three city blocks and 30% report difficulty walking up the staircase in the United States. When it comes to the people that have lost their sight the research shows that they have a bigger rate of falls [19] and smaller walking speed [41] compared to the non visually impaired.

Another problem that rises before the visually impaired is orientation in space. Visually impaired face many troubles with orientation, e.g. they are struggling with capturing important landmarks of an environment to form a mental map. While sighted people rely on their vision to orientate in unfamiliar environments, visually impaired rely on their other four senses to understand the space around them. Even though in most developed countries cities are equipped with public navigation for the visually impaired, the mobility still remains a problem, especially for the older adults. There are several solutions on how to help this community to navigate in space, e.g. mobile applications, tactile maps and so on. Any kind of assisting orientation technology, of course, first demands training. Talking about the elderly, orientation training seems to be the hardest social-rehabilitation activity for most of them according to [6].

Presently there are no such 3D tactile maps that would allow a person with visual disabilities to explore the interior and the exterior part of the building, while being able to move from one floor to another. For this reason Miroslav Macík et. al. [33] described a new method for indoor orientation and navigation for people with disabilities in the form of the haptic 3D printed model. Their work aims to simplify and speed the process of creation of a mental model of an indoor environment for the visually impaired older adults. Subsequently, Ing. Dominika Palivcová in her master thesis followed up on the project of Macík and presented a prototype of interactive tactile map of a 3D model that allows users to explore each floor of the Palata residential building for visually impaired. [15] In Palivcová's work she was focusing on design and implementation of an internal part of Palata, but not the exterior part of the building.

This thesis follows up on the work of my colleagues ([33], [15]). That is, the aim of this thesis is to implement and print the 3D printable exterior side of Palata and to design a pipeline prototype that will allow for creation of exterior 3D printable building parts for a tactile 3D model. It is important to have the exterior part of the building as it helps the visually impaired to create a mental map of the external appearance of the building and its overall layout. Furthermore, pipeline prototype can be used for creation of other buildings' 3D tactile maps for people with visual disabilities.

1.1 The Goals Of This Thesis

There are several goals to be achieved in this thesis:

1. Analysis of the outcomes of current research on the spatial cognition of visually impaired with a particular focus on older adults

   Analyze means of spacial cognition of the visually impaired. Study current research on spacial cognition of the people with visual disabilities. Follow up the results of research conducted at the DCGI and on solution described in the patent titled 'Three-dimensional model of a building primarily for visually impaired older adults' [33]

2. Study of a method for 3D model reconstruction from images

   Research a method for reconstruction of 3D models based on a set of images. Provide with some base knowledge for this process and describe the steps.

3. Analysis of a technique for segmentation of building facades

   Study a technique for facade elements detection from images of the building. Provide with individual steps of this process.

4. De nition of a pipeline for creation of a 3D exterior building part from images

   De ne a pipeline for creation of a simpli ed (number of triangles is minimized) exterior part of a building based on a set of images. Facade elements, like windows, doors, ledges, should have only an opening. Roof should be excluded.

5. Implementation of the low and high- delity prototypes of the pipeline using the UCD method

   Design and implement two generations of the prototypes for the pipeline using the UCD method.

6. Design and implementation of a 3D printable exterior part of Palata

   Design and print a 3D exterior part of Palata following the needs and requirements of the visually impaired. Attach the resulting model to the wooden model created by Macík.

7. Evaluation of the prototypes and the 3D model with the target user group

   Evaluate both low and high- delity prototypes with the target user group. Furthermore, evaluate the created 3D model with a visually impaired expert.

1.2 Methods and terms

1.2.1 User-Centered Design

User-Centered Design (UCD) is an iterative design process in which designers center around the clients and their needs in each period of the development procedure. In UCD designers use di erent research and design techniques and test their product with users in order to improve their product usability and accessibility. There's a special international standard that UCD follows: ISO 9241-210:2010.[1][8] The iterative process is composed of a few phases as is explained in the gure below.

Figure 1.1: Representation of phases of UCD and their iterative nature, from [60]

1.2.2 Usability

Usability is a term used in Human-Computer Interaction (HCI) and is a quality attribute that describes how easy it is to handle user interface for a user. "Usability" as a word is also used for product improvement process during its design. This term is de ned by several components [38]:

- Learnability - How easy it is for users to handle the user interface while using the system for the rst time?
- E ciency - How quickly do users complete tasks after they've learnt the interface?
- Memorability - How easily can user restore capability of handling the user interface after they have not been using this system interface for some time?
- Errors - How many errors are made by users, how serious are they and how easy is it to recover?
- Satisfaction - How pleasant is it to use the design?

It is important for a system or a product to be usable, since users do not tolerate di cult designs and will not use this product otherwise. In order to improve the usability designers must test the product with target users, observe their di culties when using the product and improve it.

Chapter 2

Analysis

Visual impairment is a decreased ability to see which varies among di erent degrees of vision loss. Blindness, on the other hand, is complete or almost complete loss of vision. [13]

2.1 Statistics On Visual Impairment

The International Statistical Classi cation of Diseases divided the visual impairment in several groups as is shown in Table 2.1.

Category of visual impairment	Visual acuity with best possible correction		Or central visual eld	Classi ed as
	Maximum less than	Minimum equal to or better than		
1	6/18 3/10 (0.3) 20/70	6/60 6/60 20/200		Low vision
2	6/60 1/10 (0.1) 20/200	3/60 1/20 (0.05) 20/400		Low vision
3	3/60 1/20 (0.05) 20/400	1/60 (nger counting at 1 metre) 1/50 (0.02) 5/300 (20/1200)	10 or less but more than 5	Blindness
4	1/60 (nger counting at 1 metre) 1/50 (0.02) 5/300	Light perception	5 or less	Blindness
5	No light perception			Blindness
9	Undetermined or unspeci ed			Unspeci ed

Table 2.1: Categories of severity of visual impairment, from [14]

In the year 2010 the World Health Organisation has reported statistics described in Table 2.2 that illustrate the situation in the world regarding the relationship of age to visual impairment.

Ages (in years)	Population (millions)	Blind (millions)	Low Vision (millions)	Visually Impaired (millions)
0-14	1,848.50	1.421	17.518	18.939
15-49	3548.2	5.784	74.463	80.248
50 and older	1,340.80	32.16	154.043	186.203
all ages	6,737.50	39.365 (0.58)	246.024 (3.65)	285.389 (4.24)

Table 2.2: Global estimation of the amount of people visually impaired by age and the corresponding prevalence (%), from [40]

The World Health Organisation also provides information regarding the causes of visual impairment (Figure 2.1). The main reasons are uncorrected refractive errors (RE) and cataracts. Other causes are glaucoma, age related macular degeneration (AMD), diabetic retinopathy (DR), trachoma and corneal opacities (CO). Also, a big percentage is undetermined.

Figure 2.1: Causes of visual impairment globally in percentage, from [40]

2.2 Perception Of Blind And Visually Impaired

Orientation is the ability to use one's remaining senses to understand one's location in the environment at any given time. [11]

Mental map or model is a phenomenon of a conscious experience of creation of a mental representation of anything based on a previous experience and knowledge. [12]

Spatial cognition is a branch of cognitive psychology. Spacial cognition studies how people acquire and use knowledge about their environment to determine their location, obtain resources and nd a way home. [35]

2.2.1 Orientation And Navigation

Visually impaired and blind people have a di erent perception of the world comparing to the people with sight. The space becomes a set of guiding lines, markers and orientation points for the humans with vision disabilities. But again, when talking about the blind and people with a low vision, there is some di erences: people who have low vision might still able to recognize high-contrast colors and shapes.

In the paper [39] Noordzij, Zuidhoek, and Postma state that according to their research early and late blind people build up spacial mental models more e ciently based on a route description, which is a description of the environment from the ground-level, whilst the sighted people tend to build it from a survey description, which is the "bird-eye" view on the environment and requires the knowledge of topology. This facts imply that a system that is designed speci cally for people with a sight loss has to meet some appropriate requirements in order to satisfy the needs.

Visually impaired pursue the orientation signs in space using the following means: hearing, smell, touch and temperature. The sound feedback is very important for them if they are outside, especially in the crossroads and crossings. [7] Tarik Kapić in his paper [27] conducted a survey where he performed several interview with blind and visually impaired to nd what aids are necessary to use for a navigation system. He found out several facts about the way visually impaired orientate in the outside space:

- The blind often use objects such as walls, balustrades, murals etc. in order to de ne directions
- Another big part in orientation of visually impaired plays the smell, e.g. bakeries, cafes and restaurants.
- Visually impaired also use their hearing senses a lot, e.g. the sound of the fountain, semaphore sound or a cafe that plays music daily.
- Con guration of the oor also plays a big role, e.g. the end of a pavement, change of the ooring, etc.

Macík, Malý, Balata and Míkovec in their paper [32] state that people with a sight loss tend to code spacial relations by reference with their body, which is proven to be an ine ective way for solving complex tasks. It is also proven that congenitally blind tend to code features in familiar routes better, than in an unknown ones. Research [15] conducted in Palata residence on elder people shows that some visually impaired navigate and orientate independently, but only along the routes that they already know. In fact, learning new routes seems problematic for the new elder clients: they prefer the help of the personnel and it takes a few months to learn the route.

2.2.2 Auditory Senses

One of the means of the world perception is sound. According to [44] hearing processes 11% of our perception of the world. For the visually impaired hearing is especially crucial, as it remains the main instrument of their experience of the world.

Researches show that blind participants show better sound localization than sighted people. Röder et. al. demonstrate in their studies [42] that for congenitally blind participants speech processing activates not only left-hemispheric language area, as for the sighted people, but also homologue right-hemispheric structures. This fact relates to Braille-reading abilities of visually impaired. It has been suggested that Braille-reading is connected more to the right hemisphere than reading printed languages.

People with visual disabilities are more sensible to speech and are more e cient in processing it [26] since their main reliance is sound. When semantic and syntactic processing in blind were tested [42], giving the participants both blind and sighted a phrase, where an adjective preceded a noun or a pseudo-word, it was found that the reaction of the blind participants was quicker than of the sighted subjects. This way, it was conducted that blind process the speech signals more e ective. It is assumed that due to this fact blind might have higher working memory capacities. It has also been found, that blind perceive the speech better in the context of the noisy background. [37]

2.2.3 Tactile Senses

Tactile perception are sensations obtained through the skin. Tactile sense is one of the most important senses for the blind and visually impaired, so they perceive the space through touching the objects around them. Size, material and form are the key characteristics that help visually impaired to identify an object. The interaction with an object can be done by touching, grasping, pushing or pulling. [10]

Many studies ([20], [51], [58]) show that tactile perception is more enhanced for blind people. However, researches show that congenitally blind show worse results in shape understanding than the blind people who had a vision before, which implies that visual experience plays a big role in determining the object shapes. Although, when comparing visually impaired and sighted people both groups show the same skills in representations of haptic material properties [5].

Daniel Goldreich and Ingrid Kanics in their research [20] on tactile acuity in blindness had found out that blind women have heightened tactile acuity comparing to men. They assume the reason is their greater skin compliance. In addition, it has been found that young blind participants had higher tactile acuity than the older subjects, which is believed to be caused by peripheral and/or central neuronal loss for the older adults.

Macík et. al. in their paper "Tactile symbols for visually impaired older adults" [31] have conducted two experiments on the right shape, elevation, recognizability and intelligibility of tactile symbols and symbol preference in general. The results show, that older adults with vision disabilities show more understanding towards the outline design of symbols comparing to the inline. The authors have observed, that some symbols, like down lled arrow, heart, cross and outline symbol in the form of two lines was easily connected to real-life objects by the participants (Figure 2.2). On the other hand, clock and two lines were often mistaken. Question mark was recognized by some people as a number two. This testing also showed, that most of the visually impaired were not able to assign a symbol to its meaning. The authors assume, that the meanings of the symbols were not based on mental models relevant to the target user audience. The author of [10] assumes that tactile sense allows for a smaller level of abstraction comparing to vision and hearing.

It has been shown in research of Ungar et. al.[45], that patterns, textures, separation, and spacing of individual features are the most important aspects of tactile symbol design. Shape, type, and size of the symbol have scored less,

Figure 2.2: Example of tactile symbols tested by Macík et. al., from [31]

but above average, in their study.

Finally, an interesting fact: visual cortex is being triggered from haptic experience for blind people. Several researches [9] [47] [46] that run an experiment where they were measuring the brain activity in visual cortex in blind people have found out that the visual cortex is being activated when Braille-reading.

2.3 Tactile Maps As Means Of Spacial Cognition

2.3.1 What Is A Map?

Map is a symbolic depiction of chosen qualities of a place. The process of map creation considers the needs of the target user group, which can di er, and that is why there are di erent types of maps: electronic, climatic, topological, tactile, 2D, 3D etc. Human brain processes maps di erently than it processes graphical information, thus map design has its own specialities. Map reading is not easy, therefore map creator needs to depict all symbols in such an e cient and e ective way so the user will interpret them well.

The Figure 2.3 depicts four stages of information transformation. The communication between a map maker and a map reader is the following:

- Reality is interpreted by a map maker.
- Map maker creates a tangible map according to their internal interpretation.
- Map reader interprets the created map through their own interpretation of the world, which can be di erent than the interpretation of the map maker.

Figure 2.3: Cartographic Communication Model adapted from MacEachren, 1995, from [30]

- Map reader uses the map according to their interpretation for a navigation task.

Transformations one and two of the information transformation model are for the map maker, while transformations three and four focus on the map reader. Transformation one corresponds to a process of interpretation of the world, while the transformation two represents the process of design of the map. At the transformation three user encodes the information from the map and in the transformation four they use this information to complete some navigational task.

2.3.2 Tactile Maps

Tactile maps provide blind and people with low vision with an understanding of the environment. This kind of maps are made of accessible images, that provide user with sound, verbal description or haptic feedback.

Studies [22] have shown, that visual deprivation does not a ect the amount of information acquired when touching a tactile map, nor does it a ect the cognitive load, when building a mental map. In other words, the level of