Mobile Navigation through a Science Museum for Users Who Are Blind

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Abstract. This paper presents the design and implementation of mAbES, a mobile, audio-based environment simulator to assist the development of orientation and mobility skills in people who are blind. The modeling scenario of mAbES was a science and technology museum in Porto Alegre, Brazil. The application was designed for use by people who are blind without the supervision of a facilitator or aid. The mAbES software allows for testing the creation of mental maps when people who are blind navigate through the museum.

Keywords: People who are blind, Mental map, Orientation and mobility, Navigation, Mobile application.

1 Introduction

Lacking vision is not synonymous with having low levels of spatial perception or comprehension. In general, people with visual impairment, when adequately trained, are capable of orienting themselves, and develop a pretty precise mental representation of the environment. This indicates that visual experience is not strictly necessary in order to create mental representations of space, as other senses also provide valuable spatial information [10]. In his research, Millar proposes that vision does influence coding and spatial representation, but that it is not a sole determinant of such abilities [10].

A person with visual impairment must be competent with orientation and mobility (O&M) in order to achieve a solid level of navigation, including moving about safely, efficiently and with agility, as well as independently in both familiar and unfamiliar environments [4]. The learning of O&M skills includes a set of defined techniques that children who are blind, young people and adults (or those with visual impairment) must practice stage by stage. However, learning such skills also involves other aspects such as training and refining systems of perception, and both conceptual and

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motor skills development [4]. Such skills are essential precedents for learning formal O&M techniques [4]. The primary objective of O&M is to achieve independence and to improve the quality of life for people who are blind or who have visual impairments. Instruction in such skills occurs in stages, in which the level of difficulty of the training involved varies according the learner's particular characteristics [4].

For example, mobility when navigating a route does not just require moving from point A to point B, but doing this efficiently and knowing where one is, where one is going, and how to get there [1].

It is important to point out that movement refers to the act and practice of moving, but also to the act of evaluating known facts and places in the environment in order to facilitate effective movement and to exercise one's own capacity for autonomous navigation [11]. This means that when people with visual impairment relate to their environment, they encounter certain "spatial problems". For this reason, they must constantly make "spatial decisions" regarding how to successfully navigate an environment.

From a geographical perspective [3], quality of life for both sighted and people who are blind depends on the individual's ability to infer information and make spatial decisions.

In O&M, the capacity for orientation ideally progresses from a concrete understanding of the principals of mobility, to a more functional plane for applying such principals, and finally arriving at an abstract level through which the learner can function effectively in an unfamiliar environment [4]. In this transition, it can be inferred that psycho-motor, senso-perceptive, conceptual and practical training in the use of O&M techniques and materials, are important tools for being able to generate a representation of space. This is because these tools allow for a learner to practice and test out different methods of movement in context, use memory, and to pick up on and interpret his surroundings.

The cognitive map, as a process of spatial reasoning, provides spatial information that is useful for mobility [12]. For some authors, the function of cognitive maps for an individual is to coordinate adaptive spatial behaviors, or in other words to generate action plans prior to or during the navigation of an environment, and to execute those plans effectively while moving through the environment [1].

Spatial knowledge, made up of simple concepts, complex ideas, locations and relations, is retained in the mind through cognitive images of the surrounding environment, which make up cognitive maps. The basic structure of the images consists of simplified extracts of reality, built by using perceptual and conceptual information [1]. This means that people with visual impairment also form images, which can be quite elaborate, but constructed differently than sighted people. For example, these images could be built based on sensations and movement, memories, textures, sounds, etc.

The study of spatial representation can provide relevant information regarding how people move, what information they need for mobility, and how this information is distributed in a given environment [5].

Support on a perceptual and conceptual level is important for the development of orientation skills and the construction of cognitive maps [7]. The notion of a map speaks of an internalized representation of space, a mixture of objective knowledge and subjective perception. As most of the information needed to form a mental map is collected through the visual channel [7], some authors claim that people who are blind use other sensory channels to compensate this and use alternative methods for exploration in order to construct mental maps [12].

If real-life surroundings are represented through virtual environments, it is possible to create several training applications that allow a user who is blind to interact with the elements in the simulated environment during navigation [13][14].

Videogames, when integrated with virtual training environments, represent an important tool for the development of various abilities, and O&M skills in particular [16][17]. For example, the software AbES [13][14] allows for the creation of videogames, focusing on the mental construction of real and/or fictitious environments by users who are blind navigating through virtual environments, using a computer keyboard in order to execute actions and receive audio feedback, with the aim of supporting the development of O&M.

AbES expands on the concept of using fictitious corridors used in its predecessor AudioDoom [9], in order to generate an audio-based virtual representation of real environments, thus serving as a videogame that allows for O&M training [14]. In addition, the use of audio allows increases the potential for various forms of interaction between the user and the computer.

Another study presented an audio-based virtual reality system that allows the user to explore a virtual environment by using only his sense of hearing [2]. Other authors performed empirical evaluations of various approaches through which spatial information on the environment is transmitted through the use of audio cues [6].

Various virtual environments have been designed in order to train people who are blind, and to assist them with the development of O&M skills [7][9][14]. To navigate through an environment, it is necessary to have access to the information that can be recovered from the environment, in order to then filter useful information in a way that is coherent and comprehensible for whoever needs it.

It is for this reason that in the case of people who are blind, the use of virtual environments and appropriate interfaces allows them to improve their O&M skills [15]. Such interfaces can be, for example, haptic or audio based. Such resources can also be used for recreational purposes. Other studies have researched the use of mobile applications to assist in user navigation of the city [13][14][15].

The purpose of this work is to present the design and implementation of mAbES, a mobile audio based environment simulator to assist the development of orientation and mobility skills in people who are blind. We introduce a model scenario using mAbES together with an application for navigating through a science and technology museum in Porto Alegre, Brazil. The software mAbES was designed based on a previous model of AbES.

2 AbES, Audio-Based Environments Simulator

AbES represents a real, familiar or unfamiliar environment to be navigated by a person who is blind. The virtual environment is made up of different elements and objects (walls, stairways, doors, toilets or elevators) through which the user can discover and become familiar with his location. It is possible to interact with doors, which can be opened and closed. Regarding the rest of the objects, it is possible for the user to identify them and their location in the environment. The idea is for the user to be able to move about independently and to mentally map the entire environment.

The simulator is capable of representing any real environment by using a system of cells through which the user moves [17]. The user receives audio feedback from the left, center and right side channels, and all actions are carried out through the use of a traditional keyboard, where a set of keys have different associated actions. All of the actions in the virtual environment have a particular sound associated to them. In addition to this audio feedback, there are also spoken audio cues that provide information regarding the various objects and the user's orientation in the environment. Orientation is provided by identifying the room in which the user is located and the direction in which he is facing, according to the cardinal compass points (east, west, north and south).

Stereo sound is used to achieve the user's immersion by providing information on the location of different objects, walls and doors in the virtual environment. In this way, the user is able create a mental model of the spatial dimensions of the environment. While navigating, the user can interact with each of the previously mentioned elements, and each of these elements provides different kinds of feedback that help the user become oriented in the environment. AbES includes three modes of interaction: Free Navigation, Path Navigation and Game Mode.

The free navigation mode provides the user who is blind with the possibility of exploring a building freely in order to become familiar with it. The facilitator can choose whether the user begins in a particular starting room, or let the AbES software randomly choose the starting point. Path navigation provides the user who is blind with the task of finding a particular room by first choosing an initial and destination room, and selecting the number of routes to be taken.

The game mode provides blind users with the task of searching for "jewels" placed in the building. The purpose of the game is to explore the rooms and find all the jewels, bringing them outside one at a time and then going back into the building to continue exploring. Enemies are randomly placed in the building, and try to steal the user's jewels and hide them elsewhere.

Different versions of AbES have been developed in order to simulate various real life, closed spaces. One of these versions corresponds to the St. Paul's building at the Carroll Center for the Blind in Newton, MA, USA. Later, other versions were developed to simulate the Santa Lucia School and Hellen Keller School, both located in Santiago, Chile. In the version for the St. Paul's building the entire environment could be navigated freely (see Fig. 1). The design and development of AbES was carried out by considering the ways in which blind users interact, and how audio can help them to increment certain spatial navigation skills and facilitate their cognitive development.

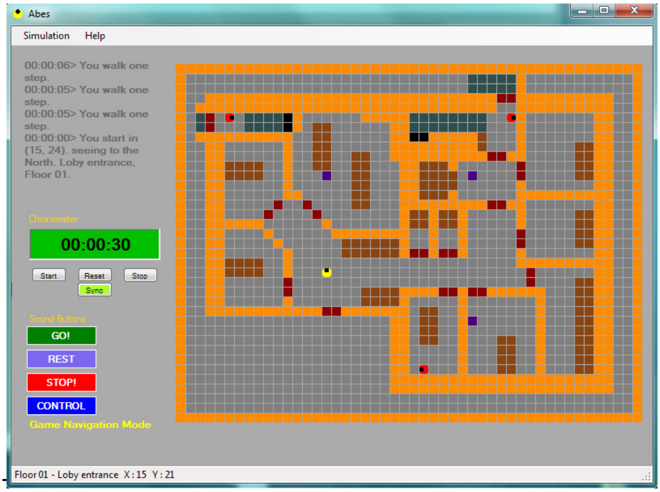

Fig. 1. A screenshot of AbES

3 Museum of Science and Technology

The application introduced here, mAbES, represents the actual physical environment of the Museum of Science and Technology, of the Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, Brazil (MCT-PUCRS). This museum is one of the largest interactive natural science museums in Latin America. Its mission is to generate, preserve and disseminate knowledge through its collections and exhibitions.

It has an area of over ten thousand square meters dedicated to public exhibitions, and about 700 interactive apparatuses that can be used by visitors. The interactive nature of the many experimental sites provides for playful experiences that facilitate the understanding of scientific concepts and theories for all ages in a creative environment.

Among the scientific exhibitions, the most impressive are related to the areas of Zoology, Botany, Paleontology and Archaeology, which are utilized by researchers and some graduate and post-graduate student of PUCRS, as well as other national and foreign institutions.

Despite the fact that the MCT is designed as a space of learning and information, there are still limitations regarding the active and autonomous participation of people with certain disabilities. There are structural accessibility and information related problems for people who use wheelchairs, people who are deaf, people who are blind, or people with cognitive disabilities. In order to facilitate the construction of a more inclusive society that recognizes the diversity of people with disabilities and the importance of their individual autonomy and independence, the MCT has formed partnerships for the development of activities that promote accessibility to the physical environment, education and information for people with disabilities.

In this context, the need emerged for the development of a software application to support the navigation (orientation and mobility) of people who are blind that visit the

MCT-PUCRS. This software was named mAbES (mobile Audio-based Environment Simulator), because it was based on the AbES software.

4 Methodology

For the development of mAbES, an XP (eXtreme Programming) methodology was utilized, including weekly technical meetings with a specialized team from the museum, rapid feedback loops, and the provision of weekly programming codes.

Members of the museum team participated in meetings in order to define the scope and to prioritize the functionalities of the software. Following the definition of the areas of the MCT-PUCRS that would be included in mAbES, a museum architect and a professor of physics, who are also part of the Educational Coordination team of the MCT, joined the software development team. In order to develop the application, the team went on constant guided tours of the museum.

The mAbES development model was also based on a model that proposes an iterative development process for mobile videogame-based software in order to improve the orientation and mobility skills of blind users [16][17]. This process includes the following phases: 1. Definition of the cognitive skills needed for navigation; 2. The software engineering process for the design and development of the applications; and 3. A validation process for the tools that are developed.

The mAbES software application was developed by using Unity, a platform for videogame development. In addition, the following were also utilized:

- Google Translate: used to convert texts of up to 101 characters into MP3 audio. The mAbES was used to generate the audio cues for the users. For example, if the user crashes into a wall, mAbES informs him: “This is a wall”. This audio was produced based on: http://translate.google.com/translate_tts?tl=pt&q=this is a wall.
- Soar MP3: Utilized to turn text conversations with over 101 characters into audio. Was used to generate an audio description of the selected MCT-PUCRS experiments.
- AutoCAD: Used to manipulate the floor plans of MCT/PUCRS in order to export them for use with Unity.
- Google Sketchup: Utilized to create 3D objects based on MCT-PUCRS, which were then exported for use with Unity.
- AutoDesk 3DS Max Design: Used to convert the museum’s floor plan files, which had been generated using AutoCAD, to a file format compatible with Unity.
- JavaScript: Optimal programming language for the Unity environment.

5 Results

The mAbES software was designed in stages, based on the decisions made regarding the specific experiments to be mapped. These choices were made according to the museum’s demands. The first phase involved the experiments in the energy section. This choice was based mainly on the following issues: the experiments were among those that had the longest shelf life in the museum, and those that represent areas of knowledge that people generally have difficulty understanding. The posterior phases will continue to map related experiments within the energy section.

In the first phase, 3 experiments were chosen: Nuclear Power Station, Energy Train, and Cool House, located on the third floor of the museum. In mAbES, these experiments are represented with 3D graphics, and information on them is available in audio format. This paper describes the results of one of these experiments.

5.1 Interfaces

The mAbES software presents information regarding the physical space of the MCT-PUCRS, the selected experiments, and also responds to the user's movements through the museum. The physical space of the museum and the experiments are represented through 3D graphics, allowing for its use by people with visual disabilities, low-level vision and sighted people as well. The interaction between mAbES and the user occurs mainly through an audio interface, while the user communicates with the software by interacting with a smartphone screen, which utilizes an array of points of the Braille system (see Figures 2 and 3).

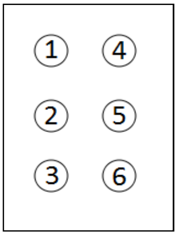

Fig. 2. Matrix of Braille points

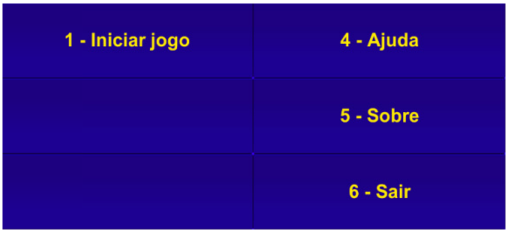

Fig. 3. Startup screen of mAbES

In following the AbES model [16][17], the user's movement using mAbES occurs in three different ways: forward, right and left. The user's movement through the museum is achieved by using the forward button, which represents the user's individual steps. The right and left buttons are used when the user turns in either direction.

The transition between floors in the MCT-PUCRS is achieved through the use of escalators (Figure 4), in which it is possible to observe the areas involved in the user's interaction when moving forward, turning right or turning left. When the user reaches an escalator, mAbES provides an audio-description about its physical appearance, functioning and how the user who is blind should use the escalator in the real context of the Museum.

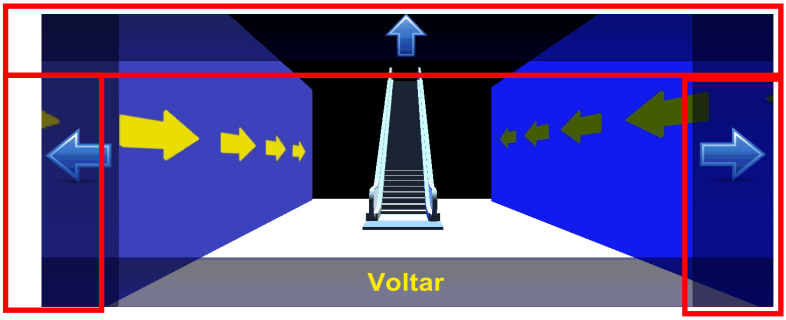

Fig. 4. Transitions between floors of the MCT-PUCRS

Information on the museum or the experiments is available to the user in audio format. The options for hearing the audio cues are: 1 – Play, 2 – Pause, 3 – Increase speed, 4 – Go back, 5 – Go forward, 6 – Help.

When the user arrives at the third floor, which is the purpose of phase 1, mAbES presents the experiments that are mapped so that the user can choose which one he wants to interact with: 1 – Nuclear Power Station, 2 – Energy Train, 3 – Cool House, 4 – Explore the space freely, 5 – More information, 6 – Exit, according to the Braille matrix.

When the user crashes into any object (wall, pillar, or escalator, for example) or comes upon any experiment (Nuclear Power Station, Energy Train, Cool House), mAbES informs the user by naming the object or experiment, and the options that are available to the user. In addition, the device's vibration functionality is utilized for each collision.

5.2 Experiments

In the following section, one of the experiments is described in order to illustrate the application of mAbES in a general area of the MCT-PUCRS, regarding the specific issue of Energy.

In the MCT-PUCRS, the Nuclear Power Station experiment simulates the production of nuclear energy, based on a mechanical interaction between the user and the technological devices involved in a nuclear power station. When a user comes upon this experiment, mAbES presents 5 different options for interaction: Challenges (options 1, 2 and 3), audio-description of the experiment (option 4), and information for exiting the Nuclear Power Station experiment (option 6). Figure 5a illustrates the nuclear power station interaction screen, while Figure 5b shows the options for interaction that are available to the user.

Fig. 5. (a) Nuclear Power Station, (b) Interaction options

The options 1, 2 and 3 present questions related to a nuclear power station as well as response options. Option 1 presents the challenge: "In the first stage of energy production, what happens to the water? Click 1 if you think that the water turns into fuel. Click 2 if you think that the water turns to steam. Click 3 if you think the water goes into the holding tank in liquid form". The options are presented using the Braille matrix. If the user chooses option 2, mAbES informs the user that the answer is correct. Otherwise, the software states that the answer is wrong.

For Option 2, the user must answer the challenge, "What is the function of the electric generator in a nuclear power station? Click 1 if you think that it is to transform the energy trapped in the movement of the water vapor into electrical energy. Click 2 if you think that it is to turn water into steam. Click 3 if you think that it is to reduce the maximum number of fission reactions". If the user chooses option 1, mAbES informs the user that the answer is correct. Otherwise, it states that the answer is wrong.

Option 3 involves the following challenge: "What happens to the steam after it makes the turbine move? Click 1 if when the steam exits the turbine, it ends up producing energy. Click 2 if the steam comes into direct contact with the seawater in order to restart the cycle. Click 3 if the steam is cooled by the seawater, turning it into a net-liquid state so that the process of energy production can be resumed". If the user chooses option 3, mAbES informs the user that the answer is correct. Otherwise, it states that the answer is wrong.

Starting at the Nuclear Power Station experiment, in following the virtual hallway represented on mAbES forward, the user will come upon the Energy Train and Cool

House experiments. The Energy Train is made up of cartoon characters of energy scientists. The mAbES application provides information on each one of them, and the user must choose the correct name of the corresponding scientist. The cartoon characters are presented as the user moves along the train.

The Cool House is one of the MCT-PUCRS experiments that require a guided experience, as it includes activities that involve the manipulation of household appliances such as a hair dryer, iron, stove, bathtub and shower, among others. All of the objects in the Cool House that can be manipulated have energy performance meters. Based on this information, questions are presented regarding electrical energy consumption. As the user navigates the house, mAbES presents movement options and audio descriptions regarding the location of the various appliances that can be manipulated. When exiting the Cool House, the software presents questions related to the experiments that the user now has the information needed to respond.

In addition, mAbES presents some questions that the user must respond to when visiting the MCT-PUCRS, such as those related to the use of fuel in the production of nuclear energy, how electrical generation turbines work in a nuclear power station, regarding the physical appearance of the scientists presented at the Energy Train, and related to electrical energy consumption when using certain kinds of household appliances.

6 Discussion and Conclusions

This study presents the design and implementation of mAbES, a mobile audio based environment simulator to assist in the development of orientation and mobility skills for people who are blind. We also introduce a model scenario for using mAbES together with an application for navigating through a science and technology museum in Porto Alegre, Brazil. This application was focused on a specific topic area, pertaining to the concept of energy and other related topics.

We present and describe the main interfaces of mAbES including both audio and graphic design, and explain the different modes of user interaction. The mAbES software was designed for use by people with visual impairment, but without excluding the possibility that sighted people can also use the application, in order to promote social inclusion.

The mAbES software supports navigation through the museum by a group with both visually impaired and sighted visitors. In this way, a blind visitor and a sighted visitor can share the use of a smartphone and earphones, and create collaborative experiences as a result of using and interacting with mAbES. This may help to avoid people with visual impairment being isolated while visiting the museum. The issue of user isolation when using a mobile museum guide is mentioned in some studies as a disadvantage [8].

Finally, future work will involve the implementation of a full usability evaluation of mAbES, with both visually impaired and sighted users. Such work would also imply the design and implementation of an impact evaluation study focusing on orientation and mobility skills. In this sense, measuring the impact of the use of mAbES on the development and practice of navigation skills is the priority for future work.

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References

1. Carreiras, M., Codina, B.: Cognición espacial, orientación y movilidad, consideraciones sobre la ceguera. Integración (11), 5–15 (1993)
2. Frauenberger, C., Noisternig, M.: 3D audio interfaces for the blind. In: Proceedings of the 2003 International Conference on Auditory Display, Boston, MA, USA, July 6-9, pp. 1–4 (2003)
3. Golledge, R.: Geography and the disabled. A survey with special reference to vision impaired and blind populations. Transactions of the Institute of British Geographers, New Series 18(1), 63–85 (1993)
4. Hill, E., Ponder, P.: Orientación y técnicas de Movilidad, Una guía para el practicante. Comité internacional pro-ciegos, México (1981)
5. Jacobson, R.D.: Cognitive mapping without sight: four preliminary studies of spatial learning. Journal of Environmental Psychology (18), 289–305 (1998)
6. Jain, S.: Assessment of audio interfaces for use in smartphone based spatial learning systems for the blind. Master of Science Thesis in Spatial Information Science and Engineering. University of Maine (2012)
7. Lahav, O., Mioduser, D.: Haptic-feedback support for cognitive mapping of unknown spaces by people who are blind. International Journal of Human-Computer Studies 66(1), 23–35 (2008)
8. Lanir, J., Kuflik, T., Dim, E., Wecker, A.J., Stock, O.: The influence of location-aware mobile guide on Museum visitors´behavior. Interacting with Computers 25(6), 443–460 (2013)
9. Lumbreras, M., Sánchez, J.: Interactive 3D sound hyperstories for blind children. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: the CHI Is the Limit, CHI 1999, Pittsburgh, Pennsylvania, United States, May 15-20, pp. 318–325 (1999)
10. Millar, S.: La comprensión y la representación del espacio, Teoría y evidencia a partir de estudios con niños ciegos y videntes, 406 págs. ONCE, Madrid (1997)
11. ONCE, Organización Nacional de Ciegos Españoles: Glosario de Términos de Rehabilitación Básica de las Personas Ciegas y Deficientes Visuales, Entre Dos Mundos, Revista de traducción sobre discapacidad visual (1998)
12. Sanabria, L.: Mapeo cognitivo y exploración háptica para comprender la disposición del espacio de videntes e invidentes. Tecné, Episteme y Didaxis: Revista de la Facultad de Ciencia y Tecnología 21, 45–65 (2007)
13. Sánchez, J., Maureira, E.: Subway Mobility Assistance Tools for Blind Users. In: Stephanidis, C., Pieper, M. (eds.) ERCIM Ws UI4ALL 2006. LNCS, vol. 4397, pp. 386–404. Springer, Heidelberg (2007)
14. Sánchez, J., Oyarzún, C.: Mobile Audio Assistance in Bus Transportation for the Blind. International Journal on Disability and Human Development (IJDHD) 10(4), 365–371 (2011)

15. Sánchez, J., de la Torre, N.: Autonomous navigation through the city for the blind. In: Proceedings of the 12th international ACM SIGACCESS Conference on Computers and Accessibility (ASSETS 2010), pp. 195–202. ACM, New York (2010)
16. Sánchez, J., Sáenz, M., Pascual-Leone, A., Merabet, L.: Enhancing navigation skills through audio gaming. In: Ext. Abstracts CHI 2010, pp. 3991–3996. ACM Press (2010)
17. Sánchez, J., Tadres, A., Pascual-Leone, A., Merabet, L.: Blind Children Navigation through Gaming and Associated Brain Plasticity. In: Proc. of the Virtual Rehabilitation 2009 International Conference, Haifa, Israel, pp. 29–36. IEEE (2009)