EXPLORATION OF INTERFACE USABILITY IN A HAPTIC 3D VIRTUAL LABYRINTH FOR VISUALLY IMPAIRED USERS

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ABSTRACT

In this paper, an experimental study is presented on navigation in a 3D virtual environment by blind and visually impaired people with haptic and audio interaction. A simple 3D labyrinth is developed with haptic and audio interfaces to allow blind and visually impaired persons to access a three-dimensional Virtual Reality scene through senses of touch and hearing. The user must move from inside of the labyrinth to find an exit. Objects with different shapes can be found inside the labyrinth with walls around them. Different navigation tools were designed in order to assist their spatial orientation and mobility with haptic and audio cues. The result of the experimental study with qualitative analysis is an investigation on the accessibility and usability for blind and visually impaired people to play online 3D virtual reality games like Second Life in a haptic and audio virtual environment. This description can later serve as an input to innovative presentations on cognitive mapping, orientation and navigation of spatial structures using haptic and auditory displays.

KEYWORDS

Haptic; Audio; Virtual Reality; Navigation, Cognitive Mapping

1 INTRODUCTION

Blind or visually impaired persons always have problem on mobility and orientation both indoors and outdoors. They often do not leave their homes alone or visit new places as it is hard for them to understand the pathway and landmarks before leaving the house. The problem of planning routes for city journeys affects blind and visually impaired people. The result is that blind and visually impaired people must depend on the assistance of sighted people to plan and undertake journeys that sighted people can undertake independently.

With the development of haptic and audio technologies, it is possible to design interfaces that allow blind and visually impaired persons to access to a three-dimensional Virtual Reality environment through the senses of touch and hearing. On one hand, it could be used for route planning to understand the pathway with landmarks before leaving the house; On the other hand, it enhances the possibility and accessibility for blind and visually impaired people to play 3D VR game like Second Life in a 3D haptic and audio virtual environment [M. de Pascale, et. al, 2008]. Interaction and design issues are common in these two research situations in order to improve usability and the user experience.

The interaction and design issues could be in terms of the way of navigation, cognitive mapping, how to orientate and move in an unknown space. This study is not mainly concerned with hardwarea nd software development but looks towards interaction and design issues to improve usability and the user experience. A simple labyrinth was developed with haptic and audio interfaces to allow blind and visually impaired persons to access to the three-dimensional Virtual Reality environment through the senses of touch and hearing. The user must move inside of the labyrinth to find an exit. Objects with different shapes can be found inside the labyrinth with walls around them. The main goal of this study is to investigate the way of navigation, cognitive mapping of unknown space, spatial orientation and mobility by blind and visually impaired people with haptic and audio interactions. Finally, throughout the experimental study, we try to understand users' requirements, particularly in terms of accessibility, usability and user experience for blind and visually impaired users, using qualitative analysis.

2 BACKGROUND

Adams described three phases of navigation [C. Adams. 1997]: preparation, gross navigation, and fine navigation. The first phase includes getting an overview of the destination area and creating a route to get there. Blind people perform this process usually at home in a safe environment. The gross navigation is performed on the way. The main task of this phase is to get from one way point to the next way point of the planned route. The fine navigation process contains tasks like obstacle detection, perceiving the material of the floor etc. However, these systems are employed when the user already is on his or her tour. With our approach we aim to provide users the experience of a walking tour in a 3D virtual environment which could be used as the preparation navigation phase.

The navigational problems for visually impaired people in using 3D virtual environments have largely been underestimated in haptic and audio research. Although there is an acknowledgement that the "lost in hyperspace" phenomenon exists and various innovative navigational systems have been developed, these have not been clearly derived from user requirements, nor have they been evaluated in terms of their effectiveness in supporting users.

An effort to explore the possibilities that haptic and audio technologies can offer to navigation in a 3D virtual game, and to provide blind users with an easier, more interactive and immersive experience is valuable.

2.1 Related work

The research concerning haptic perception and rendering techniques has increased rapidly during the last few years, and results have shown the significant role that haptic feedback plays in graphical user interfaces [Gupta et al. 1997; Hasser et al. 1998; Hurmuzlu et al. 1998]. Designers are beginning to realize the advantages of haptic displays in order to help blind individuals to overcome the challenges experienced when accessing and exploring the web [Kuber 2007]. The touch modality has also been shown to make it possible for visually impaired to explore and navigate virtual environments [Sjostrom 2001]. The interaction is enriched by the use of the sense of touch, since visually impaired users can identify objects and perceive their shape and texture. In a recent EU project, “Pure Form”, the aim was to develop a haptic display for exploration of virtual copies of statues at museums in order to make them accessible to visually impaired people, [Bergamasco et al. 2001; Bergamasco and Prisco 1998; Frisoli et al. 2002].

Haptic interface technology enables individuals who are blind to expand their knowledge by using an artificially made reality built on haptic and audio feedback. Research on the implementation of haptic technologies within Virtual Environments (VEs) has reported the potential for supporting the development of cognitive models of navigation and spatial knowledge with sighted people (Witmer et al., 1996; Giess et al., 1998; Gorman et al., 1998; Darken and Peterson, 2002) and with people who are blind as well (Colwell et al., 1998; Jansson et al., 1998).

Studies about walking in digital environments are available, as in [S. Razzaque, et al 2001], where the virtual scene interactively rotates about the user, such that the user is made to continuously walk towards the farthest “wall" of the tracker. In [M. Usoh, 1999], the authors studied the sense of presence of subjects immersed in a virtual environment during a real walking, a virtual walking (walking-in-place), and a virtual flight. Lahav and Mioduser in [2008] created a multi-sensory virtual environment enabling blind people to learn how to explore real life spaces (e.g. public buildings, schools or work places). The user interface of their proposed virtual environment consists of a real rooms and objects simulation where users can navigate using a force feedback joystick. Afterwards, further studies about the interaction with virtual objects and navigation in virtual environments have been presented [O. Lahav and D. Mioduser 2008].

The use of the internet and access to information through the web has been researched gradually. Making easier access to this information channel for blind subjects has been the subject for several studies. Hardwick et al. [A. Hardwick et al 1998] proposed to use haptic devices to perceive the 3D images of internet pages, represented in the VRML way. Ad-hoc haptic interfaces have also been created to improve access for visually impaired people to 3D computer graphics, exploiting the sense of touch. In [C. Avizzano, et al 2003, R. Iglesias, et al 2004] authors presented the GRAB system, a new haptic device provided with a set of utilities and applications that allow blind persons to explore a 3D world through touch and audio help.

An effort to explore the possibilities that haptic technologies can offer to multiuser online virtual worlds, to provide users with an easier, more interactive and immersive experience [Maurizio de Pascale, 2008]. They developed a haptic-enabled version of the Second Life Client. Two haptic based input modes have been added which help visually impaired people to navigate and explore the simulated 3D environment by exploiting force feedback capabilities of these devices.

Interfaces that convey information through multiple sensory modalities make it easier for visually impaired people to access information in the computer. There have been some approaches showing that 3D sound is suitable to convey spatial information for blind and visually impaired people. 3D sound can be used, which combines a concurrent auditory presentation of information objects with their spatial layout.

With their interactive 3D sonification for the exploration of city maps, Wilko Heuten, et.al, provide an auditory support to get a cognitive understanding of the route and its acoustic and physical landmarks. Virtually exploring the map, a user can build a mental model of the city using sound areas. For each navigation point the user will get an acoustic impression of the objects close by and further away and their direction location on the map by providing a 3D sound experience of the current virtual map environment [Wilko Heuten, et.al, 2006]. The usage of 3D sound to help navigation in immersive virtual environments has been investigated in [T. Lokki and M. Grohn 2005]. The results show, that sound cues can be used for navigation in 3D environments. Walker and Lindsay [B. N. Walker and J. Lindsay 2006] examine non-speech beacon sounds for navigation and path finding. Their conclusion shows, that that the non-speech auditory interface can definitely be used for successful navigation.

However, very few researches have focused on accessibility, usability and user experience when visually disabled users use haptic devices to navigate in a haptic audio virtual worlds. With our haptic-audio based VE, blind and visually impaired users can access the information of 3D virtual environment in order to: familiarize with the spatial layout, follow and understand routes and, locate important and/or specific facilities and learn orientation and mobility. The users will interact with the 3D VR through the sense of touch and audio information. Through investigating the exploration process of an unknown space by blind subjects, especially the ways of navigation, spatial orientation and mobility with a haptic，audio-based VE, We focus on understanding users' feelings, requirements on such 3D haptic and the audio virtual environment, particularly in terms of accessibility, usability with qualitative analysis.

3 EXPERIMENTAL STUDY

A study has been conducted in order to investigate the exploration process of a 3D virtual Labyrinth by blind subjects, especially the ways of navigation, spatial orientation and mobility with a haptic, audio interface.

3.1 Participants

Two blind and two visually impaired participants attended in the study. Their age span was 35-55 years. The participants tried the Labyrinth prototype individually. The users that were going to do the test were selected by the following standard. They have strong interests in computers. They often use a computer at home and would like to access 3D virtual world for road planning or for playing games and entertainment.

3.2 Prototype

The prototype investigated in this study, is a three-dimensional haptic, auditory and visual virtual environment (Fig.1). The scene is a Labyrinth with walls and floor that have different and discriminable textures applied to them that can be felt using a haptic device. The environment contains a number of blocks and balls. Their shape and surface friction can also be felt. This 3D Labyrinth prototype is a structured description of 3D VR scene based on the X3D, an XML based format. A phantom Omni (on the right of figure 1)was used as the haptic device to control walking in the 3D labyrinth. Appropriate force feedback is rendered when a collision with obstacles occurs (such as bumping into a wall, another avatar or objects). The haptic device is used to provide vision for exploring the environment. The sky is not considered for collision. With this application, the user will be able to interact haptically with the different elements of a 3D VR scence, such as blocks, ball, roads, interest points, walls, etc. The users feel and recognize different geometrical shapes by means of force feedback. The users can move around, touching, hearing, in order to find an interest point, get information about the user position, and get the inventory of the space.

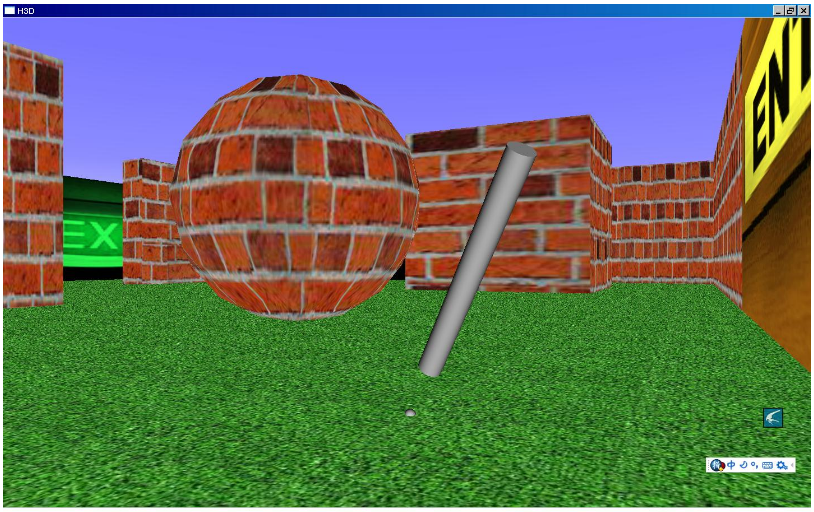

Fig. 1.A 3D haptic audio virtual environment.

A type of auditory feedback was implemented in the application. Two of the auditory cues are different piece of music playing at the entrance and exit separately. The volume of the sound is changeable according to the distance to object. It could be heard every time the avatar is close to a specific area, such as closing to exit. This audio information is non-speech information. With the volume characteristics of the audio, users can link their progress with the sound of their direction and distance to a specific area or object.

3.3 Apparatus

In the experiment, a Dell Precision Laptop with two dual core processors was used as the main hardware. One PHANTOM Omni(Fig.2), the haptic device that was connected serially to the Laptop. Because our aim is to create a 3D haptic virual environment for game or entertainment for visually impaired users, there is no requirement for a very powerful computer configuration. The H3D API 2.0 (an open source API), X3D, Python and Visual Studio .NET 2003, are employed for the application. H3D API can be used both as an API to implement C++ applications, and as a loader of applications built in X3D and Python. In the latter case the H3D system provides two executables that can be used to load the X3D file that defines the VR world. H3DLoad is a command-line tool that in its simplest use loads a specified X3D file. Camstudio was used for screen capturing during the experiment sessions.

Fig. 21. Experiment setting on the left and one Phantom Omni force feedback device on the right
(source: SensAble Technologies Inc).

3.4 Procedure

The experiment was divided into three parts; one training session for the participants, one test session and one interview session.

First of all, the researchers gave introductory information about the aim of the experiment, followed by instructions on how to use the haptic devices. The participant then got the opportunity to work with a demo program for some minutes, in which the user could feel different textures and surfaces applied to several cubes. They practiced how to feel the shape of an object, how to navigate in the three-dimensional environment and how to walk around with the audio guide. We made sure, before the real tasks were loaded, that the participants felt comfortable of working the haptic environment.

After the training session, which lasted for about 15 minutes, subject started to navigate in the virtual Labyrinth with given tasks. They need to find out what objects are included in a given place, or reach for an exit of the labyrinth starting from an unknown orientation. They were also asked to look for a single avatar instead of a group of avatars, and identify the size of object when they walk inside of the virtual labyrinth. All users found it easy to detect and reach an exit with the audio guide.

When the tasks were completed, users were interviewed in a followed interview session. The interview was semi structured and lasted for about 20 minutes. The interview session aimed at investigating the usability aspects with haptic and audio interaction. Some of questions were “Can the blind and visually impaired people access the 3D haptic and audio environment?”, “What strategies and processes people use for exploring an unknown space?”, “Can they use haptic or audio aids to perceive shapes of objects and for orientations, familiarise with the spatial layout, follow and understand routes, locate important and/or specific facilities and learn orientation and mobility?” and What were their ways of navigation, spatial orientation and mobility with a haptic and audio based VE?”.

Questions about navigation, cognitive mapping of unknown space, spatial orientation and mobility for blind and visually impaired people to play 3D haptic virtual reality game were also asked to give us more insight on how haptic and audio interfaces might support these aspects. Some of the other questions related are: “What strategies did you use for exploring an unknown space?”, “Did the haptic and audio aids provide an effective support for mobility and orientation?”,and “What more requirements do you see for haptic and audio aids?”.

3.5 Analysis

A video analysis was performed after the test sessions in this study. The observation of the video recordings was not guided by fixed categories. The categories identified as interesting during the analyses were: accessibility, usability, navigation, modality aids. The video recordings of the interaction in the virtual environment were analyzed. Major interactive actions were recorded using the video analysis software Transana. Each piece of data was categorized (piece of data were description of events). Particular actions are extracted as a way to illustrate findings.

The interviews were transcribed in their entirety. Annotations were made for each meaningful unit of the data material and a number of categories were defined. The data was analyzed in this way for each user. Finally, the results from all users were compared in order to obtain general findings and interesting patterns in the results as well as unique findings.

4 RESULTS AND FINDINGS

In this section the important findings are described which derived from the qualitative analyses of the experiment. It is interesting to observe the experimental process and have interviews with all the participants.

4.1 Accessibility

According to the interview, all users admitted that it was possible to feel things and walk in the Labyrinth, and to distinguish between objects, textures and heights with the haptic device. Once they realized that a sound will appear when they are approaching a certain area, they started to be faster to reach closer to the area where the audio raised. In this way, they can move from the start to the exit quickly and precisely. A difference between the participants is that two of them never played this kind of VR computer game before. They had never navigate in a 3D virtual environment with haptic device before. What they do most is checking emails with computer. Therefore it took them time to understand the environment, what's happening in there and it took them also time to walk virtually around to find the destination. However, one of the participants has 8% vision, and also has experience on playing on-line computer games under the assistance of families or friends. Therefore, it is pretty much easier for him to play around, understanding the environment very quickly. He just used few minutes to finish the tasks. As for audio aids, the participants said it is really important to have the audio assistance for them to find their ways towards target. Otherwise, it will be impossible for way finding. We could see audio design improve their accessibility in such haptic 3D virtual environment.

4.2 Usability

Generally, all of the participants had no problem in using the haptic equipment. It was also possible for them to feel things and to distinguish between objects, textures and heights. From the observations, the interaction with haptic and audio design was used in the intended way. All participants can use haptic device to navigate in such haptic 3D virtual labyrinth. When we raise the question “Can you use haptic or audio aids to perceive shapes of objects and for orientations, Familiarize with the spatial layout, follow and understand routes, locate important and/or specific facilities and learn orientation and mobility?”, most of the participants said “yes”, but in different level. One participant said, after practicing in the haptic environment for a while, said “yes”, but according to him, some of the 3D models should be enlarged. It also would be good to have options for users to enlarge the haptic force feedback by themselves if it is possible, as well as to design the texture on the surface of a certain object with more sensitive textures. It would be helpful and easier for them to understand the spatial layout.

Regarding audio aids in such a haptic virtual environment, all the users believe that the audio function helped them a lot to find the correct direction. They appreciated the design that once they approached closer to one area, a sound appears, the stronger that sound is, the closer it means for the participant that they are to the destination. It was obvious from the observations that the audio cues help the users for way finding when they navigate in such haptic 3D virtual environments. This also demonstrate further our findings in another study (which were submitted to TOCHI) that audio cues can make a difference in a haptic virtual environment.

However, although the sound was 3D we noticed that sometimes it was hard to describe where it comes from, whether it comes from front/back or up/down. What the user can do is to recognize the audio’s direction just by the volume approximately. This will cause a problem in a collaborative situation that it will be hard to describe the direction by words where to go for the other co-player. The participant can only understand it when they were there and feel it by themselves.

4.3 Navigation, Mobility and Orientation

During the interview session, our questions regarding navigation were about what were their strategies on navigation, and spatial orientation and mobility with haptic，audio interaction. Did the haptic and audio aids provide an effective support for mobility and orientation? What more requirements are there for haptic and audio aids?

We noticed that first of all there was a big difference on whether they understand what a labyrinth is or not. It will affect a lot on their performance. Some of them, that were not blind when they were born, and know what a labyrinth looks like in their mind, could spend less time on navigation when they use the haptic device to navigate in the labyrinth. Those who had never see and known what a abyrinth is, spent lots of time on figuring out the spatial layout, how to walk inside of it.

Secondly, some of them didn’t have any strategy; they navigate the environment and tried to find out what’s inside just by chance. They navigated without any clue to follow. But as they describe, they appreciated that the haptic function helped them to feel something concrete standing there with different texture. These are very important insights about the spatial layout. During their walking process in the haptic environment without any clue, once they hear a sound by chance, then audio cues gave them another important clue to follow for way finding. This actually helped them a lot to finish the task according to the description.

On the other hand, one of them had a strategy on how to navigate in such haptic virtual environment, as he described, once he found a wall to follow, he then tried to follow the wall with the haptic force feedback to the end of it several times and then follow it to another connected one until he got a clear view on spatial layout. Users could follow the wall making a movement with the haptic force feedback and finding the direction where to go by the audio feedback. In this way they made themselves getting closer to the destination. Therefore we can make a conclusion that the spatial architecture and texture in such environment will influence the way of navigation, mobility and audio has a crucial impact on orientation.

5 DISCUSSION

This study demonstrates the possibility and accessibility for blind and visually impaired people to play online 3D VR games like Second Life in a 3D haptic and audio virtual environment. However, from the accessibility aspect, it is not all of the visually impaired people can access the haptic 3D virtual environment easily and quickly. There is a big gap between what the environment looks like in the participants' mind and what it actually looks like. Two of the participants who had never the experience in playing haptic 3D virtual game before, spent lots of time on accessing and understand the environment. One of the participants said, that he can't understand how the distance that he did with the haptic device, Phantom Omni, matches the real distance that he walks in real life. He totally didn't understand how long or how far it will be for each step when he used the Phantom Omni to walk in such a haptic virtual environment. At this point, he felt disappointed on control. Therefore, matching the gap between what the environments should be in the participants' mind and what actually it looks like with haptic and audio interactive feedback will be a key issue for design to improve accessibility and usability for blind and visually impaired people.

Regarding navigation, mobility and orientation issues, users could follow the wall and make a movement with the haptic force feedback and find the direction where to go by the audio feedback. In this way they made themselves getting closer to the destination. Therefore we argue that spatial architecture and sensitive texture in such environment will influence the way of navigation, mobility and orientation. This study can later serve as an input to presentations on orientation and navigation of spatial structures using haptic and auditory interfaces.

Participants were highly interested in the idea of games applications with the haptic device, but some of them who figured out how to walk through the Labyrinth quickly and easily wanted the games to be more complicated like the games that sighted people play using computers.

The target audience for such an application should include blind users and visually impaired people in the workplace or in higher level education, and those blind users in the community with an interest in online computer games. An application of this kind meets the social needs for inclusion; it provides increased accessibility for blind and visually impaired people to access haptic virtual environment for route planning or entertainment purposes and improves their life quality.

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REFERENCES

Hardwick, S. Furner, and J. Rush, 1998. Tactile display of virtual reality from the World Wide Web-a potential access method for blind people. Displays, 18(3):153-161.

Beck, K. and Ralph, J., 1994. Patterns Generates Architectures. Proceedings of European Conference of Object-Oriented Programming. Bologna, Italy, pp. 139-149.

BERGAMASCO, M. AVIZZANO, C. DI PETRI, G., BARBAGLI, F. AND FRISOLI, A. 2001. The museum of pure form: system architecture, In Proceedings of 10th IEEE International Workshop on Robot and Human Interactive Communication, Piscataway, NY: IEEE Press, 112-117.

BERGAMASCO, M. AND PRISCO, G. 1998. Design of an anthropomorphic haptic interface for the human arm, In Y. Shirai and S. Hircse (Eds,), Robotic Research, the Eight International Symposiums, 278-289. London: Springer.

B. N. Walker and J. Lindsay, 2006. Navigation performance with a virtual auditory display: Effects of beacon sound, capture radius, and practice. In Human Factors, volume 48(2), pages 265–278.

C. Avizzano, S. Marcheschi, M. Angerilli, M. Fontana, M. Bergamasco, T. Gutierrez, and M. Mannegeis, 2003. A multi-finger haptic interface for visually impaired people. Robot and Human Interactive Communication. Proceedings. ROMAN 2003. The 12th IEEE International Workshop on, pages 165-170.

Colwell, C., Petrie, H., Kornbrot, D., 1998. Haptic virtual reality for blind computer users. Paper presented at the Assets '98 Conference, Los Angeles, CA. Available in: /http://phoenix.herts.ac.uk/sdru/pubs/VE/ colwell.htmlS.

Darken, R.P., Peterson, B., 2002. Spatial orientation, wayfinding, and representation. In: Stanney, K.M. (Ed.), Handbook of Virtual Environments Design, Implementation and Applications. Lawrence Erlbaum Associates, Inc., New Jersey, pp. 493 – 518.

FRISOLI, A., SIMONCINI, F. AND BERGAMASCO, M. 2002, Mechanical design of a haptic interface for the hand, In Proceedings of 2002 ASME DETC 27th Biennial Mechanisms and Robotics Conference, Montreal, Canada: ASME Press, 25-32.

Giess, C., Evers, H., Meinzer, H.P., 1998. Haptic volume rendering in different scenarios of surgical planning. Paper presented at the Third PHANTOM Users Group Workshop, M.I.T., Massachusetts.

Gorman, P.J., Lieser, J.D., Murray, W.B., Haluck, R.S., Krummel, T.M., 1998. Assessment and validation of force feedback virtual reality based surgical simulator. Paper presented at the Third PHANToM Users Group Workshop, M.I.T., Massachusetts

GUPTA, R., SHERIDAN, T. AND WHITNEY, D. 1997. Experiments Using Multimodal Virtual Environments in Design for Assembly Analysis. Presence: Teleoperators and Virtual Environments. 6(3), 318-338.

HASSER, C. J. GOLDENBERG, A. S. , MARTIN, K. M. AND ROSENBERG, L. B. 1998. User Performing a GUI Pointing Task with a Low-Cost Force-Feedback Computer Mouse, DSC-Vol. 64, Proc. of the ASME Dynamics and Control Division, 151-156.

HURMUZLU, Y., EPHANOV, A. AND STOIANOVICI, D. 1998. Effect of a Pneumatically Driven Haptic Interface on the

Perceptional Capabilities of Human Operators. Presence: Teleoperators and Virtual Environments. 7(3), 290-307.

Jacobson, R.D., Kitchin, R., Garling, T., Golledge, R., Blades, M., 1998. Learning a complex urban route without sight: comparing naturalistic versus laboratory measures. Paper presented at the International Conference of the cognitive Science Society of Ireland. Mind III, Ireland: University College, Dublin, Ireland.

KUBER, R., YU, W., AND MCALLISTER, G. 2007. Towards Developing Assistive Haptic Feedback for Visually Impaired Internet Users, In Proceedings of the 2007 Conference on Human Factors in Computing Systems, San Jose, California, USA, 1525 – 1534.

K. Rassmus-Gr¨ohn and C. Sj¨ostr¨om, 1998. Using a force feedback device to present graphical information to people with visual disabilities, In Proceedings of Second Swedish Symposium on Multimodal Communication, Lund, Sweden.

The Grab Project Members. Grab, 2003. http://www.grab-eu.com/index.htm [Online; accessed01-September-2006].

M. de Pascale, S. Mulatto and D. Prattichizzo, 2008. Bringing Haptics to Second Life. Proc. of the Workshop on Haptic in Ambient Systems 2008 (HAS2008) Quebec City.

M. de Pascale, S. Mulatto and D. Prattichizzo, 2008 Bringing Haptics to Second Life for Visually Impaired People. Proceedings of EuroHaptics 2008.

Mirko Horstmann, Wilko Heuten, Andrea Miene1, and Susanne Boll, 2006. Automatic Annotation of Geographic Maps. Proceedings of ICCHP 2006 - 10th International Conference on Computers Helping People with Special Needs , Paper and Presentation in Linz, Austria, July 11-13, 2006. Website: http://www.icchp.org/

M. Usoh, K. Arthur, M. Whitton, R. Bastos, A. Steed, M. Slater, and

F. Brooks Jr, 1999. Walking, walking-in-place, flying, in virtual environments. Proc. of the 26th annual conference on Computer graphics and interactive techniques, pages 359-364.

O. Lahav, D.Mioduser, 2008. haptic-feedback support for cognitive mapping of unknown spaces by people who are blind, International Journal of Human-Computer Studies, Volume 66, Issue 1, January 2008, Pages 23-35.

R. Iglesias, S. Casado, T. Gutierrez, J. Barbero, C. Avizzano, S. Marcheschi, M. Bergamasco, F. Labein, and S. Derio, 2004. Computer graphics access for blind people through a haptic and audio virtual environment. Haptic, Audio and Visual Environments and Their Applications, 2004. HAVE 2004. Proceedings. The 3rd IEEE International Workshop on, pages 13-18.

SJOSTROM, C. 2001. Designing Haptic Computer Interfaces for Blind People. Proc. ISSPA, 1, 68-71.

S. Razzaque, Z. Kohn, and M. Whitton, 2001. Redirected Walking, Eurographics 2001 Proc., 2001. On-line available: http://www.cs.unc.edu/eve/pubs.html.

T. Lokki and M. Grohn, 2005. Navigation with auditory cues in a virtual environment. IEEE MultiMedia, 12(2):80– 86.

Wilko Heuten, DanielWichmann, Susanne Boll,2006. Interactive 3D Sonification for the Exploration of City Maps, in proceeding of NordiCHI 2006, Oslo, Norway, October 14-18, 2006. Website: http://nordichi.net.dynamicweb.dk/

Wilko Heuten, DanielWichmann, Susanne Boll, 2006 Interactive 3D Sonification for the Exploration of City Maps, in proceeding of NordiCHI 2006, Oslo, Norway, October 14-18.

Witmer, B.G., Bailey, J.H., Knerr, B.W., Parsons, K.C., 1996. Virtual spaces and real world places: transfer of route knowledge. International J. of Human-Computer Studies 45, 413 – 428.