Toward Accessible 3D Virtual Environments for the Blind and Visually Impaired

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ABSTRACT

3D virtual environments are increasingly used for education, business and recreation but are often inaccessible to users who are visually impaired, effectively creating a digital divide. Interviews with 8 visually impaired expert users were conducted to guide design proposals, and a review of current research into haptics and 3D sound for auditory displays is presented with suggestions for navigation and feedback techniques to address these accessibility issues. The diversity and volatility of the environment makes *Second Life* an unusually complex research object, suggesting the applicability of our work for the field of HCI and accessibility in 3D virtual environments.

Categories and Subject Descriptors

K.4.2 [**COMPUTERS AND SOCIETY**]: Social Issues—*Assistive technologies for persons with disabilities*; H.5.2 [**INFORMATION INTERFACES AND PRESENTATION (e.g., HCI)**]: User Interfaces—*Auditory (non-speech) feedback, Haptic I/O, User-centered design*; H.5.1 [**INFORMATION INTERFACES AND PRESENTATION (e.g., HCI)**]: Multimedia Information Systems—*Artificial, augmented, and virtual realities*

General Terms

Human Factors, Design

Keywords

Accessibility, Visual Impairment, Second Life, Multi-User Virtual Environment, MUVE, 3D, Haptics, Sonification, Multimodal Feedback

1. INTRODUCTION

In this paper we review the accessibility issues that currently face blind users in *Second Life* (SL) and suggest proposals for their resolution. Our study began by recognising the interest that SL has generated, and the speculation that similar online Multi-User Virtual Environments (MUVEs) are likely to become more common in the future. Furthermore, 3D environments are already prevalent through diverse areas from entertainment (such as World of Warcraft [5]; PlayStation Home [42]) to information (Google Earth [18]), but rarely in an accessible form.

> "... virtual worlds are going to be the next big evolution of the web and if this happens...it's not right for blind people to be missing out on what the rest of us have available." [2]

Governmental regulation has assured a certain degree of accessibility in the physical world of public spaces, as well as online in the WWW. However, as new technological advances are made there is concern that standards to ensure accessibility are not keeping pace. For example, consider that the Web Content Accessibility Guidelines (WCAG) 1.0 guidelines [9] were developed in 1999, and WCAG 2.0 [7] were only available in 2008. Indeed, despite accessibility provisions in the physical world, and standards for assistive technology in general computer use, MUVEs such as SL are almost exclusively visual and lack accessibility for blind users. What these environments do offer, however, is the potential to bring together people from across the world, disconnected by physical space but brought together in a virtual space.

We anticipate MUVEs to become more important for online activities, and for further social, business and recreation to continue the move from physical space to virtual space that we have observed with the growth of the WWW in the past decade. Given the speed of technological development it is important that we begin to address accessibility now before we leave behind and further marginalise this sector of society.

1.1 Second Life

Second Life (SL) is a persistent, online MUVE used for a variety of activities. In addition to social recreation, SL has attracted attention from academic institutions and mainstream businesses amongst others as an addition or alternative to the WWW.

Users connect to the environment with a software program called a client or viewer, which is responsible for displaying the world and for negotiating user commands with a central server. Typically the client displays the user's avatar and

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surrounding portion of the world consisting of other avatars, landscape, buildings, etc. Most of the contents of the world are created by its users rather than by Linden Labs, the company who provide the infrastructure, hardware and software to support the MUVE. Access is initially free of cost, though Linden do charge for customisation services such as renting land on which to build a home for one's avatar. Indeed this paid customisation is one of the core mechanics of SL and is encouraged. With over 13 million residents (users) [40] spending around $1.4m per day [38], SL has a vibrant economy. Many users create objects that are then sold to other users for Linden Dollars (L$), which can be converted to and from real world currency.

Despite this success, SL is inaccessible to all blind and most visually impaired (VI) users. In order to address this issue it is necessary to examine the basic types of interaction that take place in the environment and to identify where problems arise. Additionally, to best explore alternatives it is useful to take guidance both from real blind and VI users and from other researchers working in related areas. The following section 2 presents the methods used in this study to investigate the accessibility of SL, followed by discussion of proposed solutions around the use of audio and haptic technologies, which are presented in section 3.

2. METHOD

This study was composed of two principle components, a series of interviews with blind and VI users, and an evaluation of SL in terms of accessibility for these groups. After the presentation of these methods, related work is discussed and considered in light of the study results.

2.1 Interviews

In order to ground the investigation and guide design proposals, blind and VI expert users were asked to volunteer to participate in semi-structured interviews about their personal experiences with accessibility in both real and virtual environments. Calls for participation was posted on the following accessibility and accessible gaming resources: British Computer Association for the Blind [6] mailing list; Audyssey mailing list [4]; AudioGames forum [3]; Game Accessibility forum [17]; Accessify Forum [31]; International Game Developers Game Accessibility Special Interest Group mailing list [26] and forum [25]; Additionally a post was made on our own project blog [48].

8 respondants participated and interviews were recorded via telephone or Skype chat. All of the interviewees are computer literate, male adults.

The aims of the interviews were to identify the major cues used to provide orientation and location awareness and investigate how VI people currently navigate in 3D space. The interviews were structured into three broad themes, (1) Physical space in the real world (2) Virtual space in computer games for blind (audio games) and sighted users, or other virtual environments, and (3) Speculative discussion around expectations and desires for SL in terms of interface, use cases, and interaction with others.

After recording all interviews were transcribed, and once all transcriptions were complete the data was collated and arranged into new sets of topics that were frequently raised by the interviewees. Representative comments are used throughout this paper to illustrate common issues. One additional informal interview with SL user Amaya Summers was conducted prior to the main study and is referred to in this paper where relevant.

A brief description of each participant follows.

2.1.1 Participants

Participant A. A 22 year old politics student from South Africa who is completely blind and uses a long cane. He uses Facebook, enjoys IRC and is learning to use Skype. Has some experience of playing both sighted and non-sighted games.

Participant B. A British student taking a PhD in Transport Studies, with particular comparative attention to Berlin and London from an accessibility and funding perspective. Currently has a small degree of light and dark perception in one eye. Had full sight until the age of 8. Uses a long cane and considered an ultrasonic cane but found the haptic feedback annoying. Considered a guide dog, but for his city lifestyle would find it inappropriate. Describes himself as an intermediate computer user. Uses JAWS [13] to read email and some WWW sites as well as the BCAB mailing list. Does not use Facebook or MSN. Cannot use SMS on his phone. Very happy with email and phone. Also enjoys listening to internet radio and is a ham radio user. Plays very few computer games and knows little about audio games. Doesn't know anything about SL.

Participant C. A 24 year old Britain who began to lose sight around the age of 16 and became completely blind from 18-19. He uses a long cane, has never learnt Braille but uses the JAWS screen reader for MSN to stay in touch with a friend and to read websites, especially audiogames.net. Has a BTEC National and HND in computing and software development, and has some experience of programming computers when he was younger. Enjoys playing Multi User Dungeons (MUD) and some audio games. No longer plays sighted games, though has memories of playing Quake [24] while he still had vision. Is aware of Second Life and has some friends who use it.

Participant D. A British PhD student, researching a structured definition of disability. Has poor quality monocular vision and is also synaesthesic, experiencing simultaneous colour and tactile sensations. Has very poor spatial sense and will occasionally walk into things even when he can see them. Uses an Ultracane [43]. Has a lot of experience playing audio games as well as sighted games though due to his poor spatial understanding can play very few 3D games.

Participant E. Lives in the USA, was legally blind from birth and had completely lost all sight by the end of highschool, 20 years ago. Now uses a guide dog most of the time, but still uses a cane occasionally. Has memories of playing sighted games in the early 80s, also has experience of audio games. Does not use Skype. Has heard of the Ultracane and has experience of using a PHANToM [41] haptic device and a Cave Automatic Virtual Environment in 1996. Also a keen blind skier. Has read a book about Second Life. Interested in HCI, universal accessibility and computers since 1978. Professionally involved in Section 508 [27].

Participant F/PR. Britain Peter Rainger requested that his contribution not be anonymised. He has extensive experience with technology and disability as he was a national advisor with TechDis [28], has conducted much work on accessible user interfaces and is a trained Assistive Technologist. Was deaf from the age of 7 but his hearing returned while he was began to lose his sight from 16. Became fully blind during his second year at university, after which his vision returned. During non-sighted periods he used a long cane.

Participant G. A 24 year old student from Finland with an MSc in Information Processing Science. Has been visually impaired all his life, with just a little sight in one eye. Describes himself as very poor at approximating distances, has a field of view of 50 degrees, cannot reliably distinguish very bright or dark colours from each other, and cannot recognise people by their faces or by any other uniquely identifiable attribute other than the voice. Has used a screen readers for 10 years, as well as desktop magnification. Very technically competent, can program computers and maintains his own website. Has experience of playing sighted games and is still able to play visually simple 3D games. Applied various software modifications in order to play Half Life 2 [44]. Has not played MUDs or many audio games. Dislikes realtime communication other than speech. Prefers email and newsgroups to forums, and only uses IRC and Skype when others call him. Has heard little about Second Life.

Participant H. A 23 year old British undergraduate student. Blind but with a little light perception, uses a long cane. Has considered various GPS solutions for mobile phones as well as being interested in the Ultracane, but has been put of by the cost involved with each. Plays MUDs, audio games, and enjoys hearing sighted games being played by others.

Participant I/AS. A legally blind US resident who's SL avatar is called Amaya Summers. Informally interviewed on a separate occasion about her experiences of using SL. Summers works in SL, producing content in exchange for money. Despite being classified as blind she has sufficient vision to produce art works with her computer which are then exhibited and sold in galleries in SL.

In the remainder of this introduction, in section 2.2, we present a brief overview of typical scenarios for SL users and the accessibility issues involved. Following in section 3 is a discussion of SL accessibility research currently being undertaken by other teams, and proposals for the applicability of audio and haptic research in sections 3.2 - 3.4 and 3.5 respectively. Finally concluding remarks are presented in 4. Throughout exemplary comments are used to illustrate issues raised by our expert user interviewees.

2.2 Scenarios

In the following sections we describe the four typical activities that residents engage in and identify accessibility issues involved, before considering related research and possible solutions that could be used to resolve them.

Content Creation. One of the main features of SL is the ability for users to create content. This activity is largely divided into two areas, scripting and modelling. Modelling is the process of building 3D structures such as houses, cars and clothing, composed of geometric primitives such as boxes, cylinders, spheres, or polygonal data exported directly from a conventional modelling package. This process is highly visual and therefore inaccessible to the blind, though in personal correspondence the legally blind SL artist Participant I/AS reports that for her limited vision, the building tools provided by the current client software are amongst the most accessible aspects of the package due to their use of large graphical icons with high contrast primary colours. Scripting is a way of defining the interactive behaviour of content and is expressed in simple textual programming languages called Linden Scripting Language (LSL) and Mono. As blind users are capable of programming computers using screen-reader compatible software, given the necessary changes to the client software these users could have the possibility to take an active role in creating content and hence being an active, independent participant in the SL community. This is particularly significant given the possibility to customise the SL user interface using LSL and even modify the entire client by working with the open source C++ code. Currently no significant blind user base exists in SL, but given access to these scripting and programming environments it should be possible to bootstrap such a community. Once a body of blind and VI users exits then community driven user-centred design based on real requirements and use cases will become possible.

Trade. The creation of content in SL feeds two separate drives, economic and self-expressive. The culture of SL encourages customisation of one's avatar as both a unique expression of the individual, and as producer of cultural capital in the form of scripts and models that can be sold, exchanged or gifted to other users in the community. As all forms of self-expression in terms of avatar customisation are also inherently products that can be commodified, the roles of trade and content creation are closely related. Participant I/AS has sufficient vision to create works of art that can be displayed and sold to other users in the virtual world. This virtual economy provides her with "a real job" and a feeling of taking an active part in a community. There is a great deal of commercial interest in virtual economies in general and SL in particular, with some speculation that these environments will become increasingly significant for real world economies in the future [11]. The corollary is that unless MUVEs are designed to be accessible we risk leaving behind

VI and blind users.

Spectacle. A great degree of the pleasures available in SL are visual, as they are in the actual world. Avatar customisation is largely based on visual appearance, and architectural space is often designed for visual aesthetics. Furthermore it is common to find models of signposts in SL displaying *graphical images* of text which are incapable of being read by screen-readers.

> "You know they could ID it by anything and in fact W3C would require ... you know this would be a non-text element and it would require a text element, a meaningful text element." [Participant E]

The use of graphics instead of text is particularly problematic for VI users in Orientation Island, where new residents begin their Second Life and are trained how to use the client. The inaccessibility of these tutorials is one of the first barriers to entry. Several of our interview participants suggested that objects could be tagged with metadata to indicate the type of entity (door, wall, etc), and that this data should be available to screen readers. The main impediment to implementing this in SL as it stands is lack of enforceability due to the additional burden on content creators, though Carter and Corona [8] and several of our participants propose an open, collaborative database where users may submit and rank others descriptions of content.

Communication

> "I think blind people can suffer immensely from social and physical isolation, through impaired mobility where they live, and so on. And it's often difficult for us to meet people because we can't see them and make eye contact." [Participant B]

The social aspects of SL are highly motivating for sighted users and comments from our interviewees suggest that they could be particularly compelling for the visually impaired. Currently, however, SL is incompatible with screen readers and requires use of the mouse to click on various buttons in the display, making it entirely inaccessible to the blind. The issue of compatibility with existing accessibility standards is discussed in the following section.

3. DISCUSSION

Throughout our interviews the issue of inclusion was raised many times. This is a broad topic which spans entertainment and social communication, interface design and information access, education and business. In considering the common scenarios of SL use we see potential to address some of these concerns, most applicably in the scenario of communication.

Through the remainder of this section we reflect on current trends in research that may be beneficial for accessibility in virtual environments. In particular in section 3.1 we consider our interviewees experiences with current screen readers and what changes would be necessary to adapt them for use in 3D environments. Then, in sections 3.2 through 3.4, we address the use of spatial audio, and finally in section 3.5 haptics. Through this our interest lies in addressing interface issues for communication and navigation, both spatially and informationally.

3.1 Screen Reader Clients

> "Screen-reader technology and keyboard navigation must be enhanced and extended by technical breakthroughs specific to 3D environments." [8]

Linden Labs have released the source code to their client software with which we have developed a proof-of-concept prototype demonstrating the feasibility of using text-to-speech technology to make the client accessible for VI users [47]. Currently only a small subset of interface elements (chat, gestures and notifications) feature this self-voicing capability, but our prototype demonstrates the feasibility of adapting the client software to conform to the Microsoft Active Accessibility standard [32], compatible with popular screen-readers such as JAWS.

Folmer [12] addresses the issue of accessibility through the development of a text-only client, similar in operation to a MUD or Instant Messenger (IM) client such as MSN Messenger. Carter and Corona's [8] approach, building on IBM's earlier project [2] is similar, using screen-reader technology as primary interface augmented by immersive 3D audio. Particularly emphasised in their work is the notion of "deterministic operational accessibility", the ability of VI users to be able to consistently move toward achieving their operational goals. With this in mind they propose a functional attitude towards interaction, where the interface presents data on the spatial and operational relations between objects, and can be configured to vary the type and amount of data presented suitable to the user's present activity. Several of our expert users were keen to point out the issues involved with using conventional screen-readers and stressed that data needs to be exposed in such a way that it facilitates random access rather than enforcing linear scanning. For example, the ability to list headings on a web page, ordered according to alphabet, hierarchical or absolute position on the page, allows the user to quickly and easily find the information they require without having to scan through content irrelevant to their current task. This is a natural and efficient technique for sighted users, but unless data is structured and exposed to the screen reader in an appropriate format the blind user is forced to fall back on cumbersome and tedious linear scanning.

Further studies will be required to investigate formats for exposing operational data from 3D environments to screen readers. Meanwhile in sections 3.2 through 3.5 we consider the potential for audio and haptic sensory substitution of immersive 3D visuals.

3.2 Audio Games

There is a market of video games for blind users know as audio games. These games replace visual spectacle with audible cues and are often either compatible with screen-readers or feature self-voicing capabilities so that menus and other text interface elements are spoken to the user. Of particular relevance are a class of audio games which attempt to follow the gameplay principles and simulate the presentation style of first-person shooters (FPS). Two of the most popular games were discussed by several of our expert users, Audio Quake [1], an open source modification of Quake, and Terraformers [35], both of which offer visual modes of play in addition to the native audio-only implementation. Despite these games being designed specifically for blind players, our interviewees expressed mixed feelings about their use.

> "[Terraformers] had very accurate 3D sound so you could pinpoint exactly where you were pointing in relation to objects." [Participant C]

> "I've not really been able to play anything in full 3D because I just find the spatial logic too complicated." [Participant D]

An interesting observation made during this study was to note that despite the similarities between these two games they both made use of quite different audio cues to signal similar in-game presences. Experienced sighted gamers bring an implicit understanding of the mores of video game play and a complex but consistent semiotic code for the communication of meaning within the games. Grimshaw [19] presents an extensive taxonomy of audio in sighted FPS games, but a consistent language of audible signals is not shared amongst audio games in the same way that it is for visual FPS games. That is to say the style of audio samples used varies dramatically between games, and for example there is no similarity in the "earcon" (auditory icon) for a doorway that is shared between games. This lack of a consistent language for describing the environment means that the presentation of each new virtual space must be learnt afresh each time it is encountered. While sighted players can consistently rely on visual metaphors such as muted or ghosted menu items being temporarily unavailable, there are no comparable rules applied across the range of audio games. The development of a standard for using audio to communicate 3D data in an operationally deterministic manner remains a goal of future work.

> "It's audio, and often we do that: [click]. I'm clicking away from me and this is a medium sized room because the sound is bouncing off the walls. And I could tell your room's quite big as well." [Participant H]

Another technique used in video games such as the BAFTA winning Crackdown [36], is the simulation of "early-reflections" [16]. By attending to subtle changes in reverberation the listener is able to infer the size, shape and volume of an environment and objects within it. Several of our participants explained that they used similar techniques to help their spatial understanding of both real and virtual environments. A further technique employed by various audio games is a form of sonar, similar in effect to that described by Waters [46], in which the distance to virtual objects around the user are expressed audibly in real time by changes in pitch or volume. Many of our interview participants felt this to be a powerful technique, and particularly pointed out the convenience of being able to trigger the sonar with a single button press rather than having it continuously sound.

3.3 Sonified Maps

During our interviews the subject of GPS arose a number of times, with participants expressing an interest in using these devices in the real world but being put off due to the cost involved. In the absence of these devices many of our interviewees explained that they would make use of sighted assistance to describe an environment prior to visiting it, and thereby memorise a mental model to assist them when they are there on their own.

> "I don't tend to explore new areas alone ... either my father comes with me or friend comes with me and we go through all the routes and map them all out and I build up a picture in my head and make notes perhaps on a tape recorder." [Participant B]

Heuten et al. [23] describe a technique to sonify real world map data which can be explored by blind users in advance of their journey. This allows the user to develop a mental model of the relationships between the salient features of an environment, for example the relative distance and direction between parks, roads and buildings, etc. Similar map data is available in SL but is currently only displayed visually. Such data is already stored digitally and features some content which is updated in real time, such as the location of avatars in the local vicinity. We suggest that the techniques Heuten et al. employ to assist blind users in the physical world would be easier to implement in virtual environments, and could be used not only for prior familiarisation but also for an on-demand overview of localities.

3.4 Auditory Navigation

> "I think that even in real world audio resolution isn't that good for determining exactly where someone is." [Participant G]

Lokki and Gröhn [21] [22] [29] show that audio cues are less accurate for locating sound sources than visual cues, which is supported by comments made by our expert users during interview. However, they conclude that the encoding of elevation information into the auditory cue assists subjects ability to locate their source.

> "... auditory navigation is almost as easy as visual navigation, when sound signals are carefully designed." [29]

In their experiment, subjects were placed in an immersive 3D environment through which they were required to navigate using either audio, visual or audio-visual cues. They demonstrate that in general audio-only cues were almost as effective as visual-only, but also note that typically audio cues were more effective than their visual counterparts during the initial stages of locating their target. This is due to the occlusion of other extraneous visual objects between the user and their target, as well as cases when the target was initially positioned behind the user so that a greater amount of time was initially spent trying to identify in which direction to proceed. The advantage of 3D audio in such tasks would not only be beneficial to the blind and VI, but also has very practical applications for sighted users.

Of additional interest is the design of their physical interaction device. In a navigation test subjects controlled their flight through space with a custom-made wand which responded to pointing gestures from the user. Most SL residents navigate by using a combination of keyboard to control forward and backward translation, and yaw of their avatar, and mouse to select objects and avatars to interact with. Gröhn et al. [20] observe that not only is keyboard control inefficient for 3D navigation but that wands and data gloves are measurably preferable. In the following section we will discuss several alternative interface devices that could be of use for the visually impaired.

Sensory substitution using spatial audio has been a productive avenue for navigating 3D environments, and screen reading software has been developed to a high degree of sophistication for traditional 2D Window, Icon, Menu, Pointer (WIMP) interfaces. However, applications that required both forms of information to be processed by ear are at risk of overloading the auditory channel. Research into haptic technologies could provide an alternative or multi-modal approach. Furthermore, while screen-readers are appropriate for navigation of discrete environments (windows, web pages, fixed sized rooms in MUDs), they do not provide a smooth method of navigating continuous spaces such as SL. This is further exacerbated by the absence of structural meta-data to describe 3D environments, support for screen-reader access to this data, and enforceability of regulations requiring users to include such accessible data in their content. While it is not the aim of this project to propose a solution based purely on immersive sensory substitution, a free-form approach to navigation using audio and haptics to replace visual data would provide the most generally applicable method throughout 3D virtual environments. Finally the potential for reinforcement of signals communicated simultaneously through audio and haptic modalities may in some way mitigate against the lack of visuals. In the following section we discuss research into assistive devices for blind people in the real world, and consider their applicability for SL.

3.5 Haptics

3.5.1 Real world Haptics

Froese and Spiers' Enactive Torch (ET) [15] is an assistive device shaped like a torch which uses ultrasonics to detect the presence of objects it is pointed at. The distance from the object is communicated to the user by either varying the frequency of a vibrating emitter or by the rotation of a disc positioned beneath the thumb. Similarly the Ultracane is an augmentation of a normal long cane which uses vibration feedback from ultrasonic sensors to provide analogous spatial information. Froese and Spiers report in personal correspondence that while they have yet to perform large scale tests, VI users have reported positive experiences of being able to use the torch to navigate around both indoor and outdoor environments and to locate objects in their vicinity.

> “Almost immediately a subject can use the ET to detect obstacles, and after a little training (ca. 10 minutes) has no problem of locating relatively 'invisible' objects, such as a lamppost, in space. Moreover, it has been experienced by one of us that already after around 1 hour of practice with using the vibro-tactile output, certain salient features of the environment, such as corners and open doors, take on a distinctive perceptual pattern which could be described as 'touching objects out there'.” [14]

The success of these devices at sensory substitution, and the inappropriateness of mouse and visual data for blind users suggest that it may be useful to consider alternative interfaces for virtual 3D navigation. In the following section we consider current research in this field which deals with haptic devices for SL in particular.

3.5.2 Virtual World Haptics

The principles applied by the Ultracane and Enactive Torch can be applied in virtual environments using a variety of devices, three of which we consider here, the Novint Falcon [34], Sensable Technologies PHANToM, and the Wiimote controller used with Nintendo's Wii games console [33].

The Falcon is a consumer 3D haptic device targeted at the mass gaming market. It is a force-feedback interface which operates with 3 degrees of freedom. The product is interesting for it's potential to act as an assistive device in virtual environments. It can be moved in 3 dimensions and provides resistance against the user's force when its 3D cursor comes into contact with virtual objects, thus providing a physical impression of that object. In the context of this paper it's useful to think of it as a long cane that could allow SL residents to reach out from the physical world and feel objects in the virtual world.

VanDrimmelen's team [45] are attempting to develop software to allow the Falcon to be used in virtual environments. They have focused their efforts on another virtual environment, Croquet [10], but have also worked with SL and make some interesting comments,

> “The creators of Second Life actually started their project out with a large haptic device [37], but soon abandoned it for more financially appealing options.”

Further haptic research in SL is being conducted by de Pascale et. al. [30] who employ a PHANToM Premium and custom software to provide two assistive interaction modes, Blind Walk and Blind Vision. In the walking mode the haptic device provides force feedback when the user's avatar comes into contact with objects in the virtual world, thus allowing the blind user to feel their way around. In the vision mode, however, the haptic device vibrates when it is pointed at a virtual object, and the distance from the user is indicated by the frequency of vibration, similar to both the Enactive Torch and Ultracane.

Finally Shou [39] demonstrates the use of the Nintendo Wii remote controller as an input device for the video game Half Life 2. The motion tracking and vibration feedback capabilities suggest its applicability as a low-cost input device for pointing in a similar manner to the Enactive Torch and Lokki's auditory navigation experiments.

> "Why not send information through haptic icons as opposed to audio icons." [Participant F/PR]

While all of these devices can provide information on the distance of objects, they communicate relatively little about what the object is. With the implementation of immersive 3D audio for target localisation, in addition to augmented screen-reader techniques, the blind and VI users audible channel is likely to be overloaded. This could be balanced by information alternatively conveyed through a haptic device. However, the absence of standard earcons for virtual environments is similarly found in the haptic mode, requiring further research into what kind of information is best expressed through each modality.

4. CONCLUSION

In this paper we have presented an analysis of the issues confronting the blind and visually impaired in Second Life, including comments from expert users gathered by semi-structured interview, and provided an overview of current and future avenues for research. In particular multi-modal approaches to 3D navigation have been proposed using audio and haptics, as well as more general suggestions for non-spatial interfaces such as screen readers.

The suggestions proposed in this paper have greatest applicability to the scenario of communication presented earlier. It is here that we find the broadest and most important aspect of MUVEs. Of the issues raised during interview, social inclusion is the key factor most addressed by the proposals presented. The range of areas which stand to benefit range from education and information resourcing, to shopping and socialisation. While spectacle, content creation and trade are significant activities for SL in particular, and without which the product would not have achieved the success it has, they do not form a necessary core for all MUVEs. Navigating such environments - spatially as well as informationally - will however be a recurrent issues for blind and VI users. The suggestions presented here address these issues by rethinking representation and interaction with spatial data. Operational interfaces based on structured data offer one approach, and multi-modal audio and haptic interfaces offer another.

The open nature of SL simultaneously provides a flexible and creative research object, while also presenting a large-scale, complex and dynamic environment. Furthermore it represents a possible future for online presence, which currently excludes blind and visually impaired users from business, education and social possibilities. Accessible standards, government regulation, as well as industry and academic research must address these issues as a priority if the rapid pace of technological progress is not to leave behind and further exclude an important sector of our society.

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