Accessible virtual environments for people who are blind – creating an intelligent virtual cane using the Nintendo Wii controller

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ABSTRACT

People who are blind tend to adopt sequential, route-based strategies for moving around the world (Golledge et al, 1996). Common strategies take the self as the main frame of reference, but those who perform better in navigational tasks use more spatial, map-based strategies (Hill et al, 1993). Training in such strategies can improve performance (Cummins and Rieser, 2008; Simonnet et al, 2006). Virtual Environments have great potential, both for allowing people who are blind to explore new spaces, reducing their reliance on guides, and aiding development of more efficient spatial maps and strategies. Importantly, Lahav and Mioduser (2005, 2008) have demonstrated that, when exploring virtual spaces, people who are blind use more and different strategies than when exploring real physical spaces, and develop relatively accurate spatial representations of them. The present paper describes the design, development and evaluation of a system in which a virtual environment may be explored by people who are blind using Nintendo Wii devices, with auditory and haptic feedback. Using this technology has many advantages, not least of which are that it is mainstream, readily available and cheap. The utility of the system for exploration and navigation is demonstrated. Results strongly suggest that it allows and supports the development of spatial maps and strategies. Intelligent support is discussed.

1. INTRODUCTION

The Terraformers game is playable by players who are blind, who can play the game against sighted opponents (Westin, 2004). Terraformers offers auditory navigation and game information, which blind players can use successfully to navigate its virtual environment and to play the game. Enabling users who are blind to operate in virtual environments (VEs) has many potential benefits. Skills such as navigating around the real world, traveling, and crossing the road are major challenges for the blind. Applications of VEs have been developed for training in basic skills, travel training and for learning to cross the road, for people with learning difficulties (Brown et al, 2005). Such applications would be of great benefit for people who are blind. In order for a blind person to be able to find their way around a new environment, they need first to be taken around that environment by a guide. While doing so they establish points of reference in that environment. In the case of those with a guide dog, these points of reference represent locations to which they can instruct the dog to go. People who are blind may have to be always accompanied in environments which are complex and/or not encountered frequently. Being able to practice navigating around environments, and to practice traveling and other skills in safe VEs would be helpful for building up knowledge, experience and confidence. Improving the accessibility of VEs could have many possible benefits.

People who are blind tend to adopt sequential, route-based strategies for moving around the real world; common strategies take the self (or body) as the main frame of reference, as opposed to an external frame of reference (e.g., see Golledge et al, 1996). There is a great deal of variability in the navigational strategies used by people who are blind, with those who perform better in navigational tasks being those who use more map-based strategies (Hill et al, 1993). Training in such strategies can greatly improve performance (Cummins and Rieser, 2008; Simonnet et al, 2006). Simonnet et al (2006) have detailed documented strategies and distinguish between egocentric frames of reference, where objects and locations are related to a person's particular perspective, and exocentric frames of reference, where external frames of reference are

used. External frames of reference and map based-strategies allow more efficient representation which enables flexibility, so that alternative routes can be taken, shortcuts can be made and destinations changed, because they encompass a more complete representation of the environment to enable navigation from a number of perspectives (Golledge et al, 1996). The actual mobility training people who are blind receive is generally basic and egocentric (see section 6.2 below).

VEs have great potential for supporting and facilitating the construction of exocentric cognitive maps by those who are blind. The visual modality lends itself to global spatial representations. These are more difficult to derive from haptic sources, which are by their nature more local and sequential. This property of haptic information, combined with the fear of collisions, encourages the use of egocentric frames of reference by people who are blind. However, functional equivalence of haptic and other non-visual information to visual information can, under the right conditions, be indicated and the possibility that they may all contribute to admodal spatial representations exists (Loomis and Klatzky, 2008). Cognitive maps can be created by the blind; it has already been noted that the more successful navigators tend to use more map based strategies. Lahav and Mioduser (2005, 2008) demonstrated that interacting with a haptic virtual environment can facilitate the construction of mental maps of spaces and thereby contribute to blind people's spatial performance. They found that, when an experimental group of people who are blind explored a haptic virtual environment, they developed new strategies, and applied existing strategies for navigation in different ways, compared to a control group, who explored the real physical environment. When questioned about the environment, the experimental group had better structural descriptions of it and the location of objects within it. Further, when the experimental group went on to explore the real environment, they were more successful in completing target and perspective oriented tasks, and completed them more quickly using more direct routes than the control group. These results strongly suggest that the experimental group had developed cognitive maps with properties much more like those of sighted navigators. That is, exploring the VE and experiencing the associated feedback appeared to enable the development of a more complex, wholistic, exocentric cognitive map of the environment.

The use of VEs for exploration and navigation is not only beneficial for building up knowledge, experience and confidence, but also facilitates the development of spatial models and strategies. People interact with Lahav and Mioduser's VE via a force feedback joystick, and receive several types of auditory feedback. The present research has investigated the use of the Nintendo Wii remote controller (Wiimote) as an adaptive assistive device, and in this case as a device for people who are blind to use for interacting with virtual environments. The Wiimote allows the user to interact with a system via movement and pointing. In addition, visual, auditory and haptic feedback is available. Using the Wiimote has many advantages, not least that it is mainstream, easily available and relatively cheap.

2. THE WIIMOTE AS AN ASSISTIVE DEVICE

The Wii has been investigated as a platform for the development of assistive technology, by interfacing the Wiimote with a personal computer, and by detailing the technologies involved (e.g., Battersby, 2008).

2.1   Interfacing a Wiimote with a PC

Using the Wiimote's Bluetooth capability it proved to be a simple task to interface the Wiimote with a standard PC. The Windows Wii application (WWii) was created to handle connection and pairing between the Wiimote and the target operating system. Following on from earlier iterations (see Battersby, 2008), WWii has been used to facilitate further research and development. WWii is a functional windows-based driver application written in C# with Peek's (2008) Managed Library for Nintendo's Wii remote (Wiimote) as its heart. It provides facilities for keyboard, mouse and joystick mapping, for peripheral input data capture and a basic capacity for the replay and analysis of any captured data. WWii not only provides the facility for the Wiimote to be mapped to the windows system but also supports multiple extensions such as the Wii Classic Controller, the Wii Nunchuck and the Wii Fit board. Interface panels have been created to support mapping functionality by enabling a user to configure each of the Wiimote's physical inputs to any desired keyboard or mouse input combination (see figure 1). In effect this enables the Wiimote to be seen by the system as any of the highlighted devices, limited only by the volume of inputs available from the device. Customizable feedback is developed through the feedback mapping panel, where flags may be set to operate any of the Wiimote's feedback mechanisms.

2.2   Wiimote Sensor Technology

2.2.1 The Accelerometer. The accelerometer contains a micro mechanical structure supported by silicon springs. It measures linear accelerations along three fixed axes; it is unable to distinguish between linear motions and rotations, and so it is capable of measuring only pitch and roll angles.

2.2.2 The Optical Sensor. The optical sensor is an infrared camera situated at the front end of the Wiimote. The camera is connected to an integrated image analysis chip that can identify up to four individual Infrared light sources and report their position, approximate size and level of intensity. The light sources for the present application are provided in the form of two clusters of infrared LEDs situated at two opposite ends of a stationary bar, which was a modification of an existing USB/battery powered product. The image sensor sees the light as two bright dots separated by a known distance. Triangulation is used to calculate the distance between the bar and the Wiimote. The camera projects a 1024x768 plane front of the user and positional/rotational data is obtained in reference to this plane. This is possible as the position of the sensor bar and distance between the LED clusters remains constant. This system allows the Wiimote to function as an accurate pointing device and provides the yaw value, so that the Wiimote can be tracked in 3D space.
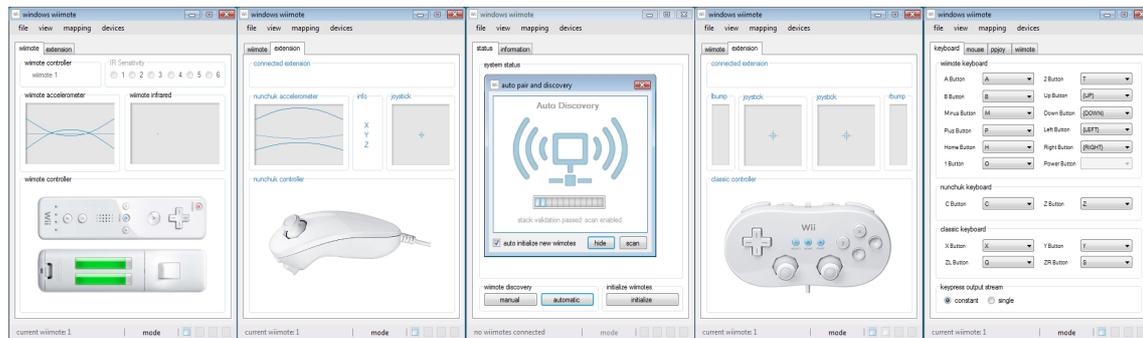

Figure 1. *Part of the Windows Wii driver application interface.*

2.3 Practical Investigations of Wiimote Sensors

In order to test the interface functionality of the two Wiimote sensors a simple test environment was created that consisted of a virtual representation of the Wiimote within 3D space. The environment was constructed within AutoDesk's 3D Studio Max application and interactive capability was provided by importing the environment into Adobe Director, where navigation and response to system input could then be coded. Successful performance was demonstrated by slaving the motion of the virtual Wiimote to that of a real world counterpart. The initial testing of the Wiimote sensors highlights the Wiimote and its technologies as more than adequate for the development of assistive concepts and solutions. Used in conjunction they provide required 6 degrees of freedom needed to orientate a body within 3D space. The Wiimote can be used as a 2D pointing device via the optical sensor and can easily provide 2D mouse-like interaction.

2.4 Feedback functionality of the Wiimote

In addition to providing system input the Wiimote is capable of providing basic auditory, visual and haptic feedback. The speaker on the Wiimote allows audio content to be transmitted from the host to be played back. By default the Wiimote indicates its player assignment by lighting the corresponding LED. The LEDs are also used to indicate the power level of the Wiimote's battery upon power up. This visual feedback is redundant for the present application. The Wiimote also includes a rumble device which can be set to either an on or off state. Manipulation of the frequency of operation can be used to provide pulses to create the illusion of differing strengths of rumble. This device offers great potential for haptic feedback.

2.5 Expansion capabilities of the Wiimote

The Wiimote features an expansion port. This provides the facility for the connection of additional auxiliary controllers to augment the input capabilities of the Wiimote. The Wiimote's assistive capabilities can also be expanded via implementation of software solutions.

All the functional attachments use the Bluetooth interface of the Wiimote to communicate with the Wii console, thus allowing them to be much simpler and cheaper to implement than the Wiimote itself. Attachments can be added and removed from the Wiimote whilst in use without resulting in device damage. The main attachment to date for the Wiimote is the Nunchuk controller. The primary component of the Nunchuk is an analogue thumbstick, which outputs 2D axis data. In addition to the thumbstick the Nunchuk has two buttons labeled as C and Z and a three-axis accelerometer sensor.

3. THE WIIMOTE AS A CANE WITHIN 3D ENVIRONMENTS

The Wiimote's ability to describe a body within 3D space means that it can be used rather like a cane, and therefore provide an interface to 3D environments for the visually impaired. The virtual Wiimote counterpart uses distance measurements obtained by ray casting to control feedback in the form of vibration and auditory signals.

3.1. Design

In order to investigate the potential of the Wiimote as a virtual cane a test environment was created. Additional functionality was added to the WWii enabling it to host Shockwave environments thus providing direct communication between the environment and the Wiimote. Other environments could easily be loaded into the application.

Iterative design and evaluation of the Wii cane system was carried out by a software engineer and a Computing Masters degree student who is blind (subject A) in line with user-centred design methodology (e.g., Lannen et al, 2002; Battersby et al, 2004). Early design iterations highlighted the need for initial orientation and calibration. A number of variables needed to be explored, including the relationship between the motion of the Wiimote and its motion relative to the environment, and the type and nature of the different types of feedback and their relationship to the environment and the objects in it. A number of alternative configurations were explored, leading to a design suitable for testing and evaluation. For all configurations, the Wiimote is used to scan the environment in front of the user; the whole plane can be scanned, that is left-right, up-down, or any other angle. Speed of motion in the VE was set at the speed identified as comfortable from extensive experience of user testing in Serious Games; strides were set at about a metre for the same reason (e.g., Brown et al, 2007).

Configuration 1:

The Nunchuck was used. The thumbstick could be used to direct motion in eight directions at each 45 degree point. The Nunchuck was used to determine direction with respect to self. That is, whatever direction the thumbstick was held in, when the Z button was pressed motion would be in that direction. The aim was to provide an on the spot point of self-reference. As with a person turning, the thumbstick would be turned and motion would proceed in that direction when the button was pressed. Rumble varied according to distance from an object, with constant rumble on collision. Pressing a button produced spoken distance and object name. However, there is no external frame of reference with respect to the environment, and the user was disoriented.

Configuration 2:

For configuration 2 the Nunchuck was removed because the added complexity appeared to outweigh any benefits. Configuration 1 needed additional environmental cues in order to orient the user within the space. Some available possible cues are footsteps, rumble on approach (pulsing could indicate distance), rumble on collision (constant), sonar and auditory signposts. The feedback used was rumble (constant) on collision, and sonar, whereby frequency of beeps indicated distance. As with the previous configurations, pressing a button produced spoken distance and object name. In addition, on entering a space, a description of the space is available via a button press. In order to turn, the Wiimote was rolled to the left or the right. A beep indicated turning mode, and every beep indicated a 10 degree turn. The left and right beeps were different to make them discriminable. Motion was provided by a button press on the Wiimote, inducing motion in the last facing direction. Because of the positions of the various buttons on the Wiimote, it proved difficult to control; additionally, button presses tended to move the Wiimote, producing positional confusion. The Nunchuck was therefore re-introduced in configuration 3.

Configuration 3:

In this final configuration, left and right turning was achieved by rolling the Nunchuk to the left and to the right, producing a 10 degree turn. Left and right step sounds provided turning feedback, which proved easy to interpret. Motion forwards and backwards was initiated by tilting the Nunchuk up or down. The Wiimote was used for scanning the space. Beeps were used for indicating different types of objects and their distance. Different tones of beep were used to indicate furniture, walls, doors, floors and out of scanning plane (accompanied by a constant rumble). The rate of the beeps increased as any object was approached. There was a constant rumble on collision. Subjects were told when they had passed from one space to another (for the last subject this was implemented as a whooshing sound on transition). As with the previous configurations, pressing a button produced spoken distance and object name.

This configuration separated motion (controlled by one hand with the Nunchuk) and scanning (controlled by the other hand with the Wiimote), and this is a clearer arrangement. The design now appeared to contain the necessary information for successful navigation, and was stable enough for evaluation.

3.2 Evaluation

3.2.1 Test environment. Having arrived at the system design of configuration 3, another VE was created for testing the system. This VE is a representation of part of the third floor of the Nottingham Trent University Computing and Informatics building (see Figure 2 for floor plan). This was chosen for a number of reasons:

   i)   It is easily available.
  ii)   It is a real functional space.
 iii)   It contains an open plan area with a number of obstacles of different types within it. Consequently it contains numerous potential areas for navigation and numerous potential navigation and perspective tasks.
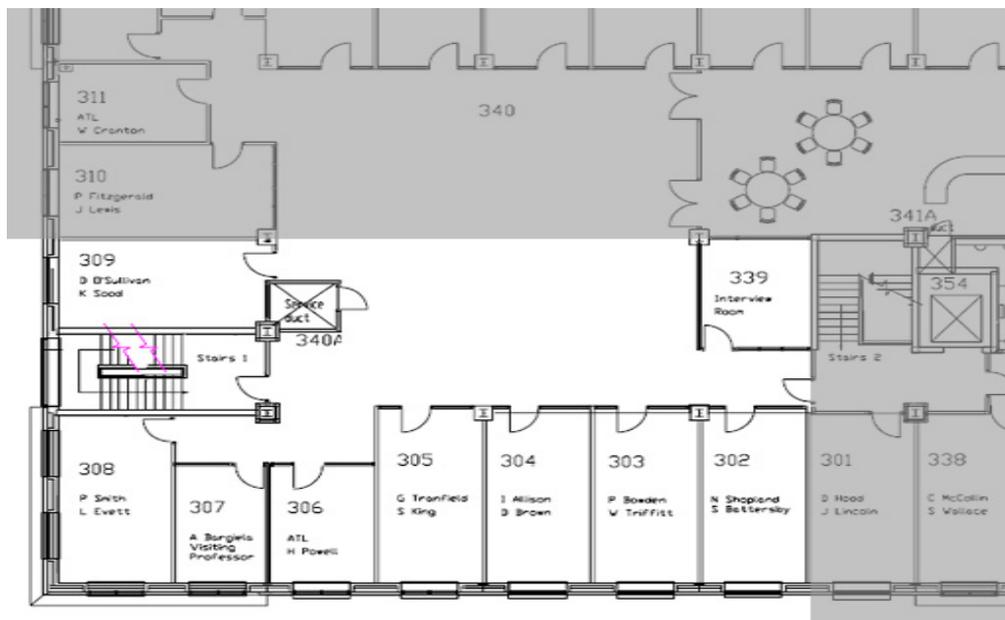 iv)   It is irregular, the level of complexity encouraging development of spatial awareness and navigational skill.

Figure 2. *Floor plan – only the shaded section was used for navigation in the present evaluation.*

3.2.2 Subjects.

Subject A:

Subject A is 52. He is the person involved with the design of the system. He has no functional vision. He can under some circumstances detect light, although this has to be very bright. His eyes were not formed properly at birth. He has Hallerman-Streiffe syndrome. He was blind until about the age of 2, when he had surgery to restore his sight. After the surgery he had functional sight; his distance vision was fine but close up he could not read without a lens, or recognise faces. He could move around and navigate without major difficulty. His sight began to deteriorate in his late 30s until the age of 42, when he had no useful remaining vision. He received basic training in the use of the cane around this time. This involved holding the cane and sweeping and turning, identifying landmarks, and the use of inner and outer shorelines. There was some discussion of using smells and sounds. There was some learning of routes. The training focused on egocentric and route strategies. Beyond this people develop their own strategies, and all three subjects reported doing so. Independent traveling in new spaces is very difficult; in such cases, a trainer will guide the person in at least the first instance. This is also true when dogs are used. The trainer will come out to help the person and the dog identify reference points for future use. Subject A has been guided by dogs for some years. Training with a dog is intense, starting with three weeks solid at a centre or at home. Routes are learnt by walking the route with the trainer, and identifying reference points to tell the dog to go to. Subject A is currently with his fourth dog, and so is experienced at being

part of a dog/person team. He commonly travels alone with the dog and is a frequent user of public transport.

Of the three people who took part in this evaluation, subject A is the most familiar with the space being used. While he often visits certain parts of it, other parts he knows very little, if at all.

Subject E:

Subject E is 27 and is partially sighted, although could be registered blind if she requested it. Currently she has minimal vision in her left eye, which is only apparent when her right eye is shut or obscured. In the right eye she has tunnel vision, with a section missing on the nasal side, and blind spots. She was very short sighted, with some retinal damage, up until 9 years ago when she suffered several bouts of optic neuritis. Her vision is currently stable but likely to get worse. She received basic cane training, similar to that of subject A, when her vision first deteriorated. She is familiar with a very limited part of the area being used in this study.

Subject H:

Subject H is 38, and was very short sighted up until the age of 17, when he was registered blind. His sight had been deteriorating from the age of about 10. He suffers from retinitis pigmentosa. When registered blind he received basic cane training. He has had a guide dog for the last three years. At work he has a full time support worker and so is often guided. Subject H has not visited the evaluation area before.

3.2.3 Testing. At the start of each session, subjects were asked their age, their sight history, the mobility training they had received, and how they generally got about. Subjects were then taken into room 302, which was designated the training room in the VE. Subject A had been in this room often, and in the room 339 opposite. Both he and subject E were aware of the short corridor leading from the door from the stairs to the rest of the space. Subject A has visited two other offices down the side of the space, and had sat on one of the sofas. This was the limit of his knowledge. Subject E had been guided to an office at the end of the line of offices on two or three occasions, and this was the limit of her knowledge. Subject H had the short entrance corridor described to him for orientation. Figure 4 shows views of the space.
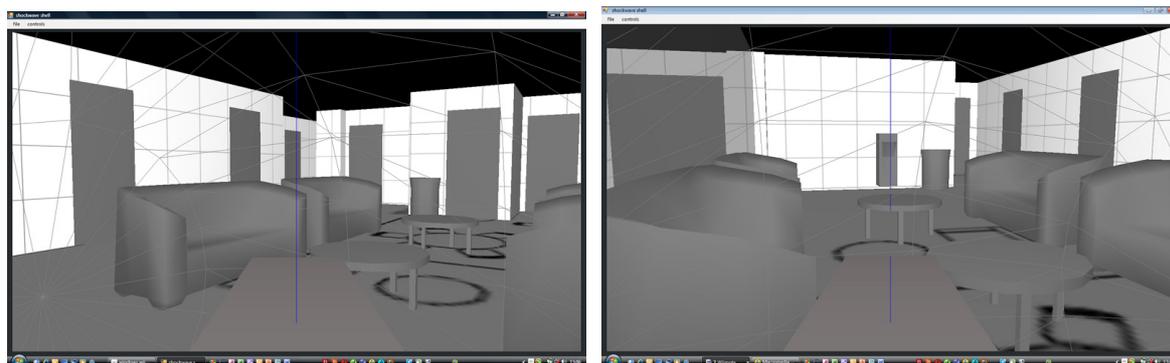

Figure 3: *A view of the space from either end*

Each subject was told that they were to use the Wii controls to explore a virtual representation of the open area, which contained some items of furniture and other items, and was edged by numbered offices and other doors. They were instructed in the use of the controls and the feedback they should expect, which were also demonstrated. They were given feedback on their use of the controls. They were asked to explore room 302 to get used to the controls and to ask any questions. The height of the infra red bar was adjusted to suit their comfortable holding of the controls. Once they seemed familiar with the controls they were asked to find the door and exit 302 (this was the only door they could pass through), and then to explore the open space for as long as they liked. During their exploration, further feedback on their use of the controls was given, and, in the case of subjects E and H, they were given tasks to complete (e.g., "there are some tables, try and find them") to ensure they had explored all of the space. Once they had explored the space to their satisfaction they were asked to return to room 302. They were then asked to describe the space. The subjects were then asked to go out into the real space with their canes. Subjects A and E were told there was an object on table 2 and were asked to find it and take it to the fire door. Subject H was not very successful in exploring the virtual space so he was taken to the top of the open space, asked to find the tables and from there the fire door.

All subjects were then asked some questions about the ease of use of the system and their views of it.

3.2.4 Results. Both subjects A and E managed to explore the whole of the space, find all the objects in it and most of the doors. When asked to describe the space they gave a fairly accurate description of it, its shape and the positions of the objects in it. When asked to find the object and take it to the fire door, they both did so directly and with confidence. They found the controls a bit challenging but also talked about the space in spatial terms and thought it would be a good way for people who are blind to learn to navigate new spaces. Subject E, when asked to find the tables in the VE said "let me picture it", thought about it and then found them.

Subject H struggled to explore the space. Although he seemed to understand the controls and the feedback, he often went out of plane and collided with objects. In these cases he made little attempt to either get back in plane or out of collision. After a short while he was reminded what the feedback was telling him and what to do about it. He did manage to visit most of the space, but mainly by luck and prompting rather than by making a systematic effort to do so. He could not describe the space apart from saying he knew there was a space, he had no idea of the shape, he knew there were sofas, tables and bins but not where they were. He was not asked to find the object but taken into the space and asked where the tables were, which he found quite easily, and from there to go to the fire door. He went to it almost directly. While he had found the exploration difficult and did not seem to have much idea of the space, he did not have any trouble finding objects in the real space. His residual vision helped him find the tables, because the tables are light coloured and under a skylight, but this would not have helped him find the fire door from the tables.

Subjects A and E had some difficulty turning. Often they did not roll the Nunchuk far enough to effect a turn, and they over-rolled it when returning to centre. However, they both liked the correspondence between the movement of the device and movement effected in the VE. Subject E had the same problem, and reported the controls as difficult. He was reluctant to move the Wiimote at all.

4. CONCLUSIONS

Overall, the results of the evaluation were positive. Subjects A and E enjoyed using the system, appeared to develop clear spatial maps of the space, and were able to successfully navigate in a space which was largely new to them. Subject H was not so successful, but did seem to have some idea of layout. Subjects A and E both use computers regularly. Subject H does use computers but described himself as a technophobe. He is often guided. Subject A often travels independently. Subject E is generally independent. Subject A is obviously familiar with the controls. Subjects E and H had both used the Wii game system previously. Subjects A and E were tested first and picked up the controls very quickly. Both these people are frequent and confident computer users. It is often noted in the literature that there is a wide range of strategies and navigational abilities used in spatial tasks amongst people who are blind (e.g., Hill et al, 1993). It was clear from the evaluation that training for subject H needed to be taken more slowly, and this may well be the case for other people. Use of the thumbstick may be easier than rolling the Nunchuk, and this will be an available option in future designs. The results support the idea that the system can be used to develop and support cognitive spatial maps and strategies. Further testing is planned to establish this point more rigourously. Incorporation of the Wii Fit board into the system would provide additional kinaesthetic and proprioceptive feedback. It is currently integrated into the WWii application, but investigation is required to integrate it into the navigational system.

The use of the Wii devices allows a greater range of navigational information than the force feedback joystick used by Lahav and Mioduser (2005, 2008). The Wiimote can be used to scan around the environment to explore and to decide where to direct motion.

Other aids to navigation are to be developed in future systems. Presently, on transition to a new space, a description of the space is available via a button press. It is planned to make this option available at any time. Incorporation of auditory signposts and intelligent tutors into the system are planned. At present, the name of an object at which the Wiimote is pointing is available with a button press. Additional information could be incorporated at this point. Auditory signposts at appropriate places, such as by doors to new spaces, that explain where the door leads and how to navigate within the new area would be useful. Virtual tutors could provide additional information. Virtual tutors could appear at points where the traveler gets stuck to advise on how to make progress. An intelligent agent, which gives context-dependant spoken warnings and advice is being designed to support the virtual cane. This will enhance navigation and will provide additional functionality. Systems such as the present one will facilitate the development of accessible Serious Games.

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