25 Multi-modal virtual reality for presenting geographic information

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Introduction

Humanity's desire to represent the world spatially is strong. From the earliest times we have tried to communicate and represent the spatial aspects of the world to each other through a variety of media: cave paintings, drawings in the sand, models, maps, works of art, photographs and, in present times, with satellite images, computer-generated worlds and virtual environments. Spatial representations also extend beyond the visual. For example, we also communicate spatial relations through the spoken and written word. In this chapter, we examine the multi-modal representation and communication of spatial information using VR technologies.

In common with most methods intended to convey spatial information, VR relies heavily on visual display. This is not surprising given that it is well noted that vision is the most useful of the senses for understanding space (Foulke, 1983). For visually-impaired people, the over-reliance on visual display for conveying spatial relations denies them access to these media. In recent years a number of studies have shown that people with visual impairments can understand spatial relations when communicated in a manner that is accessible to them. This understanding relates both to learning a new environment (Jacobson *et al.*, 1998), learning from secondary sources (Ungar, 1994), and using information gleaned from secondary sources to interact with environments (Espinosa *et al.*, 1998). Visually-impaired people are able to gain a comprehension of spatial relations because walking through an environment and interacting with a secondary source are multi-modal experiences – information is gathered through visual, auditory, haptic, kinaesthetic, proprioceptive, vestibular, olfactory and gustatory means.

Given this ability to comprehend real-world spatial relations due to their multiple modalities, it is our contention that multi-modal VR can be used successfully to augment interaction in real-world environments and also to provide a media for secondary learning for people with severe visual impairments. Multi-modal VR offers an opportunity for a better quality of life through enhanced education and mobility, opening up arenas of work and leisure. Such developments will also augment VR usage for sighted individuals by enhancing human–computer interaction (HCI).

Geographic representation, visual impairment and VR

As noted, geographic representations are mainly visual in nature and reliant on people to be sighted in order to access them. People with visual impairments are thus denied access to them and, in part, to navigating the environments they represent. Over the past few decades several different means for conveying spatial information to people with severe visual impairment have been explored. As detailed in Jacobson and Kitchin (1997), these means can be divided into those that seek to convey spatial representations using modified geographic representations (e.g. tactile or talking maps) and those that seek to act as navigation/orientation aids (e.g. talking signs and personal guidance systems).

As our case examples will illustrate, in our opinion VR systems offer qualitatively improved means of both representing spatial data and providing navigation aids. This is because of the nature of VR as a medium. Virtual reality is a wide-ranging term, with many differing meanings to different researchers. Wickens and Baker (1995) list the core 'reality giving' features in a virtual system as: dimensionality, motion, interaction, frame of reference and multi-modal interaction. These five aspects interact to make VR spaces qualitatively different to other forms of geographic visualization (e.g. maps), with a wider range of applications.

Dimensionality encompasses a continuum from two to three dimensions, including perspective and stereoscopic viewing. A 3D VR system is considered more 'real' as this replicates our perceptual experiences in the natural environment. Moreover it offers a greater potential for visualization. For example, a 2D contour map is difficult to interpret, requiring training and experience, and is more cognitively demanding than viewing a three-dimensional representation of the same terrain.

Motion refers to the degree of dynamism within the representation. VR is generally considered to be dynamic with the view changing as the user moves position. Maps, on the other hand, are static representations and the view remains the same despite the viewer moving position. However, as a static map is rotated, the ability to relate the map to the real world changes.

Interaction refers to the degree to which the user can alter or 'play' with the representation. Interaction is either closed-loop or open-loop in nature. In the open-loop form the display runs in its entirety, from beginning to end, and viewing is passive. In the closed-loop form the viewer can interact with the data or display and actively direct their navigation through the information. VR allows interaction through the adoption of a closed-loop approach, with a desktop VR 'walking' the user through a building, for example.

Frame of reference refers to the viewing position of the VR user and varies as a function of a spectrum between an ego-reference (inside-out) and a world-reference (outside-in). In an ego-referenced presentation, the display is presented from the viewer's perspective (e.g. as if looking from the user's eyes). In a world-referenced display, an exocentric view is taken, where the scene containing the user is viewed from an external location (e.g. from the top of a lamppost). Generally speaking, the egocentric perspective is easier to interpret and it is this view which is most often utilised with VR.

Multi-modal interaction consists of interaction through several different, complementary sources. For example, a multi-modal VR system might employ a number of display and input devices including conventional computer input peripherals such as keyboards, mice, joysticks, computer screens as well as novel input peripherals such as speech recognition, eye gaze tracking, gesture tracking, tactile feedback from surface textures, data gloves, force feedback, head-mounted display, screen display and so on.

To this list we add *mimetic representation* and *scalar changes*. VR systems provide representations that detail in mimetic (imitation, mimicry) visual form the multifaceted, dynamic and complex nature of geographic environments. Here, VR users see a VR landscape that has a high degree of verisimilitude (having the appearance of truth) to the real environment rather than an abstracted representation (such as a map). As with maps, mimetic representations can provide representations of both material (physical objects) and immaterial (such as heat) information. However, mimetic representation allows users to make the link between representation and reality more clearly as it partly removes the degree to which the abstraction needs to be processed in order to make connections between the abstraction and reality.

VR representations also differ qualitatively from other forms of representation because they allow users to explore the same data through a set of seamless *scalar changes*. These scalar changes can only be achieved in map-based representations by viewing a set of maps, and then always within the frame of the abstraction (flat, symbolic map containing degrees of inaccuracy and imprecision).

Although VR provides a qualitatively-enriched form of geographic representation, their combination of dimensionality, motion, interaction, frame of reference, mimetic representation, scalar changes and multi-modal peripheral input is designed to provide an augmented visual display, and therefore does not seek to cater for people without sight. We contend that these seven defining aspects can, however, be reconfigured to allow people with severe visual impairments to benefit from using these qualitatively different representations. This is achieved by providing additional multi-modal input devices. Traditional forms of spatial representation are static, unintelligent and inflexible. For example, tactile maps can only be read by one person at any time, they cannot be 'questioned', they cannot be manipulated to change scale or perspective. Like any cartographic product, tactile maps are subject to certain constraints: scale reduction, 'bird's eye view' perspective, classification, symbolisation, generalisation, etc. These constraints are exacerbated by the need for the information to be read tactually. To illustrate our contention we briefly detail two on-going projects which utilise VR. Before moving to these studies, we feel it instructive to first redefine the scope of VR in light of the discussion so far, and to detail by what means we can compensate for lack of vision.

Redefining VR

In conventional definitions of VR, reality is *re-created* as a virtual reality. Here there is a high degree of mimesis – the VR seeks to mimic reality. However, for our purposes, this definition is limiting. In a system where another dimension such as sound or touch is being used symbolically to represent visual components, the process of re-creation becomes one of abstract representation. Here, the VR system is not seeking graphically to mimic the geographic environment but provide a representation which augments interaction with either a spatial representation or the real-world environment. Moreover, geographic information within an accessible VR environment can be a representation of a representation. For example, a map in its creation has already undergone a degree of abstraction via scale change, selection, symbolisation and so on. When this is conveyed either through sound or touch through a VR, a new level of abstraction is inserted. As such, a more complicated process than re-creation is occurring. In an extended definition of VR, the VR system then seeks to provide either re-creation or augmentation. These categories are not mutually exclusive.

Using multi-modal VR to present geographic information

At present, it seems that touch (haptics) and sound (auditory) provide the best options for constructing augmented VR systems. Indeed, most work to date has concentrated on exploring these two alternative means of communicating spatial information. We will give a brief summary of the merits and limitations of each in turn.

Haptics

Haptic perception involves the sensing of the movement and position of joints, limbs and fingers (kinaesthesia and proprioception) and also the sensing of information through the skin (tactile sense) (Loomis and

Lederman, 1986). A virtual reality expressed through a haptic display allows a user to *feel* a virtual environment. The added dimensionality that haptic, kinaesthetic and tactile interfaces provide are important for three reasons. First, the display of information through the haptic senses can lead to greater immersion and realism in a virtual environment. For example, users are able to sense, feel and interact with objects represented in the virtual world. Second, the haptic channel may augment visual information, but also offers an independent channel for interaction for the non-visual or multi-modal presentation of geographic space. Third, haptic interfaces have enormous potential for enhancing virtual environments, and by the provision of information through a modality other than vision, they extend the range of applications to a wider section of the population (Brewster and Pengelly, 1998; Colwell *et al.*, 1998; Hannaford and Venema, 1995). Haptics provide a very natural interaction within body-sized spaces, for example, grasping objects.

Tactile, haptic or force feedback output can be achieved through several techniques including pneumatic (driven by air pressure), vibrotactile (vibrating tactile stimulation), electrotactile (electrical charge driven), and electromechanical stimulation. Systems adopting these outputs can be finger-based, hand-based or exoskeletal (body). Commonplace zero technology systems for haptic communication include Braille, sign language and Tadoma (non-verbal reading of speech via a hand placed on a speaker's face and neck). There are good reasons to include haptic interfaces in VR systems, particularly when an object needs to be manipulated. This is because once vision is occluded, such as an object passing out of sight behind another object, there is no perceptual feedback and it becomes difficult or almost impossible to control the occluded object. In addition, haptic interfaces are able to provide accessibility to representations of geographic space without the need for vision (Porter and Treviranus, 1998).

Auditory

Along with haptics, sound is a useful addition to VR systems providing a number of augmentations. The sound we perceive in the environment contains information about the source of that sound, and its distance and possible direction (Kramer, 1994). Vision gathers a large amount of information but only from one direction at a time. In contrast, auditory perception is omnidirectional. Moreover, as a species we are good at ascribing causal meanings to sound in a very natural way, such as identifying the ring of a doorbell or the backfire of a car exhaust (Ballas, 1993) and picking up repetitions and correlations of various kinds which give rise to a certain rhythm (Bregman, 1994).

Loomis and Soule (1996) describe the advantages of auditory displays over traditional visual or tactile displays. Auditory displays have high

temporal bandwidth, specialised mechanisms for temporal pattern processing, allow simultaneous monitoring of all spatial directions, and have low sensory thresholds, which permit the use of displays that minimally consume power. Kramer (1994) provides a comprehensive summary of the benefits of auditory display.

- An auditory display's presence is generally as an augmentation and non-interfering enhancement to a visual display.
- An auditory display increases the available dimensionality of the representational space.
- Auditory displays have superior temporal resolution. Shorter duration events can be detected with auditory displays.
- Auditory displays create user interest and engagement by decreasing learning time, reducing fatigue and increasing enthusiasm.
- Auditory displays have complementary pattern recognition capabilities by bringing new and different capacities to the detection of relationships in data.
- Auditory displays provide strong inter-modal correlations, reinforcing experiences gained through visual or other senses.
- Auditory displays enhance realism by adding immersive qualities and making virtual reality situations more realistic.
- Auditory displays are synesthetic, i.e. they replace insufficient or inappropriate cues from other sensory channels.
- Auditory displays enhance learning by providing a presentation modality suited to many students' learning style.

Clearly, the auditory sense has several advantages and benefits as a method for displaying information. It is complimentary in how and what information it can communicate to a computer user, by broadening the human–computer communication channel and taking advantage of unused 'bandwidth'.

Auditory data of use in a VR system can be divided into two categories: speech and non-speech. The non-speech category can be further subdivided. Sonification is the use of data to control a sound generator for monitoring and analysis of the data. This would include mapping data to pitch, brightness, loudness or spatial position. This is highly relevant to auditory cartography (Krygier, 1994). Within an auditory computer interface, an auditory icon is an everyday sound that is used to convey information about events in the computer (Gaver, 1994). This is done by an analogous process with an everyday sound-producing event. For example, a file being deleted may be indicated by the sound of a trashcan, and a computer process running represented by an engine running. An earcon is a tone-based symbol set where the 'lilt' of verbal language is replaced with combinations of pitch and rhythmic structures (Blattner *et al.*, 1994; Brewster *et al.*, 1994). Audiation is the direct translation of data waveform to the auditory domain for monitoring and comprehension. Examples of audiation would include listening to the waveforms of an electroencephalogram, seismogram or radio telescope data (Kramer, 1994). At present, this appears to have minimal application in the presentation of geographic data, but might be useful for representing continuous data such as rainfall or temperature that has clearly-defined spectral properties.

A set of key auditory variables that can be used in the presentation of geographic data were presented by Krygier (1994) and include:

Location – the location of a sound in a two- or three-dimensional space such as a spatially-referenced verbal landmark on a touch pad.
Loudness – the magnitude of a sound.
Pitch – the highness or lowness (frequency) of a sound.
Register – the relative location of a pitch in a given range of pitches.
Timbre – the general prevailing quality or characteristic of a sound.
Duration – the length of time a sound is (or is not) heard.
Rate of change – the relation between the durations of sound and silence over time.
Order – the sequence of sounds over time.
Attack/decay – the time it takes for a sound to reach its maximum or minimum.

Historically, sound has been applied to maps by verbal commentary and voice-over effects (Thrower, 1961). More recently multi- and hypermedia have added new dimensions to spatially-referenced data in encyclopaedias and digital atlases. Within the context of human–computer interaction, auditory icons and earcons are now regularly used. Fisher (1994) used such sounds for conveying uncertainty in a remotely-sensed image, and Jacobson (1996) used spatial auditory icons (the sound of traffic, and the bleep of a pedestrian crossing) on an audio–tactile map. Researchers have investigated navigating the World Wide Web through audio (Albers, 1996; Metois and Back, 1996) and as a tool to accessing the structure of a document (Portigal and Carey, 1994). Data sonification has been used to investigate the structure of multivariate and geometric data (Axen and Choi, 1994, 1996; Flowers *et al.*, 1996). Auditory interfaces have successfully been used in aircraft cockpits and to aid satellite ground control stations (Albers, 1994; Ballas and Kieras, 1996; Begault and Wenzel, 1996).

Two projects

Haptic–soundscapes

A current project is to construct a haptic–soundscape prototype VR system for conveying spatial representations. Work on this project has just started and builds on an earlier project which implemented a sound map system. The design and effectiveness of the sound map system is reported elsewhere (Jacobson, 1998, 1999; Jacobson and Kitchin, 1997) but we briefly outline the systems and findings here for context, before detailing the present haptic–soundscape work.

The original soundscapes project was initially conceived as a way to produce interactive maps accessible to people with visual impairment, which avoided some of the difficulties of tactile maps. Many tactile maps are relatively expensive, difficult to construct, largely unportable because they cannot be folded, and inaccessible to many visually-impaired people because they demand an ability tactilely to identify features using the fingertip or palm. Labelling is particularly problematic; when enough labels are applied to facilitate suitable understanding, the map often becomes cluttered and illegible (Tatham, 1991). Using labels in a separate legend or key reduces the immediacy of the graphic and introduces interpretative problems as referencing is disrupted (Hinton, 1993). Computer systems that link sound with touch, enhancing the tactile map with the addition of audio, have increased the utility of tactile maps. For example, when a raised area on a tactile map is touched, a corresponding sound label is triggered. Two such systems include NOMAD (Parkes, 1988) and 'talking tactile maps' (Blenkhorn and Evans, 1994). Fanstone (1995) has exploited the GIS capabilities of NOMAD to build a hierarchical audio–tactile GIS of Nottingham University campus. Access within a map is very efficient with users reporting enjoyment and ease of use (Jacobson, 1996). However, access from one map to the next remains problematic. For example, to 'zoom in' or to move to an adjacent area the user has to locate the speech label indicating that it is possible to zoom in, then remove the tactile map, search for another tactile map, register this on the touchpad and then continue map exploration. This break in the continuum of map reading is disrupting and confusing.

The sound map project sought to overcome some of these difficulties by utilising hypermedia software. Within a hypermedia environment a user can navigate between textual and cartographic information nodes in order to get a well-documented, multi-faceted representation of space, from varied sources and differing viewpoints (Milleret-Raffort, 1995). Conventional hypermedia systems are predominantly visual in nature. They can, however, also offer people with visual impairments a 'virtual' way of exploring the world (Jacobson and Kitchin, 1997). In this case, hypermedia was used to construct a bold visual (for sighted people and those with residual vision) and audio environment consisting of a set of hierarchically-distributed sound maps which could be accessed across the Internet.

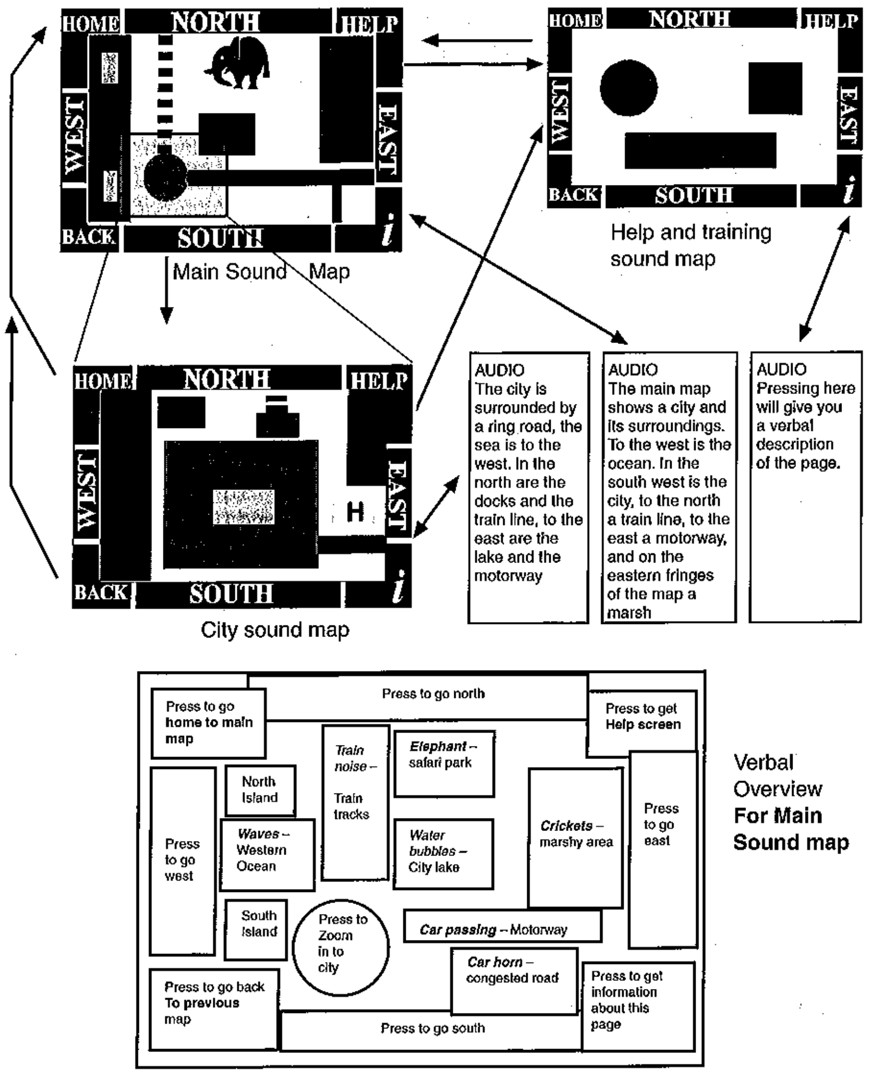
In this system, bold visual media (text and image) were augmented by spoken audio and metaphorical sound (e.g. sound of waves crashing on a beach). The work sought to build upon other projects such as Webspeak and the Graphical User Interface for Blind People Project (Petrie *et al.*, 1996) which aim to make traditional computer interfaces accessible.

The sound map system comprises a conventional personal computer, running a World Wide Web browser such as Netscape Navigator. The only specialist addition is a 'touch window', a peripheral device consisting of an electro-resistive glass screen. Touching or dragging a finger or stylus on the glass screen provides an alternative to mouse-controlled input. The touch window can be attached to a monitor so a user with limited vision is able to view the screen through the touch window, or used at table-top level where a totally blind individual is able to scan the pad with their fingertips. Spatial information is presented as an auditory map. Areas of the touch pad are overlain with sound and when the map user's finger enters the designated area the sound is played. By touching adjacent areas of the pad, users are able to determine the size and shape of a map feature by the change in sound. A collection of sounds are used to represent map information that is usually conveyed by visual symbols (text, colour, line style, shape, etc.).

For the purposes of development, an off-line World Wide Website was built which utilised inter-linking auditory maps that could be traversed solely by sound and touch. As the user's finger is dragged across the touch pad, the system 'talks', playing audio files which are triggered by the position of the user's finger. This audio–tactile hypermedia conveys cartographic information through the use of spoken audio, verbal landmarks and auditory icons. Audio consists of environmental sounds (such as traffic noise for a road) and icons which denote specific events like the edge of a map, links to further maps, or allows the user to press for more information.

Rather than direct manipulation of a tactile surface, such as pressing on the tactile maps in NOMAD, this system uses a touch window. Therefore the user has no direct cutaneous stimulus from tactile relief. The encoding from the audio–tactile stimulus meant that map information is built up from kinaesthetic sensing of movement across the pad, sensing of the distance traversed across the pad, proprioceptive sensing of the location of the fingers and location information obtained by referencing with the hands to the outside frame of the touch pad. Linking enables a blind user to traverse from one auditory map to another. As each map loads, a verbal overview describing the map is played. From all maps there is direct access to a help screen that explains the system and the modes of interaction.

Figure 25.1 displays the simple user-interface for the auditory hypermap system. As the map-reader's finger moves across the touch pad and over the 'SOUTH' bar, the audio message 'Press to go south' is played. Once this part of the touchpad is pressed the central area is filled with an auditory map to the south of the previous one. If no maps are available, this is relayed to the user verbally. NORTH, WEST and EAST all work in a similar manner. HOME returns the user to the main auditory map. The HELP button explains how to use the system. When exiting from help the user is returned to the correct map. The '*i*' button plays information about the map in view (e.g. 'the map shows a city and its surroundings, in the south-west is the city, etc.'). The BACK and FORWARD buttons allow the user to traverse through the 'history' of their links.



AUDIO
The city is surrounded by a ring road, the sea is to the west. In the north are the docks and the train line, to the east are the lake and the motorway

AUDIO
The main map shows a city and its surroundings. To the west is the ocean. In the south west is the city, to the north a train line, to the east a motorway, and on the eastern fringes of the map a marsh

AUDIO
Pressing here will give you a verbal description of the page.

Figure 25.1 Interface and functionality for sound map prototype.

The system was evaluated by five visually-impaired people and five blind people. Initial training took place for fifteen minutes using the help screen of the sound map system. Users were familiarised with the touchpad, were shown how to follow a link, and obtain more verbal information. They were given no information about the content, structure or links between the maps. During the evaluation phase, individuals had fifteen minutes to navigate through and explore the maps. They were told that they were free to go where they wished and to return to places previously visited. At the end of this fifteen-minute period, the computer was turned off and the participant was assessed using techniques adapted from cognitive mapping for people without vision (Kitchin and Jacobson, 1997). These included a verbal description of the maps and map layout, imagining they had to explain the maps to somebody over a telephone, and a graphical reconstruction of the maps using a tactile drawing pad. The whole process was videotaped and a log made of people's paths through the audio–tactile maps. Semi-structured interviews were used to get impressions of the system, feedback on how it could be improved and for ideas of where it may be beneficial. A control group explored a hard-copy tactile map version of the map obtaining verbal information from Braille labels.

All of the sound map users were able successfully to interact with the system. This included people who had never used a computer before. Interview responses suggest that the system aroused great interest and that map access was 'simple, satisfying and fun' (according to a totally blind participant). Users were able both graphically and verbally to reconstruct the maps with varying degrees of accuracy (Jacobson, 1998). The level of integration and information recall was greater among sound map users than the control group. However, the tactile map users had greater accuracy of shape (map object) reconstruction, due to the raised line tracing nature of their representations.

The current project, haptic–soundscapes, seeks to build upon the developmental sound map work in several ways. It will carry out experiments into the nature of non-visual audio–tactile perception, looking at such issues as resolution and shape recognition. The results from the perceptual experiments will be implemented to build a working demonstrator to display a map, a graphic and a graph, where experimentation and user feedback will lead to further refinements of the system. The most notable feature will be development work with a haptic mouse. A haptic mouse works in a manner similar to a conventional mouse with two key differences. First, it is an absolute pointing device rather than a relative one, so a certain mouse position will always correspond to a certain cursor position. Second, the device is able to apply force-feedback, to offer varying degrees of resistance in a two-dimensional plane. However, by the use of acceleration techniques, the mouse user perceives a three-dimensional movement, such as rolling their hand over a small hill. As such, a third dimension of haptic feedback will be added to bold visuals and auditory information to provide an interactive, multi-modal VR system. Table 25.1 and Figure 25.2 show the haptic effects.

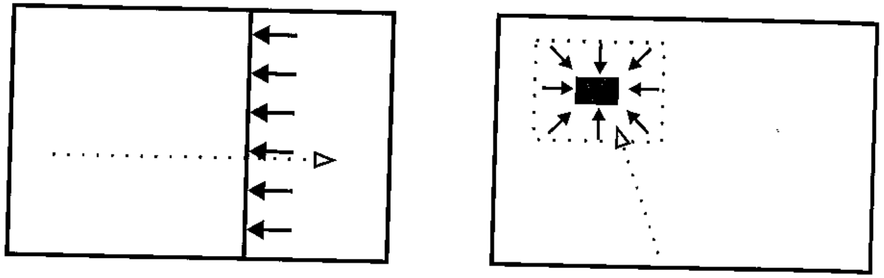
Table 25.1 Virtual effects available with VRM haptic mouse (numbers refer to Figure 25.2)

- Virtual Wall: [1]
  When a mouse cursor contacts a virtual wall, extra force will be required to pass through. This allows the user to detect different regions of the screen surrounded by walls or borders.
- Gravity Well: [2]
  When the cursor enters the active region of a gravity well, the VRM is physically drawn towards the centre of the virtual object. Thus, objects with gravity (e.g. a map object) can be found by feel alone.
- Damping: [3]
  Sections of the screen with damping provide a resistive force that is proportional to the speed the mouse is moving. This allows the user to detect different regions of the screen and to stabilise unsteady hand movements.
- Friction: [4]
  Screen areas with friction exhibit a uniform resistive force to the movement of the mouse offering the user an additional effect to differentiate various screen objects.
- Rubber Bands: [5]
  Objects with the rubber band effect have a spring-like feel so that it is easy to remain on the object while performing mouse clicks or moves (e.g. map objects, or buttons, slider bars in a desktop environment).

Source: Adapted from Control Advantage, http://www.controladv.com.

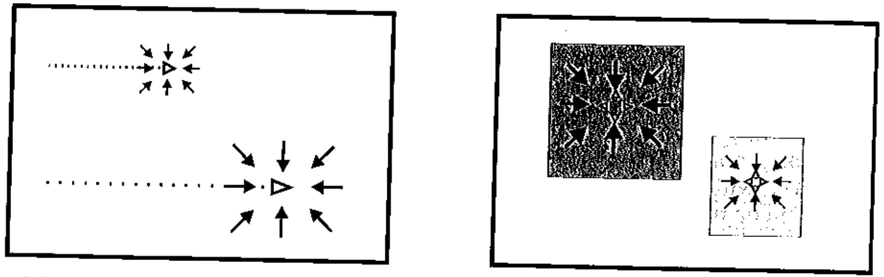
Personal Guidance System

The sound maps/haptic soundscapes projects seek to make geographic representations accessible to visually-impaired people. VR is also being used in another way to provide navigation aids for traversing environments. The Personal Guidance System developed at Santa Barbara by a team of geographers and psychologists has been extensively reported elsewhere (Golledge *et al.*, 1991, 1998; Loomis *et al.*, 1998). Therefore we will only give a brief overview. The PGS seeks to create a virtual auditory layer that is draped across the real world to augment interaction with that world. The PGS comprises three modules: a locator unit (GPS), a detailed spatial database (GIS), containing an algorithm for path selection, and a user-interface (VR). The interface of the PGS is a virtual auditory display (Loomis *et al.*, 1990). Here, the labels of the objects within 'real space' such as 'tree', 'path', 'library' and so on are spoken through stereo headphones and appear as virtual sounds at their correct (real-world) locations within the auditory space of the traveller. As such, objects appear to 'announce' themselves with the sound emanating from the geographic location of the landmark. In this system, the PGS circumnavigates some of the more troublesome aspects of spatial language in conveying spatial relations by adopting a system whereby virtual space is overlain on real space. The PGS has evolved into a fully-functional system, adapted so a naïve untrained novice can use the system, and is an example of a VR-based 'naïve' GIS



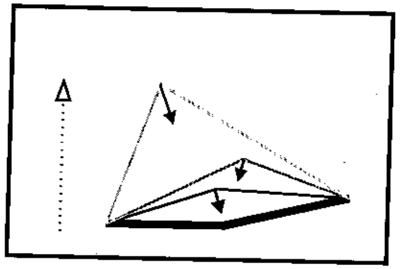
[1] Virtual wall

[2] Gravity well



[3] Damping

[4] Friction



[5] Rubber bands

Figure 25.2 Diagrammatic illustration of haptic effects.

Note
Numbers refer to description in Table 25.1.
Hollow arrows represent the direction of mouse movement.
Black arrows indicate direction of force applied.

(Egenhofer and Mark, 1995). The problem of deciding which information to present to a blind user has been overcome by using common GIS techniques: hierarchies, order, buffering and corridoring. For example, a buffer of a predetermined size is created around the user. Any features which fall within the buffer, have been allocated weights that transcend a chosen value, and 'call' the user as if sited in their real location. This feature allows visually-impaired users access to the macro environment normally experienced by vision. Features can be given a salient value within the database, so those which pose the greatest danger, or are of particular interest, are highlighted first. In addition to buffering, whole routes can be corridored. If the traveller veers from their desired route by leaving the corridor, an error is signalled and directions for their return provided. At present, the user interacts with the system by using a small keypad. In the future it is hoped that interaction will be speech controlled.

Other studies

It should be noted that other teams are exploring the use of VR for communication, education, training and rehabilitation in relation to disabled people. Many of these approaches are multi-modal and some non-visual, demonstrating the salience of presenting information non-visually. Hardwick *et al.* (1996) used a force feedback device to present the structure of the World Wide Web to blind people through a haptic interface. Data was presented through a Virtual Reality Modelling Language (VRML), to build tangible surfaces and, by combining objects into scenes, primitive haptic shapes were constructed. Porter and Treviranus (1998) have used VRML and a haptic interface to provide haptic sensing of the relief 'maps' of the continental US for children and blind individuals. Work by Fritz *et al.* (1996) was successful in presenting scientific data through 'non-visual data rendering' (auditory and haptic interfaces) to blind people. Kurze (1997) has rendered drawings for interactive haptic perception by blind individuals who were able to obtain more accurate representation of spatial relations via the haptic method than conventional tactile maps tagged with audio. Bowman (1997) used joysticks and other physical interaction devices to provide muscle re-education for stroke patients. Virtual reality technology can allow communication between non-speaking deaf people and non-signing hearing people. Speech is signed while wearing a data glove, and this is translated to synthesised speech for the hearing individual (Kalawsky, 1993). Other vision-based systems have included training cognitively-impaired students to travel independently (Mowafy and Pollack, 1995) and using virtual replications of science laboratories to allow students with physical disabilities to carry out experiments (Nemire, 1995). Wilson *et al.* (1997) provide an overview of VR in disability and rehabilitation.

Future research

There is a need for future research to address the further development and use of new interface technologies such as voice recognition, touch screens and tactile display, force feedback devices and gestural interaction. Probably the most pressing need is to improve the user-interface, as this is the largest barrier to successful and meaningful interactions with representations of spatial information in a virtual environment. There have been several novel and interesting approaches that require further investigation. A vibro-tactile mouse which registers the mouse's position over a desired spatial object on a map (Nissen, 1997), tonal interfaces for computer interaction (Alty, 1996), and 'The Voice' which can convert a two-dimensional picture, map or representation into a 'tonal soundscape' (Meijer, 1992). Further research is also needed on sonification issues in VR, haptic interaction, and their combination.

One particular problem that is frequently overlooked is that of scale, not just the mapping from one physical scale to another representational scale (i.e. from the real world to a virtual environment) but intra-virtual geography scale changes (i.e. the equivalent to a zoom in a digital cartographic database or geographic information system). This scale transformation is one that is particularly difficult to appreciate without vision. However, by seeking techniques to present this information non-visually, it offers the potential methods to present this information in situations where it is critically important, such as where visual attention may be diverted (e.g. teleoperation, medicine, driving automobiles, flying planes and in military situations).

Three preliminary means of communicating scale without vision seem worthy of further investigation. Natural language could be used to explicitly or implicitly state a scale, such as 'the map is 1 mile across' or 'the map is now a neighbourhood/town/city/region size'. With the addition of a haptic mouse, which generates force feedback from designated regions on the screen, giving rise to such sensations as 'gravity wells', 'rubberbanding', 'stickiness' and impressions of relief such as bumps and hollows, it would be possible to generate a haptic scale referent. Options may include a haptic rendering of a visual scale bar, or equating resistance to distance. The third option is the presentation of relative map distance, and hence to imply scale through the auditory domain, such as using sound decay to equate with map distance or a pulse of sound travelling at a set speed across the map. The applied reasons for presenting information in modalities other than vision are compelling, namely in situations of a visual disability, where data is visually occluded, and for the augmentation of visual displays. Multi-modal information offers another independent channel for providing information to the user.

Conclusion

In this chapter we have outlined the need for multi-modal VR systems. VR systems provide qualitatively different forms of spatial representation from traditional media such as maps. However, they remain predominantly visual in nature. A move to a multi-modal configuration opens up VR systems to people with severe visual impairment, providing media that could improve quality of life, and qualitatively improves human–computer interaction by augmenting visual presentation. The two case studies illustrated that multi-modal VR systems can be successfully developed, that they have a number of advantages over other media, and that they can be used successfully by visually-impaired people to both learn spatial relations and to navigate through a geographic environment. These systems are, however, prototypes and more experimental work on both their development and use needs to be undertaken.

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