EVALUATING HARDWARE TECHNOLOGIES FOR REAL TIME AND INTERACTIVE VIRTUAL HERITAGE PRESENTATIONS

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1. Introduction

European cultural heritage offers a wide range of possibilities for creating virtual environments, which can enable people to perceive different places, people, objects and events during different periods of history. All of these have embodied European local cultures and traditions through time and in turn they shape the developing culture of current societies. Therefore, their adequate communication and presentation can promote and provide a better understanding of the different European cultures.

Current hardware technologies offer not only the possibility to see and hear virtual environments but also to touch and even smell virtual worlds. Furthermore, interactive virtual environments are regarded as a key area of research and development towards better and more enjoyable presentations of heritage objects (Geser and Pereira 2004).

Virtual environments could be presented in two modes according to the type of experience and hardware: Virtual Reality (VR) or Augmented Reality (AR). The difference is that while VR delivers a completely computer simulated environment; AR combines real and virtual elements to generate this environment. Both types of experiences have advantages and disadvantages which have an impact on the software and hardware requirements. For example, VR environments can be presented regardless the location of the users, while AR environments require the presence of some real elements in the location where the experience takes place. As such, AR experiences usually require hardware which is portable and for single users, in order to allow interacting with the virtual environment while still experiencing the real world. On the other hand, VR environments can be presented regardless of the location and the number of users.

The hardware technologies used for both types of virtual environments are very different from those used in traditional desktop interactive systems. Hence, there is not just one good solution but instead many different hardware technologies which suitability, performance and cost depend on the specific type of application. This document attempts to identify and evaluate the available hardware technologies for assembling an efficient and cost effective virtual experience. The technologies are classified as follows:

Output devices

- Visual displays technologies
- Audio systems
- Haptic and tactile systems

Input devices

- Interaction devices

The following sections will present the different hardware technologies according to this classification.

2. Output devices

These technologies present information to the user/users of the virtual reality installation. Typically, three sensorial modes of input information are used: visual, sound and tactile information, although there have been experimental/prototype products incorporating smell.

3. Visual display technologies

Currently, the display industry is a fast growing dynamic market with new technologies constantly being developed. In this environment it is difficult to find a single leading product or technology suitable for all types of applications with any significant time-horizon and the selection of "most appropriate" needs to be made as close to deployment/installation schedules allow. It is therefore at least as valuable to describe the basis for differentiating between products as to evaluate the current range.

In order to identify the major current technologies available for efficient and cost effective virtual reality installations, the following subsections will present the main commercial display technologies and their characteristics. These characteristics (resolution, contrast ratio, brightness, display size and shape as well as stereo capabilities) will be used to compare the different technologies and they are explained in more detail in the following subsection.

3.1 Display technology characteristics

3.1.1 Resolution

Resolution is one of the most important factors to consider in any display technology. It refers to the amount of detail that can be seen on the screen and it is usually described by the number of columns and rows of pixels that can be displayed (NEC/Mitsubishi 2005). Many displays and projectors have fixed resolutions and ratios.

The key to a quality image is the best resolution that can be afforded (Musgrave 2001). According to Parkhurst and Niebiur (2002) a resolution of 18 mega pixels should be feasible for large scale displays.

Another important issue to consider is that as the resolution increases, the performance of the graphic card will drop. According to Pabst (2000) and Thon et al. (2004), the memory bandwidth of the GPU (Graphic Processor Unit) has a big impact on the frame rate at 16-bit colour depth and high resolutions (see figure 1). This gets worse at 32-bit colour depth because the amount of data that needs to be transferred between the 3D-chip and the local memory doubles almost exactly.

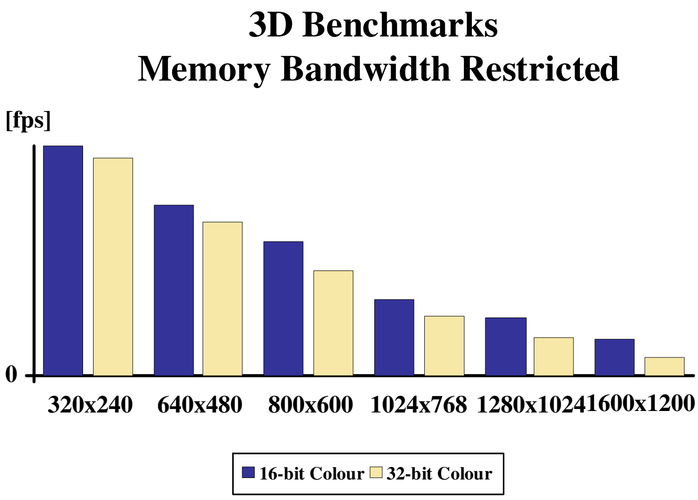

Figure 1. GPU memory bandwidth restrictions (Pabst 2000 and Thon et al. 2004)

3.1.2 Contrast Ratio

Contrast ratio is the measure of the difference of brightness levels between the brightest white and the darkest black. This is a very important specification in judging how well an image will be produced in an environment with different ambient lighting (Musgrave 2001). A good contrast ratio of 120:1 easily displays vivid colours, while ratios as high as 300:1 support superior grey scaling (NEC/ Mitsubishi 2005). There has also been research work on very high dynamic range displays (see Chalmers et al, 2004)

3.1.3 Brightness

Display brightness, which is measured in nits (candelas per meter squared cd/m2), can make a significant difference in a user's visual experience. A higher number of nits indicate a brighter display. As a general rule, 1,500 to 2,500 nits for an indoor display are required and 5,000 or more for outdoor displays (Musgrave 2001).

3.1.4 Display size and shape

Visual displays with different sizes and shapes can provide different degrees of immersion in a virtual environment. The degree of immersion are usually measured by the field of view (fov), which describes how much of the user’s view can be covered. Kjeldskov, J. (2001) suggests a classification of displays technologies according to their degree of immersion. These are:

- Full immersive displays: supports the feeling of “being in” the virtual environment
    - Head Mounted Displays (HMD)
    - Booms (HMD mounted on stand and operated by hand)
    - Six-sided Cave
    - Omnimax and other specialist facilities
- Partial immersive displays: supports the feeling of “looking at” the virtual environment
    - Large monitor
    - Panoramic screens
    - 3-5 sided caves

3.1.5 Stereo capabilities

Stereo means the capability of perceiving images on the display in 3 dimensions by presenting different images to each eye to simulate how scenes are naturally viewed. Some of the display installations offer stereo capabilities, whilst some individual display technologies now incorporate stereo capability. Stereo can be achieved in several ways as follows:

- Active Stereo: the viewer wears special eyewear consisting of two controlled shutters working in synchronization with the projector (see figure 2). When the projector displays the left eye image, the right eye shutter of the active stereo eyewear is closed, and vice versa. The single projector used must be capable of displaying at a refresh rate to alternate eyes high enough that the viewer does not perceive a flicker between alternate frames (Kjeldskov 2001).

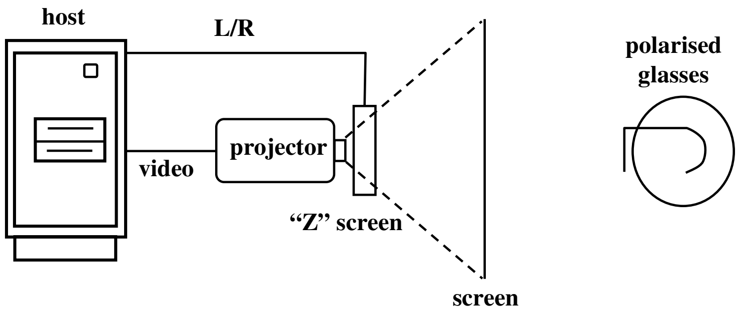

Figure 2. Active stereo display (Belleman et al. 2001)

- Passive Stereo: the viewer wears a pair of glasses containing two oppositely polarized filters -one for the left and one for the right eye. The light from each of the two projected images is polarized and can only pass through its corresponding filter. It can be implemented using one or two projectors, as shown in figure 3. The two-projector approach has the added value of providing higher brightness (Kjeldskov 2001).

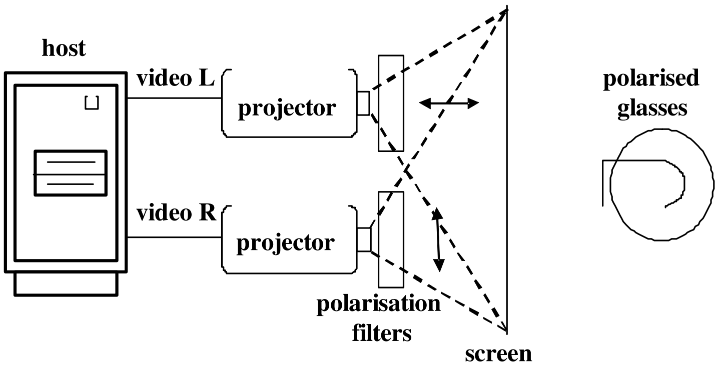

Figure 3. Passive stereo display with two projectors (Belleman et al. 2001)

- Auto stereo: this type of display allows the 3-D image to be viewed without glasses from a wide range of angles and distances. They are a relatively new addition to the 3D display market and open up a wide range of new opportunities to exploit 3D imagery. However, new problems are also introduced with the technology. For example, rather than displaying two distinct views, the display provides up to 9 which introduces new demands on other characteristics, such as resolution (Inition 2005).

3.1.6 Cost

Cost is a major factor to consider when deciding which display technology to use. As there are big differences of cost between display technologies, the available budget could become an important determinant for selecting a specific technology. Moreover, it is important to notice that prices of visual display vary rapidly due to the very dynamic nature of this industry.

3.2 Visual display technologies classification

Some years ago CRT (Cathode Ray Tubes) displays were the single prevailing display technology available in the market. Today CRT, LCD (Liquid Crystal Display), PDP (Plasma Display Panel), DLP (Digital Light Processing), and LCoS (Liquid Crystal on Silicon) are mature and mainstream, while many other technologies, such as

OLED (Organic Light Emitting Diode) and FED (Field Emission Display) are trying to emerge from the development lab and grab a significant market share.

An attempt to classify these technologies can be made by dividing them in direct view or projected technologies. Projected technologies cover both front and rear projection as the technology is shared between both markets. Figure 4 shows this classification, where CRT and LCD technology can work with either method. On the other hand plasma is limited to direct-view while DLP, LCoS and D-ILA are limited to projection because the devices are small microchips.

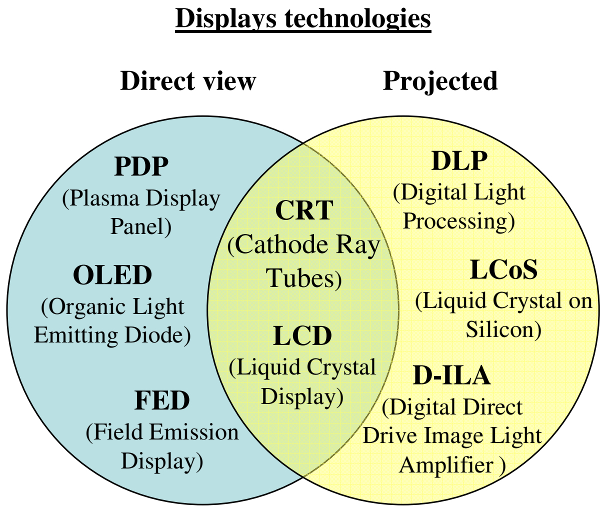

Figure 4. Display technologies classification

These technologies will be discussed in the following subsections:

3.2.1 Cathode Ray Tubes (CRT)

This 75 year old technology benefits from excellent colour and supports a wide range of resolutions. If overall image and picture quality is the absolute criterion then the direct-view CRT displays remains the best option, especially for video. However, sharpness and contrast aren't as good as the flat panels operating at their native resolution and they are bulky and heavy (Soneira 2005). Therefore, according to DeBoer (2004) this technology is already extinct as the new display technologies offer better capabilities and fewer people are willing to pay a premium price for a CRT.

3.2.2 Plasma Display Panels (PDP)

Plasma displays have captured a significant share of the non-CRT video market, mainly because their screen sizes (up to 80 inches) and lows prices. As plasma technology does not use backlight and no projection of any kind, they achieve sharp and high contrast displays with excellent colour and wide viewing angles. However, they are susceptible to the "screen door" effect due to noticeable gaps between pixels, have fixed native resolution and are very heavy. The screen door effect is when the space between pixels is visible as a minute black box around the pixel. The performance of this technology has been steadily improving with size and brightness. The real question is how plasma displays will hold up to the challenge from direct-view LCD panels (DeBoer 2004).

3.2.3 Liquid Crystal Displays (LCD)

Currently, LCDs are the dominant flat panel technology for computer applications. They offer good colour reproduction, perfect sharpness at native resolution, they are very thin and not very heavy. Some of the disadvantages of this technology include fixed native resolutions; poor contrast ratios, brightness and colour saturation generally decrease as the viewing angle increases and difficulty to produce deep blacks. However, this technology is increasingly getting bigger, faster and cheaper and many analysts predict that they will eventually take over the plasma market (Soneira 2005).

3.2.4 Active Matrix Liquid Crystal Display (AMLCD)

High Temperature Poly-Silicon (HTPS) is an example of this variant of LCD technology. Its advantages over LCDs are that it is smaller, has higher resolution and higher contrast. Its main disadvantage is that pixels cannot be made smaller without lowering brightness and reducing picture quality. This means that to produce enlarged panels without shrinking each pixel results in extra cost (DeBoer 2004).

3.2.5 Reflective LCD

This technology is a variation of LCD, where a liquid crystal layer sits on top of a highly reflective substrate, instead of being embedded in the LCD material as with conventional LCD technology. This assembly is used in a projection subsystem, providing an excellent contrast ratio (Musgrave 2001). Liquid Crystal on Silicon

(LCOS) and Digital Direct Drive Image Light Amplifier (D-ILA) are examples of this technology and they will be described in the following subsections.

3.2.5.1 Liquid Crystal on Silicon (LCOS)

LCOS is a reflective LCD display panel, which can be created as 1 chip or 3 chip systems. Pixels on LCOS panels can be made smaller than is possible with other microdisplay technologies, without compromising picture quality or manufacturability. Other advantages of this technology are excellent colour reproduction, high resolutions and no “screen door” effect. The main disadvantages are their cost and the difficulty to access this technology. LCOS technology is still relatively expensive compared to LCD and DLP projection technologies. However, DeBoer (2004) predicts that it will be developed to become better, faster and cheaper with Intel stepping in.

3.2.5.2 Digital Direct Drive Image Light Amplifier (D-ILA)

The D-ILA device, a special LCOS technology developed by JVC, is a reflective type of LCD that delivers a greater amount of light than a transmissive LCD panel. This technology eliminates almost entirely the “screen door” effect leaving a nearly-seamless picture. Overall, D-ILA projectors produce higher resolutions, better contrast ratios, less image artefacts, and better tonal and colour information than LCD front projection devices. However, this technology is still expensive.

3.2.6 Organic Light Emitting Diode (OLED) Displays

OLED technology is based on a revolutionary discovery that light-emitting, fast switching diodes could be made from polymers as well as from semiconductors. OLED technology provides not only brighter, better images at a lower cost, but it uses a material with self-luminous properties that eliminates the need for a backlight. This means that they draw far less power and they can be used with small portable devices. Other advantages of this technology are that the manufacturing process is simple and that there is virtually no restriction on size. There are two main directions in OLED (Howard 2004):

- The first technology was developed by Eastman-Kodak and is usually referred to as "small-molecule" OLED.

- A second technology, developed by Cambridge Display Technologies (2005), is called LEP or Light-Emitting Polymer.

This technology is quickly emerging from the development lab. Some of the technical problems left to overcome before this technology definitely enters the display market are its lifetime, ensuring competitive refresh rates, contrast ratios, black levels and overall performance (DeBoer 2004).

3.2.7 Field Emission Display (FED)

The biggest advantage of this emerging technology is that the display is emissive, and thus has an excellent viewing angle (160 degrees both vertically and horizontally), while remaining as thin as an LCD. In addition, they are also several microseconds quicker in response speed (Sharp 2005). Since the FED is a vacuum device, atmospheric pressure becomes a severe problem for large-area panels. This together with lifetime issues and bringing down the driving voltage are the main challenges ahead for FED developers.

3.2.8 Digital Light Processing (DLP)

Since its commercial introduction, DLP has steadily improved performance and now it is a dominant technology for both computers and video. This technology uses a semi-conductor imaging chip developed by Texas Instruments called a DMD (Digital Micromirror Device), which can be made up of one or three chips. DLP projectors offer excellent colour reproduction and produce a smooth yet sharp image with no apparent pixelation except close to the screen (Musgrave 2001). However, they have fixed native resolution and they can cause possible visual fatigue due to temporal fickle and rainbow effects in single chip systems (Soneira 2005). This technology is only available for rear projection and authors agree its future challenge will be to compete with the direct-view display market.

3.3 Direct view vs. projection displays

Direct view and projection display technologies are intensely competing in the market. Table 1 summarize the characteristics for both direct view and projection technologies according to DeBoer (2004), Soneira (2005), CTL (2005) and Howard

(2004). This overview of characteristics is further examined in order to compare all the presented technologies according to their main characteristics.

Displays	Max. Resolution	Contrast Ratio	Brightness	Screen size
Direct View				
CRT	1920 x 1080	4000+:1	1000 cd/m2	0.5m – 1m
PDP	1366 x 768	3000:1	700 cd/m2	0.76m – 2m
LCD	1280 x 1024	1300:1	450 cd/m2	0.02m – 1.4m
OLED	143 pixel per inch	1000:1	200 cd/m2	- 0.5m
FED	1280 x 768	1000:1	250 cd/m2	0.05m – 1m
Projected				
CRT	1920 x 1080	5000:1	NA	
LCD	1280 x 1024	800:1	450 cd/m2	
DLP	1280 x 720	5000:1	750+ cd/m2	
LCOS	1920 x 1080	2000:1	750+ cd/m2	
D-ILA	2048 x 1536	1500:1	550+ cd/m2	

Resolution

There is not a very large difference between the resolutions achieved by the direct view and the projected displays. D-ILA, LCOS and CRT technologies offers at the moment the higher resolution. In terms of image quality, direct view technologies are generally sharper because the pixels are generated right at the screen, while the optics and screen reduce sharpness in projection units. However, direct view technologies show much greater pixilation because the red, green and blue elements are tiled side-by-side on the screen, which means that the "screen door" effect is much greater than in projection technologies. This effect doesn't apply to direct-view CRTs because the phosphor elements are generally much smaller than the pixel size. This effect decreases as the resolution increases because the eye is unable to resolve the pixel structure at normal viewing distances.

Contrast

Regarding contrast, both direct view and projection technologies offer different contrast ratios. The best contrast ratios are achieved by DLP and CRT technologies, followed by plasmas displays. LCD projection offers the lowest contrast ratio.

Brightness

Direct view displays are much brighter than projectors. According to Musgrave (2001), the main limitation of projectors is precisely their brightness. A typical largevenue video projector with 750 cd/m2 of output will achieve only about 37% of the required brightness level.

Display size and shape

The size and shape of displays, regardless of being fully or partially immersive, differ enormously. For example, head mounted displays (HMD) and booms are fully immersive and just require a small display. On the other hand, panoramic screens and caves of 3 to 5 sides require larger displays and are only partially immersive. This suggests that the degree of immersion is not fully related to the size and shape of the display but rather to how much of the user's viewing angle is covered by the display – a conclusion backed by studies in visual perception. For full immersion, smaller displays are positioned closer to the user's eyes. Nevertheless, this solution provides the disadvantage that only one user can be immersed in the environment at any time. In order to immerse several users, larger screens are required although this solution only offers partial immersion. For this reason, there is not any predominant display solution in the market, as there is always a compromise between degree of immersion and number of users. Therefore, the suitable display's shape and size depends greatly on the type of application and the preferred number of users to use simultaneously the virtual reality installation.

In general, direct view screens are suitable for displays of smaller sizes, such as head mounted display, boom and large monitors. On the other hand, projection displays offer better image quality for larger displays sizes. Tiling screens or projectors is usually used to achieve larger display areas. This is because many display technologies cannot produce a non-projected area larger than 2 meters. As a result, it is necessary to address additional hardware and software problems, such as geometric misalignment, colour variation (Majumder and Stevens 2005) and other extra requirements imposed on the video controllers, which drive the display.

In terms of thickness, LCD and plasma direct view displays' main advantage is that they are very thin, typically 7 to 12 centimetres deep. In contrast, rear projection requires more space in the room, while front projection could be overshadowed by the users in front of the screen.

Stereo capabilities

As previously explained, stereo projection could be achieved by using projection technology. As such, CRT, DLP, LCD, D-ILA and LCOS projectors are commonly used for Virtual Reality installations with stereo capabilities. In addition, LCD and PDP direct view technology also offers stereo and auto stereo capabilities (Qinetiq 2005, Opticality Corporation 2005).

Cost

The cost of the different technologies varies widely depending on whether the technology is fully established in the market, its size, quality and performance. As previously discussed, direct view technology usually is used for smaller screens. Therefore, the prices of these technologies are more affordable. In contrast, very large direct view screens are at the more expensive end of the price range, especially when having stereoscopic capabilities. Projectors provide a cheaper option to develop a stereo capable large area display. However, depending on the technology their prices are very different, and in cases where more than one projector is needed, this price multiplies.

3.4 Display technology conclusions

The previous subsections have described advantages and disadvantages of the main display technologies available in the current market. Regarding the direct view technologies, many experts believe the present might very well be plasma's high point and that the near future will belong to LCD (Bohannon 2004). In addition, OLED technology has to go from novelty to practical competitor in a market that is constantly evolving. Unlike the screen displays, the competition between the projection technologies is closer. Currently, DLP, LCOS and LCD are the main players competing to achieve best picture quality at the lowest cost. On the other hand, D-ILA technology offers some advantages over the other technologies, such as higher resolutions and better contrast ratios, and will be battling for the next several years, something that will undoubtedly be good for the market.

In conclusion, new technologies are constantly being proposed which indicates that at the moment no single technology can fulfil all applications (IST 2005). The best advice for selecting which technology is the most suitable for assembling a Virtual Reality installation will be to produce a detailed specification outlining and prioritising system requirements. These requirements could be whether the installation will be outdoor or indoors, fully or partially immersive, number of people to accommodate, budget and others. Subsequently, these requirements should be closely matched with the characteristics provided by each technology and display type. Other useful recommendations could be to evaluate actual displays in similar usage situations, and to check references of the supplier (Musgrave 2001).

4. Audio Systems

Before discussing the different types of setup, it is useful to discuss the types of information that can be communicated through audio.

4.1 Types of audio data

Audio data can be discrete, as in individual short pieces of sound or music, or continuous pieces of music or audio in general. These different categories have different properties, and have different requirements for implementation within a virtual environment.

4.1.1 Discrete audio

Events in the real world often generate sound. As we experience life, we learn to recognise these sounds helping us to understand that an event has taken place, such as a door closing, or a gun firing. Often we chain these events together to understand them, our minds gain context from such information and can use predictive abilities to help us continue our understanding. Examples of this type of audio data are: sound effects, speech, simulated audio systems.

A unique characteristic of discrete sound is that it can have both duration and a relative direction to the user. This ties directly with environmental audio systems, which can simulate directional sound.

4.1.2 Continuous audio

Continuous sound often comes from the joining of many different discrete audio cues that recognised as a whole. Often, continuous sound can be perceived to come from an area, as opposed to a discrete position. Continuous sound is the natural grouping of many discrete audio cues, but as the cues renew themselves throughout their duration, they are considered continuous. For example, background music, wind noise in a forest, waterfalls, etc.

4.2 Types of audio system setup

Audio systems can be categorised by their use, either as part of an environmental setup, used by many users, or as a personalised setup, involving a single user. It is also possible to embed personalised setups within an environmental setup, and integration of these two types of system has issues of its own.

4.2.1 Environmental setup

An environmental sound system refers to the use of a single system for the interaction with many users. This refers to any system which is external to a group of users, and which responds to the group as a whole.

Examples of this setup could be, background music in a shop, sound effects in a theme park ride, or audio in a cinema system.

4.2.1.1 Directionality of audio cues

An environmental setup is useful for communicating both discrete directional cues, as well as continuous audio.

Directional cues are relative, meaning that if an event happens, in order to calculate which direction the user should hear it from, both the users' position and the event position must be known. It is assumed that the user will be standing in the centre of the environmental sound setup, however with a group of people, that isn't necessarily the case, and this must be taken into consideration when determining how effective a system is in communicating a single event to multiple users.

4.2.1.2 Group policy

By grouping everyone together in an environmental setup, the same information is given to everyone, and this must be taken into effect when constructing the experience – as not all information may be suitable or best used with all users of all types.

4.2.1.3 Privacy

By grouping everyone together, users are not able to take control and listen to individual content without anyone else hearing it also.

4.2.2 Personalised setup

A personalised sound system refers to the use of a single system for the interaction with a single user at a time. This refers to any system which is external to the individual, but may have many systems within a group. Examples of this setup could be a personal hi-fi or connection via a PC.

4.2.2.1 Individual policy

As a per-user approach, each setup can be tailored for the user, such as adjusting the content, volume, style etc. according to the user's needs.

4.2.2.2 Exclusion

Exclusion refers to the ability to exclude external audio from the personalised sound stage, whether that is from an environmental audio system, other users, or indeed other users' personalised audio setup. If it is desired, a personalised setup could be adapted to augment the outside world, as opposed to supposing it, meaning that environmental cues could be given to users as a group, but personalised cues could be given on a per-user level.

4.2.2.3 Directional issues

The implementation of a personalised setup is currently focused on using headphones. Headphones, by their nature, are stereo only, and therefore cannot handle direction sound except as a projected soundstage from left to right in front of the user. There is potential for simulating directional cues, either through a simulated soundstage (as demonstrated in Dolby Headphone) or through a combination of head-tracking and headphones, to adjust output.

4.3 Implementation options

With a good understanding of the theory, it is possible to assess the state of current technology to mix and match parts to fit the needs of a VR environment.

For this, audio will be actuated using speakers; each speaker fed via a channel a signal that is to originate from a computer. Sound cards are a standard method of producing such a signal from software, no matter what type of setup.

In the following subsections different speaker setups will be discussed to provide the two main types audio system.

4.3.1 Environmental setup

Environmental setups require a series of standalone speakers that together form the overall soundstage. The number and configuration of these speakers can be further categorised.

4.3.1.1 Mono sound systems

The first types of system that were concerned with listening to music or radio used a single speaker as sound actuator. From a technical point of view, a single speaker can only give information from a single direction – which is fine for speech, on a radio broadcast, but not entirely suitable for listening to music. It is as though the entire sound stage has been compressed through a single pipeline.

4.3.1.2 Stereo sound systems

Stereo, with two speakers, can act together to produce a front-side horizontal sound stage. This is similar in sound to going to a concert or performance watched from the front, giving differentiation between different music cue positioning. However, it is only front facing.

4.3.1.3 Quadraphonic and Surround sound systems

Where stereo failed to give a wider "virtual soundstage", quadraphonic sound was designed to provide an early version of surround sound, by placing four speakers at four points around the user, usually in the four corners of a room.

With the advent of Dolby Surround sound (Dolby Laboratories, Inc 2005), the virtual soundstage has expanded for use with a television screen. As figure 5 illustrates, Dolby Surround comes in the form of four surround sound speakers for "effect", whilst the focus of the user is upon the screen in front. A speaker is positioned directly in front of the user specifically for the user to listen to high definition speech, and a further speaker is placed somewhere in the vicinity giving actuation to low level sound.

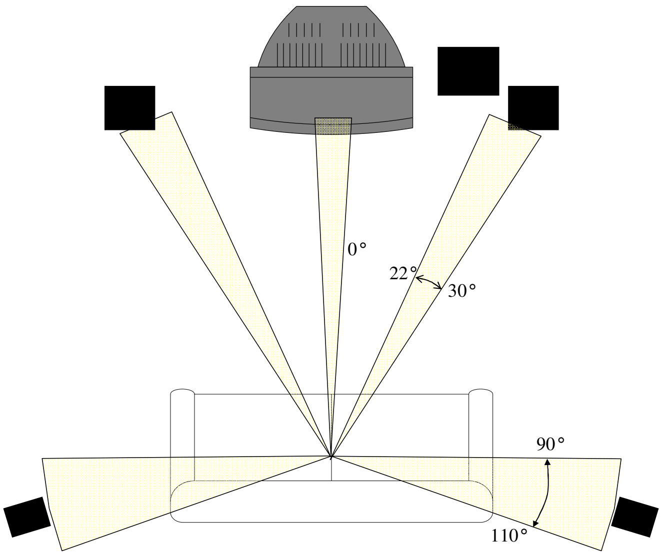

Figure5. Dolby Digital 5.1 Surround Sound setup (2005 Dolby Laboratories)

This does not correspond perfectly with the virtual environment, which by its nature may have a focus that moves dramatically, the user possibly focussing on more than one screen, being able to look around in full 3d throughout the environment. Speech or any other effect may come from any direction, whereas the Dolby Surround system is based on a planar Virtual Soundstage, having particular issues for example with non-planar sound effects such as plane flights overhead.

It has been shown that 5.1 surround sound, and its extension counterparts 6.1 (see figure 6) and 7.1, give good directional sound as far as a front facing focus is concerned. It has, however, been used in some of the latest games to good effect, the most notable being the horror/action game “Doom3”, total immersion lends strongly to atmosphere, especially concerning surround sound – being able to hear things behind you before you look around! It is certainly possible, although not optimum, to be able to use a surround sound system to work with the virtual environment to give good directional cues, lend atmosphere and depth to an otherwise mostly visual experience.

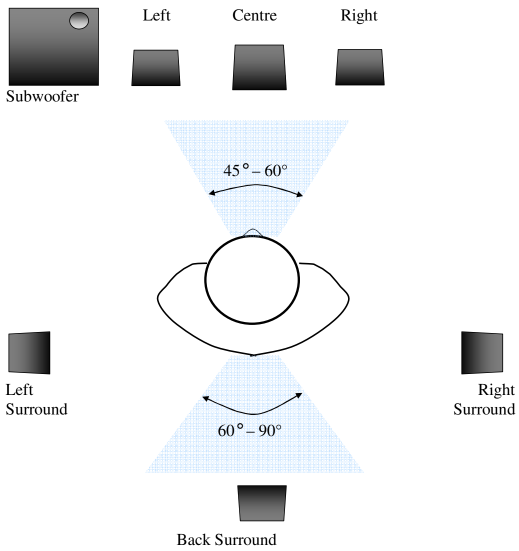

Figure 6. Dolby Digital 6.1 Surround Sound setup (2005 Dolby Laboratories)

The speakers themselves have a wide range of prices and a wide range of quality and/or power output. Whilst the quality itself does not have a unit of measurement, power output is measured in Watts, a mini system being up to 10 Watts (suitable for a child's' room), a midi-system being around 40 Watts, a living room / master bedroom size system from 100 to 150 Watts and upwards. There really isn't an upper limit for power output, although it is a concern when purchasing speakers that whether the system is specifying the Watts per speaker or of the system overall. Surround sound speakers can be in the range of 50 to 150 Watts per speaker, although as specified there really isn't an upper limit. Often, however, a higher power output also means that at lower output, there is better quality, and less distortion of the signal, but this is by no means a fixed property.

4.3.2 Personal setup

Stereo headphones come in 3 main types: internal, closed and open. Each of these types has its advantages and disadvantages, but provides sound for a single user with stereo sound.

4.3.2.1 Internal Earphones

These earphones have the greatest range in price and quality, and are placed just inside the ear. They are designed to block outside sound, and generally are of lower quality than the other two, external earphone types. They are usually used with personal stereos.

4.3.2.2 Closed Earphones

These earphones vary less in quality and tend to be better than internal earphones, although sound is still slightly distorted due to their external sound blocking ability. This ability, however, does lend to the audio environment when in a busy or noisy area, but obviously would not be suitable in an augmented audio environment.

4.3.2.3 Open earphones

These earphones are usually much better quality and slightly more expensive, but do not attempt to block outside sound. This makes them better in quieter environments, and could have direct application in a virtual environment employing augmented audio, assuming that multiple people using them would not interfere with each other.

4.3.3 PC Output

Sound cards are a good method of facilitating the conversion of a digital signal generated through software to the speakers, either in digital format via a proxy or directly from the sound card itself. There are a range of different options concerning sound cards, varying in quality of output and many options that may not be necessary in a virtual environment, such as audio input or internal software tables for the use of midi devices.

4.3.4 Integration issues

For connecting speakers to a soundcard, the best quality is achieved through the use of a digital A/V receiver, which acts as a control and amplification unit. An A/V receiver is designed to accept audio from a digital source and redistribute to a multitude of different speakers dependent upon the setup.

Below is a summary of possible audio devices, implementation aspects and possible usability issues:

- 5.1, 6.1 or 7.1 Surround Sound Systems, based around an A/V Receiver
    - Requires software implementation for 3D sound
    - Multiple users can enjoy simultaneous use.

    - Multiple users can enjoy directional sound.
- Headphones / “augmented audio”
    - Stereo only, no 3d sound
    - Requires dedicated sound card, but can be cheap (>10 pounds)
    - Requires software producing sound
    - Individual users can enjoy customized use.
- Sound cards
    - Some can produce surround or stereo signal directly for connection to speaker setup.
    - Some can produce optical digital output using SPDIF connector to an A/V receiver for digital quality surround sound.
    - Also have variations in the quality and range of midi and recording support, which may or may not have an effect in virtual environments.

5. Haptic feedback systems

Haptic devices are concerned with the communication of physical information to a human user. There are many types of physical cue to consider.

5.1 Environmental cues

Environmental cues are communicated to a group of people as a whole and represent many types of physical phenomena that are taken for granted in the real world. Examples of these types of cue include physical movement and orientation, force feedback due to environmental effects such as wind or earthquake etc.

5.1.1 Blanket user policy

Each user within the environment will be treated in the same way, however, different users will experience the same effect differently. There are immediately issues concerning the types of user that can use a particular environment, such as the suitability due to age, disability or other factors.

5.1.2 Latency and refresh rate

A simulator is an example of a virtual environment. It is a combination of a seated theatre, in which a movie is shown, with a hydraulic or pneumatic set that can control the physical orientation and change in orientation to simulate many types of movement. This helps give sensation to the user, complementing the visual cues given on screen.

In this type of set up, all of the video and physical information is pre-processed, and so as the simulation runs, there are no issues concerning the speed of update of the physical set up, because the update speed is known before rendering.

However, in a real time system, latency and refresh rate are a serious issue. A screen can change, update, up to 120 times a second. However, an environmental set up will have very different refresh rates depending upon its' type. In order to give an accurate representation of a virtual environment at any stage, an interactive environment will require an interactive rate of update.

5.2 Personalised cues

These cues are given individually on a per user basis, and have a great deal of value in terms of communicating both discrete and continues effects, such as to communicate physicality of virtual objects, to effect feedback according to a response etc.

5.2.1 Individualised user policy

Each user can be treated according to their needs, the equipment and thus the experience tailored to cope with different people.

5.2.2 Exclusions

For a personalised set up, a number of types of exclusions must be present. Users may be required to be physically excluded from each other in order to use a piece of equipment, or they may need to be physically excluded from their environment in order to use the equipment. Either way, this exclusion has implications upon the user and their ability to use to experience physical information in a virtual environment.

5.3 Implementation options

5.3.1 Environmental options

There are many options for implementing an environmental Haptic feedback system, mostly derived from the entertainment industry. These include but are not limited to : omni-orientation platforms in the form of simulators, environmental effects as used in theme park rides such as wind forces / temperature changes. Whilst these are able to produce a series of effects that simulate physical environmental forces, they are not easily applied within a virtual environment in their current states, indeed there seem to be no common interfaces for such environmental Haptic systems outside of military application-based systems such as flight simulators, which are custom built.

5.3.2 Personal options

Where the environmental options are wide but not easily implemented the research and home entertainment industries have produced a number of devices to be used as part of a personal system.

Research has yielded a few specialist devices, such as the omni-orientation Phantom (SensAble 2005), which both sends and receives orientation and position information, as well as providing force feedback. A selection of semi-immersive interaction and feedback devices is available from Immersion Ltd (Immersions 2004) in the form of interactive gloves / exoskeletons that can either give tactile information via localised actuators in the tips of the fingers, sense from the joints the position of the fingers. In the CyberGrasp system (Immersions 2004), also available is the ability to provide force feedback and restriction of movement via a metal exoskeleton.
There are also a small number of devices that use sound, particularly very low resonance waves, to "augment" via vibration, such as using a chair or simply to enhance another device.

Haptic devices do not perform processing for themselves and need to be connected to a PC, either via USB, FireWire or special PCI card configuration. Software is needed to feed a signal to the device, and multiple users need multiple hardware and software configurations. This may deem a multi-user experience a multi-PC setup requirement, networked together, as opposed to a single PC responsible for the graphics and sound of an environmental model.

The cost of these systems varies quite considerably between these areas. Whilst the games industry based devices, mostly designed to be used on home machines and games consoles, go for as little as € 30- € 45 each, the immersion systems based Cybergrasp (Inition 2005) is around € 34,585 per setup.

Haptic devices are broken into two main areas :

1. <u>Augmented Human devices</u>

These devices are assigned to a human in order to directly interact, either using total immersion (e.g. full body suit containing physical or electric sensors and/or actuators) or partial (particular areas, such as arms / legs / restrictive head movements). These types of devices are the most sophisticated but also the most expensive, a good example being the CyberGrasp system by Immersion, which combines position and orientation sensing (input) with force feedback via an actuated exoskeleton.

These types of device are only as useful as their application, immersion within a virtual environment may not require the use of all the different systems, for example simple walkthroughs may not require a system such as the CyberGrasp except to handle simple objects, open door, shake hands with avatars etc. They could, however, be useful in rendering more general environmental effects, such as simulating the force felt when walking through water etc.

2. <u>External devices</u>

These devices are often a metaphor for devices in the real world, and use generated electromagnetic forces as a way of simulating the effects that using the real device would generate. These often have very specific use in an environment, such as steering a vehicle using a force-feedback steering wheel or joystick, using a device such as the Phantom Omni as a pointing / force feedback device, or a simple game pad as a means of both inputting commands and feeling responses / events that have occurred.

The combination of external devices with sound can also be a powerful example of haptics in the form of low level audio. There are devices which are concerned with adding force feedback to the users' seating to provide low level rumbling, as an environmental form of feedback.

Below is a breakdown of possible haptic devices, implementation aspects and possible usability issues:

- Game pads
    - Around 30 euros or more
    - Vibration only for positive or event reinforcement
    - USB or Gameport requires WindowsXP, 2000, ME or special installation
    - Also allows user input, individual button and analogue stick input
    - Individual users can enjoy customized use.
    - Users may need training each time in use.
- Joysticks
    - Vibrations and force feedback restrictions movement and gives feeling of inertia
    - USB or Gameport requires WindowsXP, 2000, ME or special installation
    - Also allows user input, directional / orientation input
    - Individual users can enjoy customized use.
    - Users will not need training in use, as it is intuitive.
- Steering wheels
    - Vibrations and force feedback restrictions movement and gives feeling of inertia
    - USB or Gameport requires WindowsXP, 2000, ME or special installation
    - Also allows user input, wheel based turning and analogue input via a stick.
    - Individual users can enjoy customized use.
    - Users will not need training in use, as it is intuitive.
- Chairs
    - Range in price from around 1500.
    - Range of audio sub-woofer based vibration feedback devices, as well as one orientation device.
    - Connect to specialist hardware PCI card in PC.
    - Individual users can enjoy customized use.
    - Users will not need any training in use.
- CyberGrasp / CyberTouch systems (partial augmented humans)
    - Allow full immersive hand position sensing and orientation input
    - Allow feedback in terms of restrictive movement (CyberGrasp), fingertips actuators (CyberTouch)

- Specialist hardware PC setup
- Users will require careful training in use as equipment is fragile.
- Individual users can enjoy customized use.

6. Input Devices

Input devices for virtual reality installations are an extension of traditional Human Computer Interaction devices with an emphasis on navigation, object handling, choice selection & dialogue interactions. In order to enhance the realism of any simulation, it is necessary to increase the similarity of the use of a particular input device to the action performed in the simulation. However this principle is often compromised because in many simulations an input device must fulfil several roles. The following subsections consider characteristics that govern VR input technology and how these characteristics affect currently available input technologies. Categorisation of such input devices is difficult on account of the large variation in methods of interaction and data they provide. Two existing taxonomies are described by Baecker & Buxton (1987) and Card, Mackinlay & Robertson (1990).

6.1 Input device characteristics

6.1.1 Modality of interaction

Modality of interaction governs which actions a user must take to interact with the input device. Examples of different modalities are hand motion, walking, speech & eye movement. Many tasks can be completed by a number of different modalities of interaction though some are more intuitive for users. One measure of the appropriateness of a modality to a particular form of input is referred to as the "Gulf of Execution" (Hutchins et al. 1986).

Multimodal input systems can increase a user's sense of immersion whilst allowing them to interact more rapidly with a system. A drawback of multimodal systems is that the additional complexity of such interactions can result in greater training periods.

6.1.2 Dimensionality

All input devices are governed by the number of independent channels that they can pass information from the user to the system. Each of these channels representing a dimension. Where input devices are used for navigation it is normal for as many as 6 dimensions to be required. Three are for linear movement and a further three for rotational movement. Within heritage VR environments it is quite likely that navigation in the additional dimension of time could be required.

Where input devices have less channels available than the number of dimensions they are required to interact with then it is still possible to use them provided that different dimensions can be interacted with in a sequential manner.

6.1.3 Discrete vs. continuous

Input can take the form of a continuous signal or a discrete value. More information can be passed between the user and system where a continuous channel is employed but this can be at the expense of harder control for the user.

6.1.4 Tracking vs. selection

Rather than having to make intentional signals to interact with a system through an input device, it is possible for a more naturalistic user experience where the users can have parts of their body or the whole of it tracked and their natural motions can be used as the input device. Tracking devices can result in very quick training periods for users.

Where selection input devices are employed the user is able to decide whether they wish to make a particular interaction with the system but this is not always possible where a tracking input system is used.

A potential problem for some tracking devices is the space requirement. In order to make movements that are possible within the system, it must clearly be possible to make such movements in reality. A constricted space for the user who is being tracked would not allow them to take full advantage of unencumbered space within the virtual environment.

6.1.5 Bandwidth

The time taken for the intentions of a user to be acted upon by the system can have significant effect on the immersive sensation experienced by a user. As this time increases, so a lag will grow between a users action and the effect the user will experience with this action. For the input device two factors affect this rate, the time for the user to make the physical action and the time for the input device to encode this action and transmit it to the application (Card, Mackinlay & Robertson 1990).

For VR simulations particularly this lag time needs to be as short as possible as the application handling the input will add further lag before feedback is created for the user. For most input devices interface circuitry rather than the sensors presents the greatest delay (Mulder 94).

6.1.6 Precision

The precision of any particular device will determine the appropriateness of the device for any particular task. Within VR simulations where the user has immediate feedback from input actions, high degrees of precision are not required as the user is able to easily adapt to the behaviour of the input device.

6.1.7 Reconfiguration

Due to a number of restrictions such as space and cost, it is likely that an input device is to take many roles within a virtual reality interaction, therefore it has to be as appropriate as possible for the different positions. For such input devices there is a trade off between having a complex device with simple separate functionality for each type of input against a simpler device with few input channels but each being multifunctional.

6.1.8 Ease of Use

On account of the wide variety of possible input devices, many will be unfamiliar to users, the first time they interact with a particular VR environment. Some input devices are more intuitive to use than others though this is very dependent on the context in which they are used in the VR simulation.

Size and shape of the input devices can influence the ease with which users can employ the input devices. Weight, position, sensitivity and requirements of mobility all can have significant effects on limiting or excluding users.

6.1.9 Privacy

Privacy of a user's interactions with a system can be influenced by the type of input device used. User privacy can affect some users' reticence to engage with an environment and also create difficulties on account of interference of overlapping input where two users are in close proximity.

6.1.10 Cost

The cost of input devices can vary quickly particularly where new technologies are being adopted. Given the enormous gulf of price differences between input devices cost acts as an important differentiator for products suitable for large installations verses professional tools. Cost is very significant where there are multiple users with each user having a separate input device. Further, in public installations where it is likely that input devices will experience heavy use, the cost of maintaining and servicing must be considered.

6.1.11 Durability

Input is an interface between the user and the computer system so by its very nature it must withstand interactions with the hardest user it will encounter. Within a museum and heritage environment this is the general public. Where an installation is to be supervised, devices are required to be less durable than environments which are unsupervised. Durability often will have an effect on sensitivity of an input device with more durable devices being less sensitive. Where an input device has separate detachable components then its durability will decrease with a higher risk of such components being lost. A further requirement for any input device is to withstand continuous cleansing where it is to be shared amongst many users.

7. Input device technologies

Input devices for VR systems have emerged from GUIs in desktop computer technology. These devices fall into two broad categories, trackers and selection input devices. Trackers allow a user to behave in a normal fashion as though they are interacting with a real version of the environment that is being simulated. The user's motions are then captured and this information is used to update the simulation to reflect how the environment would change relative to the user if they had undertaken a similar action in the real world. Intentional input devices allow a user to make specific actions which map to arbitrarily defined (though good design will dictate that they are intuitive) behaviours within the VR system.

Within these two broad categories the various input devices are then organised by modality of interaction. The most common being with users hands and fingers though body movement, eye movement and speech are also considered.

7.1 Selection Input Devices

7.1.1 Game pads / joysticks

Joysticks are an intuitive interface for navigation and spatial control and have been adopted as a computer interface from the field of avionics. A single joystick offers continuous input in 2 dimensions and with some form of toggle switching this dimensionality can be increased indefinitely, though at the cost of only 2 dimensions being accessed simultaneously. The adoption of joysticks by the gaming industry in the form of game pads that typically integrate 2 joysticks and a number of discrete buttons into a single unit has ensured that the input device is both familiar, cheap and robust. The use of 2 joysticks simultaneously ensures that game pads have double the bandwidth of a single joystick, though this comes at the cost of new users taking longer to learn to use the device.

7.1.2 Keyboard

The keyboard is very familiar for many users but difficult to use fluidly for those not experienced even with a short training period. Furthermore, the layout of keyboards varies from one language to another even where similar alphabets are shared so within a multinational context such as tourism complete familiarity will not be common. Furthermore it is difficult to convey navigation controls as there is not an intuitive correlation between the discrete keys and continuous spatial movement. The ability of a keyboard to transmit language means that this input device is most suited to natural language like interactions, issuing commands and responding to menu selections. The complexity of the keyboard as an input device could result in it being distracting to the user who might need to be concentrating on the keyboard rather than the screen. Keyboards are both cheap and in the case of membrane keyboards, robust.

7.1.3 Mouse / trackpad

The mouse is one of the most familiar input devices for computer interaction, offering continuous input in 2 dimensions. Like the joystick, the mouse incorporates additional buttons that can be used for selection and toggling to adjust the dimensions that the mouse movement controls. Unlike the joystick, the mouse is not a fixed device thus reducing its robustness. Trackpads, which now replace mice on portable computers, offer a similar form of interaction but can be made more robust as they do not need to be moved.

7.1.4 3D mouse / spaceball

3D mice offer a similar form of interaction to the traditional mouse, but with additional dimensionality. These are a less familiar form of computer interaction than the traditional 2D mouse. An extension is the Space ball that allows the user to interact with an additional 3 dimensions by monitoring not only translation but also rotation. These dimensions map well to typical dimensions required to explore a 3D environment.

7.1.5 Touch screen

Touch screens are computer monitors which register where on the monitor, in relation to the pixels that they display, they are touched by the user. Software is thus able to determine both discrete presses and movement made by the user. By adjusting the display according to the type of input required from the user, the touch screen can simultaneously simulate any number of discrete buttons (even a keyboard), trackpad like devices and context relevant buttons such as hypertext and graphical hyperlinks such as image maps.

On account of the possibility for direct correlation between user action and the point of interaction, touch screen input devices can be very intuitive. This is further enhanced by their ability to dynamically update the look of the point of interaction to provide any further information that helps with that interaction.

Touch screens offer the advantage of highly reconfigurable input devices that allow many types of input to be performed in a little space. This flexibility comes at a cost for additional development time. They are durable (typically 30-50 million presses at any single point).

7.1.6 Voice recognition

Voice recognition allows users to interact with a system through both natural language by dialogue and the issuing of commands. This is achieved by the user talking into a PC microphone and the resulting signal is analysed by speech recognition software on the PC. Such software currently places a relatively expensive computational burden on the system and the cost of such an input device must incorporate both a dedicated PC and the voice recognition software.

Currently voice recognition software presents difficulty with a multilingual audience as systems not only are trained for a specific language but also work better for specific dialects and accents. Voice recognition systems also work better after a training period in which both the user and the system can adjust towards better interactions.

Where voice recognition is to be used for natural dialogue, current technology must limit this to specific domains in order to be able to handle the complexity of language understanding (Martin et al. 2004).

7.1.7 Gesture recognition

Gesture recognition input devices offer a natural way for users to interact with a system even if most users would currently be unfamiliar with such an input device. Hauptmann notes that it is intuitive for all.

"there are no expert users for gesture communications. It is a channel that is equally accessible to all computer users" (Hauptmann 1989 p. 244)

Two forms of input device that exploit gesture recognition are input gloves (Krueger 1991) and hand trackers such as the Vectorix (Kulik and al. 2004) and Phantom (Sensable 2005). In the case of the glove a user places this over their hand and it monitors movements of both the hand and the fingers. This allows for a multidimensional input device as the hand is able to move with six degrees of freedom and each finger can have several degrees of freedom. With the hand trackers, the user can move a limb around in space and in the case of the Phantom haptic feedback is possible. Both approaches are easy to manipulate but training is required to link different motions with input channels that are not spatially correlated (MacKenzie 1995).

The use of a glove as an input device presents some difficulty from a user acceptability perspective. One issue is on account of a device that works for all user hand sizes and the other is with respect to hygiene maintenance (MacKenzie 1995).

7.2 Trackers

Tracking devices and wands allow natural motions of users and objects manipulated by users to be tracked moving through space. This can be used not only for users to interact with a VR system in real time but also as a means of acquiring natural motion for avatars and moving objects within the virtual model. This technique is referred to as motion capture. Three technologies dominate this domain, inertial, magnetic and visual tracking. Each of these approaches presents unique difficulties. Such input devices also allow for directed input through gesture recognition systems.

7.2.1 Magnetic trackers

Magnetic tracking devices require a user to wear or carry a transmitter whose signal is picked up by a number of sensors within close proximity of the user and is then used to determine both the position of the transmitter and its orientation. If the transmitter is tightly coupled with the user then this also provides the same information about the user. For magnetic trackers there are restrictions in movement range of the users. Magnetic trackers such as Ascensions 'Flock of Birds' (Ascension 2004) offer ranges between 1meter and 3meters and the user must support a cube with dimensions of 20 cm.

Three systems are currently employed relying respectively on, DC electromagnetic (EM) pulse, AC EM field strength, and AC EM field. The DC approach suffers from interference from magnetic fields such as the Earth's whereas the AC approaches place restrictions on environments to not include additional ferro-magnetic materials (Mulder 94).

7.2.2 Inertial trackers

Inertial tracking systems can be quite robust and require relatively little additional computational power to provide information about their positioning. With the potential for wireless integration, they can also be quite unobtrusive. A problem with such systems is that they need to be recalibrated frequently as errors can act accumulatively.

7.2.3 Visual trackers

Visual tracking systems work by using a series of cameras to monitor user movements. Thus a user is free to move around an environment and their movements are automatically monitored to update the environment. This can be achieved through the identification of body shapes or more easily where users have markers placed on specific parts of their bodies. The placing of such markers can present difficulties both from the perspective of privacy and accuracy.

Visual tracking systems tend to be quite expensive on account of the high speed cameras and the extensive computational power required to analyse scenes. Furthermore, the large amount of computer power required can mean that the response times of the input device might be larger than is acceptable for some VR applications.

The arena in which visual tracking works must be restricted so that the user can never be too far away from cameras in order that the cameras can resolve the actions of the user and the lighting must be controlled so that it is quite constant throughout (Mulder 1994).

A particular problem to affect visual tracking systems is occlusion. More cameras used by the system can help to partially alleviate this problem (at the expense of additional computational burden) but it will still exist particularly where there are multiple users within a single arena but also with smaller body parts such as hands with a single user.

7.2.4 GPS trackers

GPS offers low accuracy at present with precision limited to approx 30cm. A further problem with this technology is that signals are very weak so it will not work indoors. An advantage is that there is no limit to the area it will cover (Mulder 1994).

7.2.5 Eye trackers

In visually-mediated applications then eye trackers can be a powerful input device (Duchowski 2002). Typically eye trackers provide an accuracy of between 0.5 – 2.5 degrees with a response time of 100 milliseconds (EL-MAR 2002). As well as monitoring direction of gaze, trackers can also be configured to recognise certain combinations of blinking actions to activate switching behaviour.

Trackers are either mounted on a headset, or separately from the user. Where the tracker is mounted separately, the user is restricted to motion within a small area in front of the tracker, typically 10-20cm motion in any direction (Duchowski 2002). Where the tracker is mounted via a headset, the headset includes a camera (or two where stereo eye tracking is employed) which is not very robust. In order to establish the direction of gaze, the user must adopt a fixed position, normally with some chin rest, or their head position and orientation must also be tracked and integrated with direction of gaze (Huang et al. 2004).

The difference in cost between the head mounted systems and separated systems can vary by over an order of magnitude.

7.2.6 Tread mill / walking detectors

Both single and multidimensional treadmills have been developed to be used for VR input. Examples of walking detectors are the "Fantastic Phantom Slipper", an infrared

–emitting pair of shoes that are tracked and "Joyfoot" which uses acceleration sensors (Barrera et al. 2003). Whilst such devices can offer more immersive VR experiences, they can also act as an encumbrance as navigation through a large virtual world might be achieved too slowly through walking or running. Furthermore, such an input device can act as a total obstacle to users with restricted mobility.

7.2.7 Biometric measure

Further input devices where the user has less control are biometric monitors. Examples of such devices are the heart rate monitor and skin surface conductivity meter which could help determine a user's emotional response to different parts of a system. Work has also been pioneered to use EEG as an additional source of input (Freidman et al. 2004). Caution must be taken with regard to user privacy with such intrusive devices.

7.3 Input device conclusions

The suitability of a variety of input devices has been considered for Virtual Reality systems within the cultural heritage domain where the main tasks are navigation, object handling, language interaction and choice selection. Input devices offer a way for users to interact with virtual environments and where the actions required to operate input devices correspond to similar actions performed within the virtual environment then an intuitive understanding of the device can be readily achieved as well as a more immersive experience. A joystick does not provide an easy interface for conversation and speech input is not the easiest method for navigation. However, other considerations can outweigh these benefits. For example, by tracking walking behaviour a user could navigate in a very intuitive manner through a virtual environment, but space restrictions as well as cost might dictate against this as an input device and an alternative of using a joystick could be more successful.

The input devices of a system must provide a means for users to explore all aspects of interaction of the system. This means that a device must have sufficient bandwidth for all degrees of freedom within a system to be manipulated. This bandwidth is not just between the input device and the system but also between the user and the device. Clearly additional bandwidth can be achieved where several devices are employed simultaneously such as the two joysticks and many individual buttons on a gamepad, as long as they employ different modalities of input from the user, but this approach can get harder for users to learn.

By employing an input device that is reconfigurable then it can adapt to be used for many types of input rather than relying on the user having to switch between devices or use a single device often in a non optimal way to perform many types of input.

8. References

1. Ascension (2004) Flock of Birds specification http://www.ascension-tech.com/products/flockofbirds.php
2. Baecker, R. M., & Buxton, W. (Eds.), (1987). Readings in human-computer interaction: A multidisciplinary approach. Los Altos, CA Morgan Kaufmann, 357-365
3. Barrera, S., Romanos, H. Takahashi, S. and Nakajima, M., (2003) Real Time Detection Interface for Walking in CAVE. Proceedings Computer Graphics International 2003: 105-111
4. Belleman Robert, Stolk Bram, de Vries Raymond (2001) Immersive Virtual Reality on commodity hardware, Proceedings of the 7th annual conference of the Advanced School for Computing and Imaging, pages 297--304, Heijen, the Netherlands, May 30-June 1 2001
5. Bohannon William, (2004) Large-screen displays, Part One, 2004, Presentation
6. Cambridge Display Technology (2005) http://www.cdtltd.co.uk/technology
7. Card, S.K., Mackinlay, J.D. and Robertson, G.G, (1990) The Design Space of Input Devices Proceedings of the CHI '90 Conference on Human Factors in Computing Systems,. New York: ACM.
8. CNET Networks, Inc. (1995-2005), http://reviews.cnet.com/Creative_Sound_Blaster_Audigy_2_ZS_Platinum_Pro/4505-3022_7-30558408.html
9. Creative Technology Ltd (1998 - 2005). http://www.soundblaster.com/
10. DeBoer Clint (2004) Display Technologies Guide: D-ILA Projection, http://www.audioholics.com/techtips/specsformats/displays_D-ILA_projectors6.html
11. DeBoer Clint (2004) Organic LED Displays (OLEDs) - The Next Trend?, http://www.audioholics.com/techtips/specsformats/organicOLEDsdisplays.php
12. Dolby Laboratories, Inc (2005). http://www.dolby.com
13. Duchowski, A., (2002) Eye Tracking Methodology: Theory & Practice London, UK: Springer-Verlag (London), Inc.
14. Freidman, D.A., Slater, M., Steed, A., Leeb, R., Pfurtscheller, G. and Guger, C. (2004) Using a Brain-Computer Interface in Highly-Immersive Virtual Reality. In Beyond Wand and Glove Based Interaction IEEE VR 2004 Workshop p.43 http://www.vr2004.org
15. Hauptmann, A. G. (1989). Speech and gestures for graphic image manipulation. Proceedings of the CHI '89 Conference on Human Factors in Computing Systems, 241-245. New York: ACM.
16. HeadRoom LLC (1995-2005), http://www.headphone.com
17. HomeRecording.com Inc., (2003) http://www.homerecording.com/sound_card_basics.html
18. Howard, Webster E. (2004). Better Displays with Organic Films. Scientific American, p. 76
19. http://www.hitl.washington.edu/scivw/faq.html
20. Huang, H., Allison, R. and Jenkin, M. (2004) Combined Head – Eye Tracking for Immersive Virtual Reality The proceedings of the ICAT 2004 Conference
21. Hutchins, E.L., Hollan, J.D. and Norman, D.A., (1986) "Direct Manipulation Interfaces" in User Centered Systems Design: New Perspectives on Human-computer Interaction, ed by Norman, D.A. and Draper, S.W. pp.87-124, Lawrence Erlbaum, Hillsdale, NJ.
22. Immersion Corporation 2004, http://www.immersion.com/3d/products/cyber_grasp.php
23. Inition (2005) http://www.inition.co.uk/inition/guide_stereovis_autostereo.htm
24. Inition (2005), http://www.inition.co.uk/inition/product_glove_vti_grasp.php
25. IST, Displays and large area electronics, http://www.cordis.lu/ist/ka4/vision/irg_displays_and_large_area_electronics_2705.htm, last accessed on February (2005)
26. Jayakar Joel Henry (2004), Haptic Feedback Devices, IMfgE at Wichita State University

27. Kjeldskov, J. (2001). Interaction: Full and partial Immersive Virtual Reality Displays. Proceedings of IRIS24, Bergen, Norway.
28. Krueger, M. W. (1991). Artificial reality II. Reading, MA: Addison-Wesley
29. Kulik, A., Paneque, D. and Hochstrate, J. 2004 Vectorix: A Low-Tech Mechanical Tracking System. . In Beyond Wand and Glove Based Interaction IEEE VR 2004 Workshop p.43 http://www.vr2004.org
30. Laboratory for Intelligent Mechanical Systems, Northwestern University, http://haptic.mech.northwestern.edu/intro/gallery/
31. MacKenzie, I. S. (1995). Input devices and interaction techniques for advanced computing. In W. Barfield, & T. A. Furness III (Eds.), Virtual environments and advanced interface design, pp. 437-470. Oxford, UK: Oxford University Press.
32. Majumder Aditi, Stevens Rick (2005) Perceptual photometric seamlessness in projection-based tiled displays, ACM Transactions on Graphics (TOG) Volume 24 , Issue 1 (January 2005)
33. Manual of EL-MAR VISION2000, (2000) "Video Eye-Tracking System", Version 5.0
34. Martin, J-C., Buisine, S. & Abrilian, S. (2004) 2D Gestural and Multimaodal Behavior of Users Interacting with Embodied Agents Nice Project http://www.niceproject.com
35. Mulder, A. (1994) Human movement tracking technology. Hand Centered Studies of Human Movement Project Technical Report 94-1 Simon Fraser University, Canada
36. Musgrave Garry (2001) Very Large-Screen Video Displays, Conceptron Associates
37. Musgrave Garry (2001), Choosing a Video Projector, Conceptron Associates
38. NEC/Mitsubishi, (2005) Monitor Technology Guide, http://www.necmitsubishi.com/support/css/monitortechguide/index03.htm#resolution
39. Opticality Corporation (2005) http://www.opticalitycorporation.com/technology/index.html
40. Pabst Thomas (2000), 3D Benchmarking - Understanding Frame Rate Scores, http://www20.graphics.tomshardware.com/graphic/20000704/index.html
41. Parkhurst, D., and Niebiur, E. (2002). Variable resolution displays: a theoretical, practical and behavioral evaluation. Human Factors 44, 4, 611--29.
42. Qinetiq (2005) http://www.qinetiq.com/home
43. Sensable (2005) http://www.sensable.com/products/phantom_ghost/phantom.asp
44. SenseGraphics AB (2004), http://www.sensegraphics.se/
45. Sharp (2005) http://sharp-world.com/sc/library/lcd_e/s2_6_3e.htm
46. Soneira Raymond (2005) Display Technology Shoot-Out: Part IV, ExtremeTech Headlines
47. Thon Harald and Weinand Lars (2004) GeForce Go 6800 Reaches For Desktop Graphics Performance, http://www.tomshardware.com/mobile/20041108/index.html