SECTION I

THE TECHNOLOGY OF VIRTUAL REALITY

Virtual environment technology has been developing over a long period, and offering presence simulation to users as an interface metaphor to a synthesized world has become the research agenda for a growing community of researchers and industries.
Considerable achievements have been obtained in the last few years, and we can finally say that virtual reality is here, and here to stay.

Gobbetti and Scateni, 1998

Communications Through Virtual Technology:
Identity Community and Technology in the Internet Age
Edited by *G. Riva* and *F. Davide*, IOS Press: Amsterdam, 2001 - © 2001, 2002, 2003

1 Virtual Reality hardware and software: complex usable devices?

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Abstract. The technology which lies behind Virtual Reality is, in fact, quite straight-forward and easy to understand, the consequences of its usage and the potential this gives people rather less so.
This chapter describes the Virtual Reality hardware and software currently available and how these have purportedly been built to be usable by people. Future trends of this technology are also considered as well as the challenges which lie ahead for its developers in making user-friendly technology which aids rather than hinders communication.

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1.1 Introduction

Human beings are adept at making fantasies, of tuning out the real world and replacing it with another. It is a by-product of intelligence and imagination, and its simplest form is generated by the brain itself in dreams and daydreams. People even like to convey to others their own fantasies. A work of fiction is an attempt by an author to make a fantasy for an audience in which they can immerse themselves, the skill of the author in manipulating words determining how successful this is. Even a description of a scene can, through the individual in the audience's imagination, build up a fantastic vision, a virtual environment in their minds (though each individual's version would be different and coloured by their background, previous experiences, and so forth). Sometimes, a fantasy is intended to convey information. A myth, for example, is an attempt to explain what is perceived in terms of what is familiar, a fable to provide moralistic instruction.

How can a fantasy be conveyed? The simplest and oldest form is by speech. Nowadays, many other forms of media are also available, with most being based on light and sound since we humans primarily use vision and hearing to exchange information. These may include acting, pictures, text, music, sounds and speech, for example. The fantasy may be perceived directly, as with a live play or television, or stored for later perusal, as in a book or a videotape, and it may be planned or entirely spontaneous. Computers and the Internet allow this process to occur dynamically over the entire planet, and are blurring the author-audience distinctions. The communication can occur in both directions, with the audience making modifications to a fantasy created originally by a different person.

This is the form of fantasy which is described in this chapter, specifically, the form called Virtual Reality (VR); we shall be looking at the enabling technology. Virtual Reality is a rather prosaic fantasy creation method since it often leaves very little to the imagination and requires a computer to create a complete, complex Virtual Environment (VE) with many of the details of reality to ensure the person perceiving it cannot be mistaken as to the intention of the author.

There are many types of Virtual Reality system from games consoles for the home television to advanced visualisation centres affordable by only the largest companies and research institutes. Various authors have written books about VR in general [for example 1, 2, 3] whilst others have concentrated on the human perception aspects [4]. However, the rate at which the technology is advancing makes such documents snapshots of the moment they were written. Presented here is a depiction based on my own experiences and research [5], tempered by my practical way of thinking, with a consideration of whether such systems are in fact usable for fantasy creation as well as some ideas of what we shall be seeing in the future.

1.2 Usability

What are the factors that make something usable? Take, for example, the design of a new portable CD player. If it performs its function of playing a CD and I can listen to the sound through the earphones and carry it easily in my hand, is it usable? Very likely – it can, in principle, function as intended and I, one of the specified users, can use that functionality for the specified goal, so it can be deemed useful [6]. *Usefulness* depends on *utility* (i.e. functionality) and *usability* [6]. However, if the power consumption is such that the batteries only last for one CD, I would have to conclude that it is not *efficient* and thus not very usable. To the definition of usability, one must also add learnability, memorability, few errors and subjective satisfaction for completeness [6]. These are included in the terms of *effectiveness* and *satisfaction* in the 1998 ISO 9241 standard for usability [7]:

- usability is “The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use”;
- effectiveness is “Measures of the accuracy and completeness of goals achieved”; and
- efficiency is “Measures of the accuracy and completeness of goals accomplished relative to the resources (e.g. time, human effort) used to achieve the goals”.

How does one measure usability? One indicator of usability is whether a tool is actually used or not [8]. If I don’t like the feel of a pen, I’m not so likely to use it, thus it is not usable since I won’t purchase it. This definition can help in determining the usability of a product after it has been available for a time, but does little to help us design a specific tool unless we make a large number of prototypes, give them to the users and see which get used.

To try and predefine usability, some sort of checklist is needed for the designer. One such is called the REAL model of usability [9] and takes into account the:

- *Relevance* of the system – how well it serves the users’ needs;
- *Efficiency* of the users in carrying out their tasks using the system;
- *Attitude* of the users to the system; and
- *Learnability* – how easy is it for a novice to learn? And how well do the users remember the skills over time?

Using these, it is possible to design a tool to be usable. We must see that:

- the functionality of the tool matches the task to be performed and what the users want to do;
- it is possible for the intended users to use the tool efficiently for the intended task;
- the tool can be learnt to be used, either quickly if casual users are the intended user group, or memorably for more long-term users; and
- it is desirable for the users to use the tool.

So, a designer must define the task and the intended user group, figure out what functions are needed and then fathom how to make the tool for the intended user group using the functions to perform the task, not forgetting learnability, desirability and cost. Unfortunately, even with such a checklist, it is still very easy for a designer to make a tool which is quite unusable [9, 10, 11]. This is partly because design is not a sequential process – design decisions affect which people can use a tool, thus requiring the original design to be rethought, and partly because designers are not the potential users and driven by other forces such as a love of technology.

Nevertheless, there is hope. There comes a time when the design of a product is no longer driven by technological advances, but instead drawn forward by the users who have expectations of usability and take for granted the basic performance [12]. Products that are unusable fall by the wayside.

In the Virtual Reality field, this time may come sooner than expected since its very nature – of trying to emulate reality – means the users have an expectation that the technology should be as easy to use as everyday objects in the real world. If this is not so, they may become disillusioned and the technology, no matter how potentially useful it may be, will be spurned.

1.3 Parts of a VR system

There are six essential parts to the VR system; the person, the computer, the virtual environment, input devices, output devices and a network (fig. 1.1).

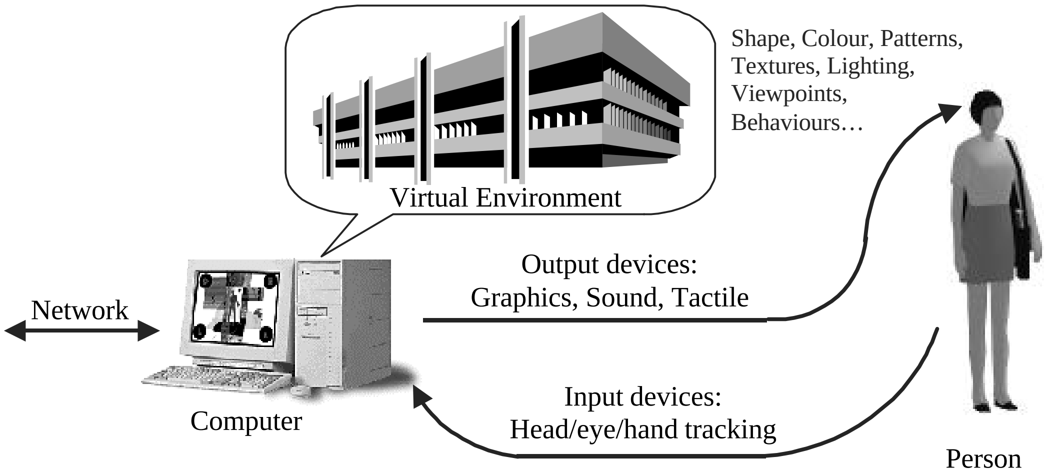


Figure 1.1 The six parts of a Virtual Reality system

Of these, the *person* is the most important, for without this, there is little point. The *Virtual Environment* is a three dimensional model (or world, as it is often called) within the computer containing details such as shape, colour, position, texture, lighting and other physical attributes of the objects with which the person is to interact. The computer needs this information in order to render those objects to the user as realistically as possible. One particularly important characteristic is how the object is to behave. Does it fall when dropped? Does it turn on when a button is pushed? This real-time, dynamic, interactive ability is one of the main distinctions between VR and just three-dimensional pictures on a computer screen. The sensory experience of this environment (often called a viewpoint) is provided by the computer through the *output devices* which are designed to match the person's mode of perception.

The person can control the position of the viewpoint and interact with the VE through the *input devices*, which are similarly designed to come close to the person's natural mode of communication. The *network* provides a means of communication with other people sharing the same VE through their own computers, often through the Internet.

However, why bother creating a virtual experience? One reason is that creating a VE gives the author absolute and total control over what the audience will perceive. Even laws of physics can be altered. It provides a cleaner and safer alternative to reality, and it is often cheaper to produce a computerised model than a real one.

Sometimes, the purpose is to try to convince the person that they are actually present within a VE so that they can experience, say, a piece of architecture before it is actually built. Then again, the purpose may be to provide a background for communication or game playing. Often, the goal is to train the person in some safety procedure or the usage of a piece of equipment, or perhaps to facilitate the comparison of several designs. Whatever the purpose, it naturally affects the degree of realism required, how much the person must be immersed within the VE, and thus what technology should be used.

To provide the most complete experience, all the senses of the person need to be affected and a high degree of *presence* must be achieved [13, 14]. A flight simulator, for example, gives feelings of full-body motion by lifting the person on pneumatic legs and tipping or dropping at the appropriate times to simulate inertia and acceleration. The pilot is totally enclosed as in an airplane cockpit, the view out of the windows is as they would expect in reality, they can hear the engines and other sounds, and all the instruments and controls look, act and feel as they would in reality. The main difference is the consequence of mistakes made during a training session – no lives are lost or equipment damaged.

However, it is not always necessary to provide a totally perfect rendition – often a simpler version is sufficient to convince the person (see Chapters 2 and 3 for in depth discussion about this issue), and an adequate experience or degree of presence can be produced within a lower budget. This also depends on what the goal is. Does the author wish to provide a total sensory experience – convince the person they are within the VE, or is the purpose to sell a game to owners of standard home computers?

To summarise, the purpose of VR technology is to convey a Virtual Environment to a person with some degree of realism and impart a feeling of presence, and that therefore designers of Virtual Technology must be aware of how people perceive and think in order to trick them into believing they are actually within the VE and design devices that are usable by the intended audience.

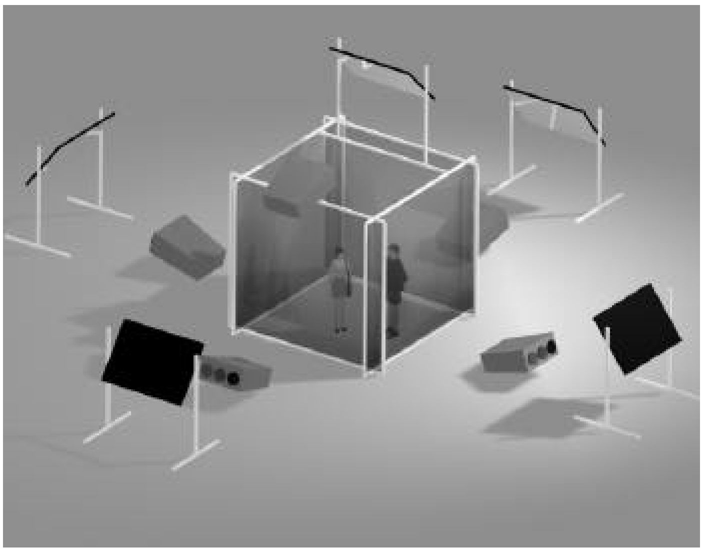
1.4 Output devices

The output devices are the part of the hardware which allows the computer to communicate to the person. Since VR can nowadays be found in the home as well as advanced research institutes, the form of output devices can vary wildly.

1.4.1 Visual devices

1.4.1.1 Immersion

A VR system is usually classified as *immersive* or *non-immersive* (or *desktop*).



(a) An immersive projector based system

(b) A Head Mounted Display

(c) A single-projector screen

Figure 1.2 Examples of immersive Virtual Reality display hardware

Figs.1.2 (a) and (b) show two examples of immersive VR displays. Fig.1.2 (a) is perhaps the most advanced type of system that can be purchased and consists of a number of opaque screens on which are projected images from the VE in stereo. Mirrors are usually required so that the distance between the screens and projectors need not be too great. The most complex of these has six projectors, though most common are four projector systems (three walls and the floor). The user(s) stand inside the central area and are thus totally surrounded by the VE. The feeling is that the VE is all around, it completely covers the field-of-view, and the objects appear with the users in the space between the screens. One can walk around, peer under and in objects, and if programmed, even interact with them. Of course, it is also possible to walk through the objects as they have no substance. The central square is usually about three by three metres, thus several people can take part at once, though there are problems with perspective as described below.

Another method of covering the field-of-view is to project on a large surface in front of the users. The simplest of these involves a projector and flat screen, thus achieving a larger viewing area than an ordinary computer screen, however, the viewers must sit quite close for the field-of-view to be filled and not turn their heads. To allow a more comfortable viewing distance, the screen can be curved; just slightly to make a dish or arc, or all around to make a dome (fig.1.3). The sizes can vary from a one-person device to being suitable for twenty people or more. Generally, the larger the device and the more surfaces which have images on them, the more projectors are required.

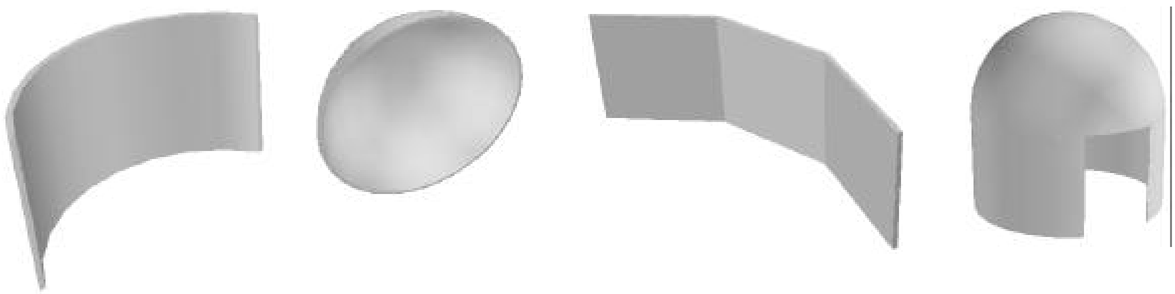


Figure 1.3 Shaped Projection Screens for VR

To further complicate issues, the projectors can either be placed in front of the screens, or behind, giving rise to the terms; *front projection* and *back projection*, respectively. Fig.1.2 (a) and (c) require back projection, whilst a large curved screen may be constructed as a front projection system. The chief problem with front projection is that if the user goes close to the screen, they cast an obscuring shadow.

A single person can wear a *Head Mounted Display* (HMD) (fig. 1.2 (b)) and thus also be immersed in the VE. In the front part of the HMD are two tiny screens, one for each eye which display images at a suitable size for the VE to appear to be on a one to one scale. Lenses are required to allow the eye to focus correctly and the view is often displayed in stereo or partial stereo. One problem, however, is the limited field of view – HMDs typically do not cover much of the peripheral vision resulting in a feeling like looking through a cardboard box with no bottom.

Non-immersive VR is typified by a standard desktop computer or television monitor showing a view into the VE on a standard computer screen. In this case, unless an object in the VE would actually fit into the computer screen, the scale is not one to one. A variant of this is for the user to stand in front of a large screen (about two meters across) which is projected on from underneath (fig. 1.2 (c)). The view can be either shown in stereo or mono. This latter variant can be classified as either immersive or non-immersive, depending on the size of the VE in relation to the user and whether stereo is used.

Whether immersive or non-immersive VR should be used depends on the effect one wishes to achieve. For some applications it is vital that an environment is seen at the correct scale so that space can be perceived accurately, such as when viewing a planned building [15], or in flying an aeroplane in a flight simulator. However, desktop VR is often adequate, for example, for training procedures using VR or where it is sufficient for the user to think themselves into the VE even though they sit outside it.

1.4.1.2 Creating stereo vision

In perceiving depth in the real world, we use both monocular and binocular cues [16]. Many of the monocular cues such as linear perspective, aerial perspective (haziness of far-off objects), interposition (nearer objects obscure farther ones), shading, texture, familiarity with object's size and motion parallax are used by the software to portray a feeling of depth in a VE view. However, it is also possible to make use of the binocular cues of convergence of the eyes, and stereopsis (disparity between the images on each retina) to further enhance the stereo effect.

In other words, the computer can use exactly the same trick as for producing stereo-pair photos for a stereoscope. For each view into the VE, the computer calculates two pictures, one for the left eye, and one for the right (fig.1.4) for the current viewpoint. These are then relayed to the appropriate eye. The advantages, though, of computerised stereo images over photos is that the inter-ocular distance (the distance between the eyes) can be adjusted dynamically to best suit the current user, and that the picture is not static – the user can move around and look behind objects, for example.

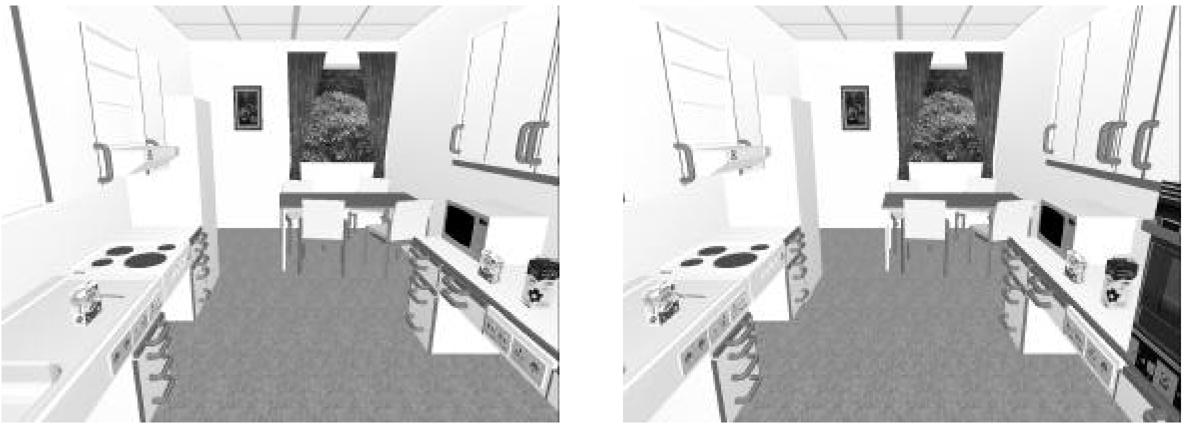


Figure 1.4: Virtual Reality stereo pairs to produce a feeling of depth

Special hardware is required to get the left image to the left eye and the right image to the right eye. The most common of these, called *active stereo*, is based on glasses with liquid crystal shutter lenses. The lenses are electronically controlled to close off one eye or the other at the same time as the screen shows alternatively the left or right image. This occurs 120 times per second so that little flickering is noticed. The effect is that the user perceives depth in the screen. A synchronisation signal is sent from the computer to the glasses by infrared so that no wires are required.

Liquid Crystal Shutter glasses are, however, rather expensive, though cheaper varieties are starting to be included with advanced PC 3D games-accelerator cards. Thus, another method for producing stereo has been developed which uses polarised light from one or two projectors and cheap polarised plastic glasses. Each projector is polarised differently and the images are projected on top of each other on the same screen. This is termed *pas-*

sive stereo since the glasses contain no electronics. The left and right lenses have different polarisations to shut out the one image and let through the other, so again, the correct image reaches the correct eye. For larger audiences, passive stereo is more economical than active, though sets a higher requirement on the quality of the projection screens.

Alternatively, for a single user, there are cheaper alternatives using lenses fitted over the screen in a plastic hood and a stereo pair image to give a feeling of depth, however this is not so portable as the crystal shutter glasses. Similarly, a HMD makes use of stereo pairs to produce a feeling of depth by sending the correct image to the correct screen.

The liquid crystal shutter glass technology is both used for producing stereo on standard monitors as well as projector screens. Immersive active stereo projector based systems as in fig. 1.2 (a) have stereo images in each wall of the inner cube, as well as the projection on the floor. The effect is that it feels like the VE is all around, much like a large, interactive hologram. Similarly, shutter glasses are required for the single-projector screen (fig. 1.2 (c)).

1.4.1.3 Calculating perspective

In order to provide the most realistic stereo feeling, the computer also needs to know the user's head orientation. With this information, it can calculate perspective changes as the head moves, thus making it possible to peer behind, under or in objects. For immersive projector based systems, this is essential as the viewer can move around within the inner square. However, this immediately poses a problem: if there is more than one viewer, the computer must also calculate the correct perspective for each of the extra viewers. This in turn means that each viewer requires different pictures, so for two viewers, four pictures must be continuously swapped. Each person thus sees the screens for only half the time, resulting in a correspondingly darker image. Furthermore, current projectors can manage at best about 150 image changes per second, thus for two people, each eye's image is updated only about 30 times per second, resulting in a noticeable flicker.

In the majority of systems, however, the computer only worries about where one person is – this person is the leader, and any other viewers have to try to keep their heads as close to the leader's as possible to obtain the correct perspective view.

When the computer doesn't worry about tracking the head movements, it calculates perspective for a 'sweetspot' at a comfortable sitting distance from the screen – the most correct view is obtained there. This is used for desktop monitor systems as well as large curved screens for larger audiences.

There are some situations where stereo imagery is beneficial. For example when working with objects up close, a stereo view coupled with hand tracking allows the user to grasp and manipulate objects. For situations were the main view is into the distance, the stereo effect is almost unnoticeable and can be dispensed with. Similarly, stereo is usually unnecessary for simple desktop systems as the view is not immersive, nor does the user have the ability to grasp and manipulate objects with the hands.

1.4.2 Audio devices

The effect of sound in the total experience of a VE is often relegated to an afterthought, yet it undoubtedly strengthens the feeling of reality (just think how dull a movie or TV program is without sound effects and music). This is probably due to two factors, first, for people with normal vision, over 60% of the information that comes in is visual [16], so designers tend to concentrate on that; and secondly, availability of programmable hardware to produce believable three dimensional sound effects have lagged behind the visual device development.

The most promising work in this area comes from the rehabilitation field, particularly in using VR for blind children to teach them orientation and mobility skills [17] and for exploring interactive VEs [18, 19]. Similarly, it has also been found that sound effects are important in improving the believability of VEs used for phobia therapy [20] (for sighted people).

However, sound cards for PCs that support surround sound and positioning of sound sources in a 3D virtual space are becoming increasingly available. This is due to 3D games that try to be as realistic as possible. Maybe we will soon see VEs where you can hear the echo of your footsteps as you enter a room and from that obtain a feeling for size and openness as a complement to the visual impression.

1.4.3 Haptic devices

Not only vision and sound are supported. Nowadays, it is quite common to be able to at least partially feel a VE. The most common devices use force feedback, pushing against the user's hand (or other part of the body) when a virtual object is encountered. Force feedback joysticks can be coupled to games, for example, to give an extra dimension to the experience. These devices use small motors to simulate the forces that your body feels when pushing against objects. Your body uses its proprioceptive sense to interpret these forces into object shapes. The proprioceptive sense is the way the body knows its location through positional information relayed to the brain from the joints, tendons and muscles. Devices for VR are more sophisticated than joysticks and work much like a robot in reverse but still do not really allow a full hands-on haptic sensation of the VE. Such devices are though common in medicine where VR is being used for training surgical skills [21].

The other form of touch, tactile sensation, which occurs at the skin, can be simulated with gloves that provide finger-top sensation using, for example, vibrotactile stimulators. This would improve the feedback to the wearer when an object is being grasped, but doesn't provide the proprioceptive information from the fingers. A combination of the two would seem to be the best.

Another form of haptic device is evident in what is called *mixed reality*. This is where VR and real-world objects are used together. So for example, moving a block on a table might move an object in a VE which is displayed on a wall screen (strictly speaking, this is not a haptic output device, but since the visual image corresponds to the position of the object, is perceived as such). Similarly, a flight simulator mixes VR (the view out of the windows) with real-world objects (the flight controls and instruments). This mixing of reality and VR provides the most realistic haptic sensations as the entire hand can be used and both proprioceptive and tactile sensations are supported. However, such a VE may be more difficult to quickly alter since new physical objects must also be constructed.

1.4.4 Other devices

Two other senses can be stimulated by VR output devices; the olfactory sense and the sense of full-body motion. The former is not yet common amongst standard VR devices, whilst the latter has been successfully used in flight simulators and arcade games, though is not common in industrial VR installations.

1.4.5 Future trends

What can we expect in future output devices? The ultimate VR device must be the holodeck portrayed in the Startrek™ TV series and movies. This allows the users to see, hear and feel (and probably taste and smell as well) objects as if they were real. It is difficult to imagine how such technology might actually work, so we shall consider the more immediate future of output devices which will soon be moving from the research laboratory to the salesroom.

We can expect visual devices that produce better quality images (higher resolution, higher update rate etc.) which cover a larger part of the field-of-view. Screens and projectors may eventually be replaced by the newly emerging bendable flat-screen technology and it should soon be no longer necessary to wear special glasses when looking at a screen in order to perceive stereo images (each pixel can be directed at one or other eye). HMDs will soon be no bigger than a pair of sunglasses and also cover the entire field-of-view. One advancement I would like to see is the development of a holographic display device which would allow viewers to sit at any position around the display and see the VE with the correct perspective. This would significantly improve, for example, collaborative design using VR.

Audio devices in themselves may not change much, however, they will become more integrated into VR systems as the designers appreciate the importance of sound to the total experience. Audio can even be used to counteract a lack of visual realism.

Tactile interfaces are also becoming more common as designers realise that people like to manipulate objects they can feel – moving an object in a VE without any tactile feedback can be quite tricky. In some areas, haptic display devices have been successfully employed, such as for training surgeons. However, for more general usage, future devices will need to allow full-hand grasping and manipulation of virtual objects and full-arm movement of the objects around the virtual space.

1.5 Input devices

The input devices allow a person to express their wishes to the computer – to move around in the VE and to interact with virtual objects.

1.5.1 Tracking body movements

To calculate perspective, the computer needs to know the person's head position, and for object interaction, the computer must know the position of the hands. For this, some form of tracking system is required. The most common of these has a sender that spreads out a magnetic field which individual sensors placed on the observer's body pick up and convert to position and rotation information. Thus the computer can know not only where the head or hand is, but in which direction it is pointing. This magnetic field, however, is disturbed by metal beams and other fixtures, so other varieties have also been designed based on ultrasonic sensors or optical markers and cameras. These instead suffer from problems of occlusion.

Tracking is most commonly used with immersive, stereo, projector based systems and HMDs and rarely with non-immersive desktop systems.

1.5.2 Moving around in a VE

Apart from head movements and movement within the limits of the tracking system, the user may in fact wish to move further in the VE. The most natural means to do this is to walk, the problem, though, is to walk as if going somewhere without actually moving in the real world.

On the other hand, a VE that simulates the driving of a car, or the flying of an aeroplane can use input devices that are similar to those found in a car or aeroplane to control the virtual vehicle whilst the user sits.

In this section, we shall present the current range of commonly available input devices.

1.5.2.1 Immersive VR navigation devices

Movement trackers can be attached to a person’s legs, and they can walk in place to simulate movement. Devices that allow natural walking in place based on tracks, rubber belts and bearings are also being designed and evaluated. However, such methods are seldom supported by standard VR systems.

Most commonly, moving around an immersive VE requires the user to make a gesture with a hand, or to close a switch by pressing together metal pads in the fingertips of a data-glove. This is hardly a natural form of movement and requires considerable training to be used effectively. Most often, an expert is required to show a novice around a VE.

1.5.2.2 Desktop VR navigation devices

Navigation devices for desktop VR are, in many ways, more developed and can provide more exact movement in a VE than immersive VR navigation devices. Spacemice, spaceballs and cyberpucks (fig. 1.5) are the names given to some of the six degrees of freedom desktop input devices, whilst joysticks have two or three degrees of freedom. A degree of freedom is a direction in which an object can move or rotate. So, when I sit on an office chair with wheels, I could say that I have three degrees of freedom – I can go back or forwards, I can go left or right and I can spin around. If my chair had a motor that allowed it to be raised and lowered as well, that would be another degree of freedom.

In VR (as in reality), there are three degrees of freedom for translation (moving from one place to another) and three for rotation. These are usually called movement in the X, Y and Z directions and roll, pitch and yaw, respectively.

(a) A Spacemouse *(b) A Spaceball* *(c) A Cyberpuck* *(d) A Joystick*

Figure 1.5 Desktop input devices for Virtual Reality

A six degree of freedom input device, therefore allows the user to move and rotate the viewpoint in all of these directions. These sit on a flat surface, usually a desk, and allow an experienced user to peer into any part of the VE they wish, and a novice to get completely lost – some training is required. The devices are used by holding the movable bit (the ball or disk) and lifting, pushing, pulling or rotating it in the direction one wishes to move or rotate. A joystick doesn't allow the same freedom of movement as the others, but is quite adequate for walking or driving around a VE. Versions of this have been available for game-playing since games started being programmed on computers.

1.5.3 Interacting with objects

Interacting with objects is more difficult for the novice user, though perhaps surprisingly, easier in desktop VR than immersive VR due to the easy-to-use pointing device; the mouse. Three-dimensional, non-stereo computer games often use the mouse, or limit object interaction to picking up and putting down objects (which can be controlled by switches on the input device). Immersive VR requires the person to use hand gestures for interaction with objects. A dataglove is needed for this which can either use fibreoptic wires in the fingers to determine finger flexion or fingertip switch pads – putting two fingertips together when the hand is within an object can attach it to the hand allowing it to be moved and then released when the grasp is relaxed.

This leads naturally towards the idea of tactile interfaces. A force-feedback tactile device is also an input device allowing a user to push and lift objects within the VE. Similarly, as previously mentioned, there is an interest in allowing users to manipulate real world objects to control a VE. Systems have been designed that allow recognition of hand gestures for controlling a computer [23, 24] and a VR system has been constructed where the movement of objects in the VE is achieved by physically moving representative objects on a table [25].

1.5.4 Future trends

One of the most challenging areas of VR research is to make input devices more usable [19, 25]. In many ways, it is these that currently limit the users most and cause the greatest disillusionment with the technology. However, work is beginning to be performed to ascertain which devices are in fact best [5].

Technological advances will mean that we shall soon see input devices that work on computer vision recognition so that hand and head movements can be determined without putting on gloves or sensors. It should also soon be possible to both speak and use meaningful gestures to the computer, so for example, an object can be created in an immersive VE by pointing with the hand and saying “create an X there”.

1.6 The Computer

The computer has quite a difficult task. It must take the inputs from the user, interpret these into movements and interactions within the VE, update the objects in the VE (for example, move objects that are currently falling one further step downwards) and calculate the views, audio signals, tactile feedback etc. to send back to the user. This program loop takes a certain amount of time to perform. At the same time, it must keep track of changes to the VE coming down the network from the other inhabitants and possibly provide an audio and visual communication channel. The time between making a movement and seeing a change in the VE is termed the *lag*; if this becomes too great, say a tenth of a second, the system becomes unusable.

Nowadays, it is possible to buy a standard-cost personal computer with a good graphics card (the electronics which produces the signals for the computer screen) and audio card, and be able to run a single-screen stereo display with tracking and a dataglove or other input devices. Games consoles can be bought for the television which allow single screen mono VR and stereo audio, though with a limited input device. A computer with the same capabilities would have cost ten times as much two years ago. This progression has been driven by the games industry and the market for cheap graphics-capable, ordinary computers for three-dimensional games. While great news for VR researchers, paradoxically this gives the temptation to use a more advanced system than perhaps is necessary simply because it is available.

For VR systems with two or more projectors, however, a standard PC is not presently powerful enough. For example, a five projector immersive system, the computer must calculate and produce ten pictures (two for each screen) at a rate of sixty per second. For each screen, it must first check what the observer is looking at (where the head is), calculate the perspective as seen from that point and generate two two-dimensional pictures. To draw each of those pictures and to make use of monocular cues, the computer must go through the entire model each time and work out which objects lie behind others. A computer that can manage this currently costs about a hundred times as much as a standard personal computer.

Similarly, it is not uncommon to split the tasks between several computers. One computer may manage the visual devices, another the audio and another the tactile, with one further computer co-ordinating these and communicating with the other co-ordinating computers on the network. The main difficulty here is to ensure that all remain synchronised.

1.6.1 Virtual Reality software

As mentioned above, the computer must run in a perpetual fast loop to serve the VE to the users. However, even before the VE reaches that stage, it must be constructed; as yet, very few VEs allow construction directly by the user. The majority of model construction packages are quite definitely intended for experts and require considerable training and expertise to master. Computer Aided Design (CAD) packages are used to create the basic models, and the VR development packages to add sounds, textures, object behaviours etc. One problem that frequently arises is incompatibilities in data formats between programmes for representing the virtual objects.

VE authors also use tricks in the construction of the environments to both compensate for limitations in the VR technology and to increase the sense of presence. There is a direct positive relationship between the complexity of a VE (how many objects, how convoluted those objects are and how many patterns are placed on those objects) and the time it takes for the computer to render them to the user. With a HMD, if the framerate is low, a lag develops between moving the head and the view catching up. This can cause nausea in much the same way as a rocking boat does through the dislocation of the visual and balance signals. Most of the tricks build on the idea that there is no point bothering about parts of the VE that the user is not currently looking at (or touching or listening to) and that the place for the most accurate rendition is exactly where the user is currently concentrating their attention. In a VE, if there is nobody to hear a tree falling, it makes no sound as the computer won't waste its time on it. Here are a few other tricks [5]:

- Objects outside the field of vision do not need to be drawn, neither do objects outside the field of audible perception need to make a sound.

- As the user moves away from an object and it gets smaller in the field of view, it can be replaced by a gradually simpler one to speed up the processing.
- If the user goes into a virtual room, and closes the door so that the corridor is not visible, then the computer can turn off the corridor until the user goes into it again.
- Complex objects such as trees with thousands of leaves and twigs can often be satisfactorily modelled as a flat object with a digital picture on it. If the user wants to look at individual leaves, the simpler object can be replaced by a more complex one when the user is sufficiently close to be able to tell the difference.
- Patterns (such as a wood look) on objects can often be replaced by simple colours without seriously affecting the visual impression.
- No VR system renders shadows or realistic lighting effects, it is too time consuming. If these are essential, they can be calculated beforehand and put on the objects as a static pattern. Simple shadows can be made by putting flat black blocks under objects.
- Virtual objects don’t need to have all the complexities (screws, bolts, perfectly rounded forms etc) that the real ones do. Often a much simpler object is sufficient. For example, a door need not have hinges to hold it in place in a VE.
- Sound can often compensate for missing visual effects. For example, in pouring water from one container to another, a running water sound can cover the fact that the water level simply drops in the one container and raises in the other without any apparent flow between.

1.6.2 Future trends

Decreasing costs and increasing performance of computer technology have yet to show signs of levelling off. Thus we can soon expect a hand-held computer to be capable of complex VR applications, allowing, for example, a person with a learning disability to have with them a three-dimensional and intuitive help system for performing daily tasks.

VE development packages are also becoming more readily available. One problem with many VR packages is the high cost, not only of the development tool, but of the player software that each user must have. However, many VR computer games now come with a level builder and modelling package which allow complex VEs to be constructed, though still requiring some computer expertise. Such games cost a mere fraction of advanced VR software, though rarely support advanced input or output devices. This software availability will bring VE construction into the public domain and reduce its exclusivity, in the process bringing down the cost of commercial VR development packages in order to remain competitive.

1.7 Networking VR – connecting people

In the pioneering days of VR, wandering around a VE was a lonely pastime with the chief purpose of the system to give a virtual experience to a single person. However, the Internet has changed this and spawned a new form of Virtual Reality where communication with others is the primary goal and the virtual experience of secondary importance. Even VR games usually allow one to connect to a central server and combat others from around the world – a form of communication.

In the most developed packages, a person with a standard personal computer can enter a virtual world on the Internet and then take part in activities with others in much the same way as one does in reality. People can agree to meet at a certain place and time, there may be somebody giving a lecture or a movie may be being broadcast in a particular room. In some, it is even possible to build your own space to which you can invite others.

Standard VR packages have also been affected with the majority now allowing networking capabilities. This gives great potential for many forms of distance communication: home designers can show potential purchasers around a new house; ergonomics experts can show workers how they might modify their work patterns to improve working conditions; game designers can show players ideas for new levels; players can exchange tips for solving game puzzles with other players; lecturers can teach students from the comfort of their homes; the list is virtually endless. One feature that is often lacking with standard VR packages, though, is a facility for voice or text communication, however, this omission will undoubtedly be rectified in due course.

Virtual communities can form over the Internet, with, say, individuals who are physically unable to take part in activities in the real world being an active member of the virtual community.

This tendency is likely to grow with the popularity and availability of the Internet and interacting with others in a VE so commonplace that the virtual community will become just another aspect of ordinary life.

1.8 Conclusions

We have briefly surveyed the currently available VR technology and considered future trends whilst also saying a few words about usability. A full usability analysis of particular applications (hardware, software and VE) is beyond the scope of this chapter, but when next you interact with a VE, critically ask yourself the following questions:

- How *relevant* is the VE to the user's needs?
- How *efficiently* does the system help the user to carry out the tasks intended?
- What is the *attitude* of the users to the system?
- How easy is it to *learn* to use the system?

The technology described in this chapter is that which has more-or-less successfully managed to move from the research and development laboratories to the commercial arena, thus it can be considered usable in an evolutionary sense. However, high performance VR is still an exclusive occupation with a large installation requiring many millions of any currency and only the most forward-thinking and rich companies venturing into these uncertain waters [26]. Furthermore, in my experience, developers still have a long way to go before VR can truly be considered usable by ordinary people.

The public is exposed to considerable hype about VR through movies, books, newspapers etc. This means that when first-time visitors come to a VR installation, it is not uncommon to begin with a small lecture pointing out the limitations of the system and describing its complexity to ensure the people are duly impressed and not disappointed by the washed-out look, intangibility of objects and poor user interface compared to their expectations.

There is also a growing reluctance on the part of VR solutions companies to just sell hardware and software. Fingers have been burnt by purchasers who have bought expensive equipment and then been disappointed. Now, it is not uncommon to begin with an analysis of the customer's needs and expectations and to then tailor a specific VR solution. This is good, but of course only relevant to those purchasing moderate to large installations.

I would say that the VR community is close to overcoming its initial technological euphoria where one can accept complex products and a low level of usability because it is new and exciting. The new wave of users will be ordinary people and the technology will have to cater to them, but must increasingly do this better. Books are being published that cater to the ordinary person [27]. These users will expect virtual reality to be as easy to use as 'real' reality and not suffer complexities easily; otherwise, the technology will not be bought. The computer games industry and the Internet are two driving forces. The pressure of VR-based games has resulted in graphics and sound capable computers that two years ago only existed in the best research laboratories and the Internet has given the potential for new forms of communication not even conceivable a few scant years ago. The time is upon us when any home PC is capable of VR. We must, now, as designers, seriously consider the usability of VR devices, and use our knowledge of how people function to improve them to be beneficial and not harmful. There is a risk that otherwise, devices will become popular that are not necessarily the best for the task or the user. Are, for example, the typical games console controllers the best means for controlling and interacting with a VE?

In the early days of computing, computers were large, programmers wore white lab coats, and the computer operator was considered a vital part of the functioning mechanism. So it appears for many Virtual Reality (VR) systems today. The computers are large, soft shoes are required to protect the surface of the floor-screens, and the operator is still lurking in the background, or more often than not, the foreground. Indeed, the complexity of these systems, which have been designed to work closely with the natural modes of interaction for people, means that a very well-trained expert in 3D CAD modelling must work hand in hand with the equipment operator in order to allow ordinary people to be able to work experience a VE.

Nowadays, personal computers can fit in your pocket, and the computer operator is the ordinary person. We will see the same trend for VR technology and we must be ready.

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