Chapter 1

Introduction

The relentless increase both in CPU power and storage capacity, has made practical applications which generate vast amounts of information. The problems that application developers now face are: how to display that information in a manner which is meaningful to the user; and how to allow the user to control the simulations effectively. *Virtual Reality* may well be the solution.

1.1 What is 'Virtual Reality'?

Virtual Reality (VR) is a class of user interface which attempts to present large amounts of information in a natural manner, allowing the user to manipulate it using a more intuitive interaction method than the traditional graphical user interface. It does this by capitalizing on natural human attributes, such as the ability to manipulate objects in space.

It is important to distinguish Virtual Reality systems from simple three dimensional computer aided design packages. In a Virtual Reality system the subject becomes an active part of a simulated environment, being able to interact with objects and modify the model of the world. This definition requires the user to have influence over his environment which excludes simple systems designed only to view a three dimensional scene. Natural forms of interaction are used to make the system easier to use - instead of selecting an object with a mouse, the user can reach out a hand and pick the object up or turn it around to look at it from a different angle.

The aim of this simulation is to induce a sense of *presence* - where the user feels part of the simulated world. When this happens it is hoped that he will start thinking more in terms of interacting with the objects in the simulated world and less in terms of interacting with a computer and thus be able to complete tasks faster and more efficiently.

Immersive Virtual Reality systems typically produce the greatest feeling of presence. In such a system the user is surrounded by the display of the virtual world. This immersion is typically achieved by the use of a *Head Mounted Display* (HMD) (such as the early one proposed by Sutherland in 1968 **[Suth68]**) or by the use of large projection displays (such as the CAVE **[CNSD93]**). Non-immersive display techniques (such as LCD shutter glasses in conjunction with a conventional monitor - see **Chapter 2**) do not surround the user with the simulated environment, consequently the sense of presence is reduced. This is similar to the difference between watching a film on a television and a large cinema screen.

In a system based around a head mounted display, the position and orientation of the user's head is monitored and fed back to the rendering system so that it can produce an image which corresponds to the direction in which the user is looking. An example of an application of this type of system may be in designing a three dimensional object. The user sees the object in three dimensions and can walk around the object. He can reach out with his hand (which he can see a representation of), grab the simulated object and turn or move it. In a good VR system this type of interaction is a lot more natural than moving an object on a screen with a mouse. Some systems allow tactile feedback which allows the user to feel when he has touched the object.

Many of the initial ideas of Virtual Reality were set forward in 'The Ultimate Display' **[Suth65]** which is the first reference to the possibility of using computer generated virtual worlds. In this paper Sutherland initiates the idea of a computer generated world in which the user can see, and potentially hear, touch and manipulate objects.

The term *Virtual Environments* is often used to emphasise the fact that VR systems do not necessarily attempt to simulate reality. This thesis covers Virtual Reality, virtual environments, augmented reality and all similar systems. Throughout the rest of this thesis the term Virtual Reality (or just VR) will be used to indicate that a section is relevant to all Virtual Reality based problems.

1.2 Uses of Virtual Reality

As a first step in understanding the needs of Virtual Reality rendering systems, this section provides an overview of the applications that are being proposed for Virtual Reality. Details of the way in which some of these applications use the rendering hardware is discussed in more detail in **Chapter 5** .

1.2.1 Telepresence

> *"Telepresence:*
>
> *A term to cover the situation where the remote operator receives sufficient information about the environment and the teleoperator such that the remote operator feels physically immersed in the environment of the teleoperator."* **[Kala93]**.

The concept of telepresence has been present in science fiction since at least the end of the 19th century **[Bell97]**. The first practical system called 'Headsight' (described briefly in **[Kala93]**) was developed by Philco Corporation in 1958. This system consisted of a monocular head mounted display coupled to a remote camera whose orientation was matched to the orientation of the user's head.

The aim of 'Headsight' and more recent telepresence systems (such as those being developed by NASA, also described in **[Kala93]**) is to allow exploration of environments hazardous to human operators from a safe position, usually allowing the operation of a robotic device remotely.

Most of these systems rely on images of the physical world gathered in real time using television cameras. In some of these hazardous situations it is not possible to gather high quality images in real time due to environmental conditions or - in the case of space exploration applications - due to a large communication delay between the operator and the robotic device. In these situations it may be useful to provide computer generated representations of the remote view using other sources of information such as range finding equipment, infrared cameras or pre-calculated models of the environment.

1.2.2 Training

During training in any subject area it is expected that the trainee will make mistakes. Unfortunately in some fields making a mistake can be highly dangerous and/or highly expensive. It is in these areas that Virtual Reality is most useful.

- Driving and Flight simulation

  Driving and flight simulation are one of the commonest (and oldest) uses of Virtual Reality. Early systems used simple filmed sequences which seriously limited the range of manoeuvres and situations. The use of computer generated images allows an unlimited range of manoeuvres, control over environmental conditions and a wide range of situations in which to test the user. The requirements for flight simulation equipment, are given in **[CAA89]**, which also describes the types of training which may be carried out completely within a simulator.

  Driving and flight simulation often take place in full scale models of (sections of) the simulated vehicle. The windows of the vehicle are then often replaced with screens onto which the images are projected. Usually these models are mounted on motion platforms which produce a feeling of motion similar to that felt in the real vehicle.

- Battle simulation

  Training military tank and air personnel for battle has been possible for a number of years using the American SIMNET system **[Prat93]**. While the control of the vehicles is similar to driving and flight simulation, battle simulation requires training in participation between a number of people; this is accomplished by networking a number of systems. The system also adds simulated vehicles to recreate a full scale battle.

- Medical Training

  Medical students usually train for surgery using cadavers, which are difficult to obtain. The shortage of cadavers, means that the number of situations which can be experienced by the trainee is limited and that the trainee can not repeat a procedure to perfect it. It is hoped that when the technology reaches a suitable level of refinement, immersive Virtual Reality will provide a partial replacement for the cadaver, providing increased flexibility.

1.2.3 Design

When building a model of an object a designer takes advantage of his inbuilt capability to manipulate and explore objects in three dimensions. The use of Virtual Reality systems in design can help reinstate those abilities that are unavailable to designers using paper or two dimensional graphical displays.

- Architectural Walk-through

  One of the applications of Virtual Reality which has attracted most press coverage is architectural walk-through. The participant is able to walk around a building which may no longer exist, or has not been built. This type of system allows an architect to show clients a building which has yet to be built or an archeologist to examine a model of a building which no longer exists. In some senses it may be argued that a simple architectural walk-through system only just qualifies as being Virtual Reality since their is very little user interaction. A system which allowed the user to design the building, walk around it and attempt some of the intended uses for the building in the virtual world would be closer to using the full potential of Virtual Reality.

- CADCentre

  CADCentre is a company which specialises in producing software for designing chemical plants, oil rigs and similar installations. The Advanced Interfaces Group at the University of Manchester Department of Computer Science (in which this research was carried out) is working with CADCentre to explore the application of Virtual Reality techniques in their design tools. Figure 1.1 shows a typical design.

Figure 1.1: An image generated using the CADCentre design software

- Jack

  One problem when designing an object, is ensuring that people can easily interact with it. *Jack* (Figure 1.2) is a program developed by the University of

Pennsylvania Computer Graphics Research Laboratory, which helps test the way in which people interact with their environment. *Jack* models the way in which a person moves his body - and in particular his limbs. The user of *Jack* may set the dimensions of the model person and find out information such as how much force *Jack* has to exert to reach a particular object in the scene.

Figure 1.2: The '*Jack*' system

- Virtual Sculpting

  Designing objects in very flexible materials (like clay) is difficult in traditional design packages. Using tactile feedback it should be possible to create a system which allows the user to mould the material and feel the shape of the object that he is designing.

- Molecular synthesis

  In certain molecular design tasks the designer must create a molecule which is shaped in the correct way so as to engage with a reaction site on another molecule. The 'Grope' system **[Broo90]** displays a three dimensional model of the molecules being designed and allows the user to manipulate the molecule using a mechanical force feedback arm. The force on this arm allows the user to feel how well the molecule fits the receptor site.

1.2.4 Visualisation

Applications which deal with vast amounts of information are becoming more and more commonplace. Displaying this information in an accessible fashion is the task of visualisation.

- Medical Visualisation

  Medical scanners using Magnetic Resonance Imaging (MRI) and Computed Tomography (CT), produce very large three dimensional data sets. Although this data can be displayed as a series of two dimensional slices, a three dimensional representation is more useful for many applications. One application of Virtual Reality to visualizing this data is in radiation treatment planning **[Kala93]**. In this application the position of the radiation beams could be displayed overlaid on the patient's CT scan.

  The next stage after treatment planning is the active use of Virtual Reality in an operating theatre environment. A system for overlaying the images generated by ultrasound scans onto a patient is shown in **[BFO92]**. With this overlay the surgeon sees the patient through a video camera and the scan is overlaid onto the image of the real world.

- Financial Visualisation

  A financial dealer must analyse many different variables which affect the value of the shares, stocks etc. that he deals in. This problem is one example of displaying multi-dimensional data. A series of two dimensional graphs is one method of display but does not show the interactions between more than two variables. Feiner and Beshers describe methods of displaying this type of data using VR techniques **[FeBe90]**.

- Scientific Visualisation

  Scientific simulation of fluid flow and weather patterns generate large amounts of information. NASA Ames Research centre have developed a 'virtual wind tunnel'. This system allows the scientist to observe an object (such as an aeroplane) and the way it interacts with particle traces - analogous to smoke in a real wind tunnel. The user may change the orientation of the object, and start new particle traces and observe the effects. In this example the computational power available, together with the particular application, allow it to be used in an interactive manner; however this is not yet possible for many applications due to the amount of computation required.

- Flight data visualisation

  In **[Kala93]** Kalawsky describes the research at British Aerospace into 'virtual cockpits'. This technique acts as an advanced type of 'head-up display', overlaying information onto the pilots view of the landscape. It is hoped that this technique will simplify the task of the pilot, who has to analyse a very large amount of information in a very short time.

  These type of systems are not without problems. Safety considerations mean that integrating present display technology into cockpits is difficult and care is needed to ensure that data overlaid on the pilots view does not change their perception of the world, in particular their perception of distance.

- Air traffic control

  A simple application of Virtual Reality to air traffic control is being implemented in the Advanced Interfaces Group by Mashhuda Khote (based on work by Benny Tam). In this system the position of a number of aircraft are displayed as a series of tubes. Each tube represents the position of the plane over a short period centred about the current time. With this system it is easy to see if any plane is coming close to any other.

1.2.5 Other applications

Many other applications of VR are being considered, some examples are:

- Electronic publishing

  Recently it has been possible to place entire maintenance manuals on portable computers; this allows maintenance engineers to find information more quickly and efficiently. However the engineer still has the problem of having to look at both the computer screen and the object being maintained. British Aerospace have demonstrated a system where the maintenance documentation is overlaid on the real world view of the maintenance engineer **[Kala93]**.

- Entertainment

  The entertainment possibilities for Virtual Reality are often ignored in a lot of serious research environments, although the potential market is vast. The simplicity of these systems and large market may encourage the development of low cost peripherals; equally the limited abilities of the system may create false impressions about the real possibilities of VR.

1.3 Cost implications

In the sections above, a wide range of Virtual Reality applications has been described. The way in which the applications interact with the user, the type of images they display and the type of underlying model they use vary from application to application. This variability presents one of the greatest challenges to the designer of a rendering system aimed at the VR market. One factor which eases this problem is that the VR market is actually a number of smaller (overlapping) markets subdivided by the amount of money which the user is prepared to invest in the system; this enables the designer to create a system aimed at a smaller section of the market and hence reduce the variability the system must handle. To the military, a few million pounds for a flight simulator may seem quite reasonable compared to the cost of an aircraft. At the other end of the scale a home entertainment system must cost much less than one thousand pounds to be able to command a reasonable level of sales. This environment is beneficial to all involved, since the needs of flight simulator systems and similarly expensive equipment drives the development of systems for high end performance, while the entertainment industry finds ways of making technology that is a few years out of date available at a reasonable cost.

A lot of the applications described above are still in the research phase. The position sensing, eye tracking and display technology commonly available are too poor to allow many of these systems to be usable on a day to day basis. Care should be exercised when examining any application closely, since the effect of rapid improvements in these technologies can significantly change their structure and use of the rendering system.

1.4 An overview of a typical 'Virtual Reality' system

Figure 1.3 shows a block diagram of a simple Virtual Reality system.

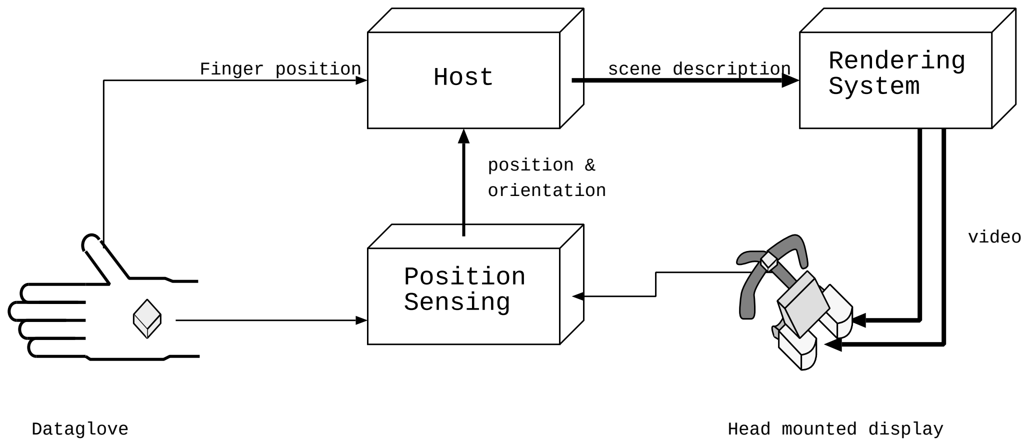

Figure 1.3: A Typical Virtual Reality System

Its components are:

- Input device (e.g. Dataglove)

  The input devices allow the user to communicate with the host. The most common types of input sensors are used to measure the position and orientation of the user's hand and head, and possibly the position of his fingers. The position of the hand is then used to generate a representation of the hand which the user can see, and the position of the head is used by the rendering system to render an image corresponding to the user's direction of view. Many other input devices are available; some of which are discussed in **Chapter 2**.

- Position Sensing

  This takes the raw output of sensors attached to the subject and processes them into a form that the host can understand. Typically this stage will also drive some type of transmitter to provide a signal which will be picked up in the sensors on the headset etc.

- The Host

  This is a computer system which generates the description of the virtual world, modifies it in accordance with the user's actions and performs any other housekeeping functions necessary.

- Rendering system

  The rendering system generates the images which are displayed in the head set. These images are generated in accordance with the descriptions provided by the host. Where stereoscopic displays are being used, separate images must be generated for each eye.

- Head set

  The head set incorporates a number of displays, a position sensor and possibly head phones for audio feedback.

- Operator

  In effect a VR system consists of a feedback loop which is completed by the operator. The user's actions influence the state of the model and the appearance of the model influences the user's actions. As with all feedback systems it is important to keep the latency low (for the moment the latency can be defined as the time from an input changing until the output is updated to reflect this input change). These and other requirements which influence the performance of the user are discussed in detail in **Chapter 4**.

Note that the configuration of this system is just an example; there are many things which can be different. For example stereo projection systems could be used instead of a head mounted display, the rendering may be incorporated into the host, and there could be many more peripherals.

1.5 This thesis

This thesis is mainly concerned with the detail of the rendering system, and the specialist requirements of a rendering system used in Virtual Reality applications. **Chapter 2** describes some of the peripheral devices used in VR system and outlines some of the problems associated with them. After that, the structure of conventional rendering systems is described in **Chapter 3**. **Chapter 4** describes the specialist requirements of VR applications and shows how these are different from the capabilities of conventional rendering systems previously described. One measure of the performance of a rendering system is the complexity of the scene it can render in a given time; **Chapter 5** looks at ways of measuring complexity and presents measurements from some of the scenes used in a number of applications. It also explains why these scenes are so complex and examines ways of reducing scene complexity. This chapter includes a novel culling algorithm, developed by the author, which can help reduce the work of later sections of the rendering system in scenes with a high depth complexity. **Chapter 6** examines a range of existing rendering systems and software and describes their suitability for Virtual Reality applications. Finally **Chapter 7**, draws together the findings of the previous chapters to form conclusions on the present state of rendering systems used in Virtual Reality, and offers suggestions for future research.

In addition **Appendix A** describes a number of other considerations and approaches to the rendering problem; in particular it includes a description of the way in which parallelism is used in rendering systems. **Appendix B** describes some of the tools used during this research; including a discrete event simulator that the author has written.