A low cost Virtual Reality interface for CAD model manipulation and visualization

Abhishek Seth

Iowa State University

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A low cost Virtual Reality interface

for

CAD model manipulation and visualization

by

Abhishek Seth

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Shana S-F. Smith, Major Professor
Judy M. Vance
Joseph Chen

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This is to certify that the master’s thesis of
Abhishek Seth
has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy
Dedicated to my beloved parents to whom I will always be indebted.
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GENERAL INTRODUCTION

The problems present in modern CAD system interfaces are well recognized. The human-computer interface technology provided in modern CAD systems makes the use of two dimensional (2D) computer interfaces, e.g. a keyboard and mouse, to generate and interact with CAD models. In addition, all CAD systems project complex 3D CAD models on a two dimensional computer screen, and the designer has to understand the spatial relationship of the different parts in the assembly by visualize it in his/her mind. This becomes more and more difficult as the design complicates further. Because of the 2D nature of the keyboard and mouse, their interaction with complex 3D CAD models is restrictive and unintuitive. Virtual reality (VR), an emerging technology, offers a solution to such interface problems present in modern CAD systems by providing an interface which is better suited for interacting with complex 3D CAD models. VR allows the users to interact with CAD models in the 3D environment with the same number of degrees of freedom as the environment in which the actual part exists. As compared to the traditional computer interface, VR provides a more interactive and intuitive interface for interacting with complex 3D CAD models. However, the high cost related to the VR equipment and the high level of technical skill required for implementing these technologies have restricted the wide spread acceptance of such useful technologies.

With the development of low cost VR technologies in recent years, VR solutions have become more accessible. Low Cost VR techniques have brought VR to a level that allows people with basic technical computer skills and limited resources to use this technology. The objective of the research presented in this thesis is to implement the currently available low cost VR technology for providing solution to the human-computer interaction problems present in today’s CAD applications.
The thesis first reviews and analyzes some of the low cost VR applications like Nvidia Quadro View, TGS 3Spae Assistant, etc., which are available in the market for interacting with CAD models. It then elucidates the development and implementation of a low cost VR human-computer interface, called the “VR CAD Model Viewer”, which is capable of importing and rendering stereo views of CAD models made in CAD systems like Pro/Engineer. The application developed, also provides the user with 3D 6-degree of freedom Data Glove device, which senses the finger and hand movements and helps the designers to interact with CAD models using their hands.

A Microsoft foundation class (MFC) interface is provided to make the application user friendly for Windows users. A human subjects study is also performed which aims at recording the interface performance and user feedback about the ease of use and intuitiveness of the interface. Studying this new type of learning experience of the use of VR in CAD and to chart its strengths and limits, is an important frontier for cognitive science research, scientific modelling, and constructive pedagogy.

**Thesis Organization**

This thesis consists of two papers, each covering different sections of the work. The overall background, objectives and scope of the thesis have been described in the general introduction.

In Chapter 1, titled “A PC based VR Approach for CAD Model Viewing”, the objective is to assess the current available Windows PC-based virtual reality software for stereo viewing of CAD models. The study explores the possible ways to transfer CAD data from professional CAD software to VR stereo viewing applications. Moreover, the study also throws light on the different kinds of rendering techniques available, and other technical aspects involved.
In Chapter 2, titled “A Low Cost Virtual Reality Human Computer Interface for CAD Model Manipulation”, presents a virtual reality human computer interface system, for interacting with 3D CAD models made in standard CAD systems like Pro/Engineer. Users manipulate 3D CAD models in a virtual design space with the help of a data glove device and the application provides real-time active stereo vision using LCD shutter glasses to make the visualization more realistic. A human subject study is also conducted to determine the ease of use and intuitiveness of the developed interface.

Finally, general concluding remarks are presented in the final chapter.
CHAPTER 1. A PC-BASED VR APPROACH FOR CAD MODEL VIEWING

A paper accepted in the Journal of Technology Studies.
Abhishek Seth\textsuperscript{1} and Shana S-F. Smith\textsuperscript{2}
Department of Industrial Technology
Iowa State University, Ames, IA-50014, USA.
e-mail: abhiseth@iastate.edu, sssmith@iastate.edu.

Abstract

Computer Aided Design (CAD) software are an indispensable tool for the designers in a design process. Analyzing and understanding complicated three dimensional (3D) Computer Aided Design (CAD) models using a two dimensional desktop computer viewing interface has always been a challenge for the designers. Virtual Reality (VR) can provide an interface to computers that is better suited for interacting with 3D models (Perles, 1999). In the past, the costs of VR facilities have been prohibitive. However, with the advent of low cost Windows PC-based VR technologies, VR solutions have become more accessible. However, numerous different competing technologies promising solutions to such problems are causing confusion among those who want to deploy them. Thus, it is important to review the currently available low cost PC-based VR technologies and the challenges involved in moving from traditional CAD to CAD-VR interfaces.

This paper throws light on the different kinds of rendering techniques and reviews some major low cost Windows PC-based VR software available for CAD model viewing.
1 Introduction

Product design is a critical activity, because it has been estimated that 70% to 80% of the cost of product development and manufacture is determined by the decisions made in the initial design stages (Kalpakjian & Schmid, 2001). During the design process, 92% of communications are graphically based (Bertoline, Wiebe, Miller, & Mohler, 1997). Graphics is a visual communication language, which helps designers understand their developing designs and to convey their ideas to others. Thus, efficient graphics communication tools can improve design and decision-making processes.

Most designers currently use traditional CAD tools to help communicate their designs to others. However, CAD tools only allow users to examine 3D models from outside flat computer monitors. In other words, the models and the viewers are in different realms. Using traditional CAD tools, the designers cannot view models with natural stereoscopic vision.

Recently, virtual reality (VR), as an emerging visualization technology, has introduced an unprecedented communication method for collaborative design. Virtual reality (VR) refers to an immersive, interactive, multi-sensory, viewer centred, 3D computer generated environment and the combination of technologies required to build such an environment (Aukstakalnis & Blatner, 1992; Cruz-Niera, 1993). VR technology breaks down barriers between humans and computers by immersing viewers in a computer-generated stereoscopic environment. VR allows users to experience a strong sense of presence in a virtual scene and enhances user interactivity.

Using VR technology, depth cues provided by a stereo image help convey spatial relationships in the 3D model, which enhances users' understanding of a design. Viewers can perceive distance and spatial relationships between different object
components more realistically and accurately than with conventional visualization tools.

In industry, VR has proven to be an effective tool for helping workers evaluate product designs (Kelsick, 1998). Using VR enables everyone on a design team to understand the designs better, leading to more informed and meaningful communications. Such rapid and less-ambiguous communication greatly enhances the speed and accuracy with which decisions can be made and designs can be completed.

Several major companies have incorporated VR technology into their design or production processes. In 1999, BMW explored the capability of virtual reality for verifying product design (Gomes de Sa & Zachmann, 1999). They concluded that VR has the potential to reduce the number of physical mock-ups needed, to improve overall product quality, and to obtain quick answers in an intuitive way, during the concept phase of a product. In addition, Motorola developed a VR system for training workers to run a pager assembly line (Wittenberg, 1995). They found that VR can be used to successfully train manufacturing personnel, and that participants trained in VR environments perform better on the job than those trained for the same time in real environments. In 1998, GE Corporate Research developed two VR software applications, Product Vision and Galileo, which allowed engineers to interactively fly through a virtual jet engine (Abshire & Barron, 1998). They reported that the two applications were used successfully to enhance design communication and to solve maintenance problems early, with minimal cost, delays, and effort. They also reported that using the VR applications helped make maintenance an integral part of their product design process.

Usually, implementation of VR technology is not easy, and it requires skilled technical people and highly specialized, sometimes costly equipment. These
requirements prevent the widespread use of VR in research and industrial communities (Olson, 2002). However, now, most PC workstations have stereoscopic graphic display capability built into their graphics card chip sets. PC-based VR techniques, also called low-cost VR, bring virtual reality to a usable level for people with basic technical computer skills and limited resources. Low-cost VR takes advantage of recent advances in low-end graphics systems and other inexpensive VR commodities. VR solutions thus are becoming more accessible.

The number of companies producing low-cost VR related hardware and software is continuously increasing. Some tools have better performance or are cheaper than others, for certain applications. Thus, choosing the right VR tool for a particular application is challenging for potential users. In addition, new hardware and software technical terms are confusing or meaningless to people without any prior background in VR. This paper assesses different available stereo image rendering techniques, such as anaglyphic, page flipping, and sync doubling, and major low-cost VR hardware and software tools available for CAD model viewing.

2 What is Stereo Viewing

When an object is viewed, an image of the object is formed in the viewer's brain. Because a person’s two eyes are some distance apart, upon seeing the same object, the image viewed by their right eye is slightly different from the one viewed by their left eye. The effect caused by the distance between the eyes is called “parallax” or "binocular disparity". The two distinct images from the two eyes are fused within the brain to form a single stereo image. Depth cues provided by the different images from the right eye and the left eye help the viewer perceive a realistic 3D effect, a concept known as stereo viewing. Computerized stereo viewing can deliver the most realistic visual representation for complex digital solid models. Therefore, to
see a stereo image on a PC screen, one needs to generate different images for the right eye and the left eye, respectively, and arrange the two images such that the right eye sees only the right view, and the left eye sees only the left view.

PC-based VR systems typically use one of several types of special viewing glasses to selectively send the right- and the left-eye images to the correct eyes. Depending upon the type of glasses used, stereo systems can be classified into passive or active stereo systems. "Passive" systems use glasses without electronic components; "active" systems use glasses with electronic components.

2.1 Passive Stereo Systems

Passive stereo systems are the most common and basic type of stereo systems. They are popular because they are very inexpensive, and cost is often a critical factor in public environments. To the naked eye, passive stereo images appear to overlap and are doubled and blurry. However, when the stereo images are viewed with glasses made from coloured or polarized filters, the images become stereoscopic.

Passive anaglyphic systems create a different coloured image for the right and left eye. Users then view the coloured images using anaglyphic glasses made from coloured filters (e.g., blue for the right eye and red for the left eye). Anaglyphic glasses used for passive stereo cost about $0.8 USD per pair (VRex, http://www.vrex.com). However, image quality in passive anaglyphic systems is relatively poor, and coloured views are not possible. The lack of coloured viewing capability is one of the major drawbacks of anaglyphic passive stereo systems.
Another method for passive stereo viewing is based on the principle of light polarization. With oppositely polarized filters attached to two projectors and matching filters in a pair of glasses, right- and left-eye images can be separated, and multiple colours can also be viewed. The theory behind polarized viewing systems is based upon the vibration characteristics of light (Stereoscopic Projection, n.d.). Non-polarized light waves can vibrate in any direction. A light wave vibrating in a single direction is called polarized light. The polarization of a light wave at any given moment is determined by the specific orientation of the wave at that moment. Non-polarized light can be transformed to polarized light by passing the light wave through a polarizer (see figure 1). The depth perception required for stereo images can be created by directing different visual information, using different polarization
directions, to the right and left eye. Thus, such a stereo system uses two projectors, as shown in figure 2. Polarizing light waves does not create any degradation in image quality, because human eyes are largely insensitive to polarization. The cost for a polarization projector system is around $20,000 USD (VRex, http://www.vrex.com; 3-D ImageTeck, http://www.3dimagetek.com).

If light is polarized in a single direction (north/south, east/west, or even diagonally), the light is linearly polarized. If a viewer changes the orientation of linearly polarized glasses by tilting his or her head, the resulting polarization orientation of the viewer’s glasses will not match that of the polarization filters mounted on the projectors, and there will be a loss of stereo information, as perceived by the viewer (Steroscopic Projection, n.d.). Nevertheless, linear polarization is a cost-effective technology that can produce excellent right-eye and left-eye image separation, for stereoscopic applications for which head tilting is limited.

Using circularly, rather than linearly, polarized light is an effective solution to the head-tilting problem. For circularly polarized light, head tilting does not result in a loss of stereo information, since the light is not polarized in a single direction. StereoGraphics Corporation’s Monitor ZScreen series provides a stereoscopic panel, which mounts on a regular PC computer monitor to circularly polarize the right-eye and left-eye images (Stereographics Corporation, http://www.stereographics.com). The cost of a Monitor ZScreen system is $2,345 USD. Polarized glasses range in cost from $3.95- $50 USD per pair (Stereographics Corporation, http://www.stereographics.com; VRex, http://www.vrex.com).

One of the important advantages of polarized stereo viewing systems is that they can be driven by non-stereo-capable hardware. In addition, the polarizing method can provide colored and high quality stereo images.
2.2 Active Stereo Systems

In active stereo systems, the viewing glasses used contain electronic components. Stereo images are presented by rapidly alternating the display of right-eye and left-eye images, while alternately masking the right and left eye using synchronous shutter eyewear, such as LCD shutter glasses.

Available LCD shutter glasses use various image switching techniques. The following three modes are most popular (Lipton et. al., 2002):

Interlacing
Page Flipping
Sync Doubling

2.21 Interlacing

Interlacing is used in existing television systems, such as NTSC, PAL etc., to transmit and broadcast signals. In interlace mode, a single frame is divided into two fields; the odd scan-line field and the even scan-line field. When the interlace mode is used for stereo imaging, the right-eye image and the left-eye image are divided into odd and even scan-line fields, or vice versa. First the odd scan-lines (1, 3, 5, 7, etc.) are presented, followed by the even scan-lines (2, 4, 6, 8, etc.) (see figure 3). When the right-eye frame is displayed on the screen, the left eye is covered by the glasses, and when the left-eye frame is shown on the screen, the right eye is covered by the shutter glasses.
2.22 Page-Flipping

In page-flipping mode, the right- and the left-eye frames are shown alternately on the screen (see figure 4). When the right-eye frame is shown on the screen, the left eye is covered by the shutter glasses, and, when the left-eye frame is shown on the screen, the right eye is covered by the shutter glasses. In this mode, both the horizontal and vertical resolutions are kept the same, since the frames are displayed one by one on the entire screen. For page-flipping, high end PC hardware is typically required.

The vertical scan frequency of the monitor should be 120Hz or higher, and specially designed hardware is often required. As mentioned earlier, page-flipping provides full resolution picture quality and, thus, provides the best visual effect among the display modes for shutter glasses. However, software and hardware dependence is a major drawback.

2.23 Sync-Doubling

With sync-doubling, the right-eye and left-eye frames of the image are scaled down in the vertical direction and arranged on the upper and lower half of the screen (see figure 5). Sync-doubling differs from interlacing and page-flipping modes in that no specialized computer peripherals are required.
To create a stereo view, software designers only need to arrange the right- and left-eye images properly on the screen, as shown in figure 5. An external circuit (called a sync doubler) is then used, which allows the right- and left-eye images to stretch to normal size and appear in an interlaced pattern on screen. The image quality is not as good as page flipping, because the monitor's vertical frequency needs to be doubled to stretch the frames to full screen. Overall image resolution is therefore reduced by one-half. However, the advantage of sync-doubling is that it is not limited by computer hardware capabilities.

3 Available Software

Presently, there are number of VR software tools available for viewing CAD models stereoscopically. Some of them can be downloaded, free, from the Internet, while many must be purchased. 3Space Assistant by Template Graphics Software (Template Graphics Software, http://www.tgs.com) and Quadro View by Nvidia Corporation (Nvidia Corporation, http://www.nvidia.com) are assessed in this paper. The two companies are well established and the software tools are easy to use.

To activate stereo modes, using either tool, the computer system used must have an OpenGL driver installed. Otherwise, the applications can not be executed. OpenGL is a cross-platform, high-performance standard library for 3D graphics applications. It has become one of the most widely used and supported 2D and 3D graphics application programming interface (API) standards, bringing 3D applications to a wide variety of computer platforms. Most graphics cards now used in PCs come only with drivers for Microsoft Direct3D, which is the 3D interface from Microsoft. The main reason for using Microsoft Direct3D is that developing OpenGL drivers can be considerably more complex than developing Direct3D
drivers. For this reason, many graphics cards companies have not released quality OpenGL drivers for their hardware.

If an OpenGL driver for the graphics card being used is unavailable or, if the driver is not installed when the active stereo mode is used, the computer will display the message “No OpenGL driver installed on the computer”, and the stereo image will not be shown on the screen. GL Direct, by the SciTech Software Inc. (SciTech Software Inc., www.scitechsoft.com), provides a solution to the above problem. GL Direct enables OpenGL based applications to use available Direct3D drivers.

A trial version of the software can be downloaded from the SciTech Software Website; the trial version works for 21 days. After the software is installed, it needs to be configured. For initial setup, select the Stereo tab and then select Change (see figure 6). Select the type of shutter glasses being used. Subsequently, whenever any
stereo application (e.g., TGS 3Space Assistant or Quadro View) starts, SciTech GL Direct will automatically start.

3.1 TGS 3Space Assistant

Template Graphics Software has been working in the field of 3D graphics and data visualization since 1986. Their products provide graphic visualization capability, using standards like OpenGL, Open Inventor, DirectX, Java 3D, and PHIGS+. 3Space Assistant from Template Graphics Software, Inc. is a stand-alone viewer that enables CAD model viewing in Open Inventor binary and ASCII (.iv), VRML 1.0 and VRML97 (.wrl), and AutoCAD DXF R14 (.dxf) formats. To view CAD files in other high-end file formats, e.g., STL, IGES, STEP, etc., the files first need to be converted into Open Inventor or VRML format. The latest release of 3Space Assistant is 3.7, which is compatible with Microsoft Windows NT 4.0/2000/XP and Windows 98/ME. A free trial version of the software can be downloaded from the company’s Web site. Cost for purchasing a working version of 3-Space Assistant is $399 USD.

Stereo Support

3Space Assistant supports stereo CAD model viewing using the Open Inventor toolkit. This stereo viewing option is deactivated when the software is first installed. For viewing a CAD model in stereo, the stereo function needs to be activated by selecting the desired type of stereo mode in View>Stereo Settings.

The advantage of 3Space Assistant is that it allows stereo viewing in a number of stereo modes like Raw OpenGL, Horizontal Interlaced, Vertical Interlaced, Red-Cyan Anaglyphic, and Blue-Yellow Anaglyphic (see figure 7). If the active stereo mode is used, LCD shutter glasses such as the Eye3D from I-Art Corporation ($50-200/pair) (http://www.iart3d.com), CrystalEyes from Stereographics Corporation ($795/pair), or other compatible glasses are required. If the anaglyphic stereo mode
is enabled, passive colored filter glasses (red/cyan, blue/yellow, or green/ magenta) are required.

Options for adjusting stereo quality, like increasing or decreasing parallax offset, swapping views, and maximizing to full screen view, are also available. By changing the background color, viewers can also create better visualization effects. 3Space Assistant works on a system with a Pentium 166 or higher processor and 20 MB hard disk space.

![Figure 7 Stereo settings in the view menu of 3Space Assistant](image)
**Other Important Modules**

3Space Assistant also allows users to edit 3D geometry, materials, colors, and lights by enabling 3D cut and paste and other similar functions. Users can also add 3D text to a model. A 3D decimation module and polygon reduction can be used to simplify the level of detail, for faster viewing on slower systems. 3Space Assistant also provides the ability to open Internet Web addresses (URLs) to view 3D files and navigate 3D worlds on the Web.

### 3.2 Nvidia Quadro View

NVIDIA (Nvidia Corporation, [http://www.nvidia.com](http://www.nvidia.com); Redmond, 2002) produces quality graphics processors, media, and communication devices. The NVIDIA Quadro View workstation application comes free with an Nvidia Quadro workstation card. With other graphic cards, a 30 days trial version of the software is available. Typically, Nvidia’s Quadro series graphics cards range in cost from $150-$1000 USD.

Quadro View can be used with Windows XP/2000 and Windows NT 4.0. The function of the viewer module is to render 3D models in real-time. It utilizes the Open Inventor 3D library, which is a scene graph class library based on OpenGL. Using Quadro View, 3D CAD models in VRML (.wrl) or Open Inventor (.iv) format can be viewed. Other formats are not supported by this application. However, Quadro View can export files in bmp, rgb, tif, jpg, avi, wrl, iv, and eps formats.

**Stereo Support**

The Quadro View stereo viewing option is deactivated when the software is first installed. For viewing a CAD model in stereo, the stereo module needs to be activated by selecting the desired type of stereo mode in the **View>Preferences>I/O Settings>Stereo** menu, as shown in figure 8.
The display can be switched to stereo mode by selecting the *Raw OpenGL* option in the menu shown in figure 8. The stereo quality is very good, but the part handling features are not very user friendly. The application also needs a large amount of memory to run smoothly. Nvidia Quadro View offers options for stereo adjustment similar to those in TGS 3Space Assistant. Using Quadro View, 3D CAD models can be viewed using passive as well as active stereo modes.

![Figure 8 Stereo settings in the preferences menu of Quadro View](image)

**Stereo Requirements**

If the quad-buffered Raw OpenGL Stereo mode is enabled in Quadro View, LCD shutter glasses are required to view stereo scenes. If the anaglyphic stereo mode is enabled in Quadro View, passive colored filter glasses are required. Quadro View is designed to run on Microsoft Windows XP/2000 or Windows NT 4.0. Complete installation of the software requires 40MB of hard disk space. The system must have
an Nvidia Quadro series Workstation video card, or an equivalent ELSA graphics card, installed.

Other Important Modules

One of the unique features in Quadro View is its compatibility with other CAD design packages, which makes it different from all other stereo viewers. Stereo Graphics Corporation used to provide a plug-in for AutoCAD and Mechanical Desktop to enable stereo mode, which made stereo viewing possible directly in AutoCAD or Mechanical Desktop. However, Stereo Graphics Corporation no longer offers the plug-in.

To configure CAD software like AutoCAD or Mechanical Desktop with Quadro View, all the software must be installed before installing Quadro View. When Quadro View is installed, it automatically searches for compatible CAD software. By checking boxes in the "Demand Load" module in Quadro View, Quadro View will automatically start when a compatible CAD package is launched. Quadro View also provides an option for transferring an entire CAD model or selected parts of a model directly from the CAD package.


4 Conclusions

Traditional CAD tools typically project 3D objects into 2D images for display on flat computer screens. As a result, product designers often find it difficult to accurately realize depth and detail on complex CAD models. VR tools, by generating stereoscopic views, can help designers gain a better spatial
understanding of 3D geometrical models than traditional CAD tools. As a result, many large companies (e.g., Ford, GE, and BMW) have used expensive VR tools for virtual prototyping, virtual design verification, and product assembly training.

Now, low-cost VR software tools like 3Space Assistant (from Template Graphics Software, Inc.) and Quadro View (from Nvidia Corporation) can be used to make VR capability available to designers in smaller companies and universities. For the hardware and software tested, the stereographic effect and overall display quality is very good. The authors have tested low-cost VR systems for use in both research and education. To use VR for design verification, designers can now use existing PC-CAD hardware and software and transfer CAD models into VR tools installed on the same PC-compatible workstations.

To use Nvidia's Quadro View tool, users need to purchase a quad-buffered graphics card, or a computer system that already has a quad-buffered graphics card installed. Nvidia supplies Quadro View free with the purchase of an Nvidia Quadro series graphics card. Template Graphics Software offers another low-cost VR solution, 3Space Assistant. 3Space Assistant requires no special hardware. Users can download a free trial version of 3Space Assistant from the Template Graphics Web site. Both software tools require users to purchase and use special eyewear for viewing models (e.g., Eye3D LCD shutter glasses from I-Art Corporation or CrystalEyes from Stereographics Corporation).

PC-based VR, in the future, will incorporate haptic and audio devices to give a better sense of immersion in the computer generated scene and provide more intuitive experience for design models.
References


CHAPTER 2. A LOW COST VIRTUAL REALITY HUMAN COMPUTER INTERFACE FOR CAD MODEL MANIPULATION

A paper to be submitted to Computer Aided Design

Abhishek Seth\textsuperscript{a}, Shana S-F. Smith\textsuperscript{a}, and Mack C. Shelley\textsuperscript{b}

\textsuperscript{a}Department of Industrial Technology, Iowa State University, Ames, IA.

\textsuperscript{b}Department of Statistics, Iowa State University, Ames, IA.

Abstract

Interactions with high volume complex three-dimensional data using traditional two-dimensional computer interfaces have always been inefficient and restrictive. During the past decade, virtual reality (VR) has presented a new paradigm of human-computer interaction techniques. This paper presents a VR human-computer interface system, which aims at providing a solution to the human-computer interaction problems present in today's CAD applications. A data glove device is used as a 3D interface for CAD model manipulation in a virtual design space. To make the visualization more realistic, real-time active stereo vision is provided using LCD shutter glasses. The concept behind this project is to make use of 3D interaction devices like the data glove possible for common design applications rather than only in specific research applications.

To determine the ease of use and intuitiveness of the interface, an experiment is conducted for performing standard CAD manipulation tasks. The analysis results show that the data glove device is more intuitive for performing object manipulation in a 3D design space.

\textbf{Keywords:} Virtual Reality, Computer-Aided Design, Human-Computer Interaction, Data Glove, Stereo Viewing.
1 Introduction

The present computer-aided design (CAD) systems use 2D computer interfaces, e.g. a keyboard and mouse, to generate and interact with CAD models. Because of the 2D nature of the keyboard and mouse, their interaction with complex 3D models is restrictive. Analyzing and understanding complicated 3D CAD models using a 2D desktop computer interface always has been a challenge for the designers. Although creative programming has enhanced the capabilities of 2D interface techniques to a certain extent, it never has been successful in making them naturally intuitive and completely efficient. It is very easy for the designers to miss design errors using a 2D interface that would have been clearly visible using a 3D interface.

The problem of object manipulation in today's CAD systems is well documented [2]. Most CAD systems provide only one single transformation for object manipulation at a time, e.g. either rotation about an axis or translation along an axis, etc. Thus, to attain a desired view of a model, the designer has to perform a series of transformations. This is often unnatural and not intuitive, compared to manually manipulating a 3D physical object.

Modern CAD systems also lack realistic visualization capability for displaying CAD models. In most CAD systems, 3D representations of CAD models are projected on a 2D computer screen to create the effect of a third dimension on a 2D computer monitor. This type of display technique is not capable of providing significant information about the spatial relationship of the parts, which is very important as the geometry becomes complicated.

Recently, VR has provided a human-computer interface that is better suited to interact with 3D models [14]. VR empowers users to see and analyze abstract and complicated features by mapping high-volume, multidimensional data into meaningful stereo displays and by enabling 3D intuitive interactions [16].
Several attempts have been made to implement VR to make CAD interfaces more intuitive and efficient while dealing with 3D data. But the requirement of costly and unaffordable hardware and high technical skill restricted their use [13]. Further, the problem of importing CAD data from commercial CAD systems into VR tools is not properly addressed in the previously proposed solutions.

This paper presents a prototype of a user-friendly CAD-VR system called the VR CAD Model Viewer, which requires only low-cost VR hardware without sacrificing the performance of the virtual environment. It also provides a solution for importing CAD data from Pro/Engineer directly into the virtual design space.

2 Related Work

Human-computer interaction is a vital part of present VR technology. A lot of research has been conducted to make the VR interfaces efficient while manipulating CAD models in virtual environments. As a result, several 3D human-computer interaction techniques [1, 7, 23] have been evolved to provide effective, intuitive, and more efficient control over 3D data.

Dani and Gadh [5] provided the concept of a VR interface (COVIRDS or Conceptual VIRtual Design System) for the creation of concept shape designs in CAD. They proposed the use of a bimodal voice and hand gesture interface to create and modify 3D shapes in a virtual environment. They used the Mattel PowerGlove for hand position sensing and gesture recognition. OpenGL was used for rendering, and stereo vision is provided by the use of LCD shutter glasses or a HMD (Head Mounted Display).

Yuan and Sun [24] used data glove devices to perform mechanical assembly in virtual environments. They used different hand shapes (postures) to generate four discrete control commands for performing the assembly tasks. They concluded that
the use of an intuitive 3D interaction device in virtual environments requires less user training time and increases the work productivity.

Trika et al. [19] provided the prototype of a VR-based CAD system. They used a wand (a 3D mouse) and speech as the two interaction modes to interact with the VR-CAD system. The CAVE [3] (Computer Aided Virtual Environment) library was used to provide functionality to the user interface, and the system supported three types of VR systems: CAVE, the Immersadesk [4], and a workstation that supported OpenGL standards [22].

Chu et al. [2] conducted an experiment to check the performance of VR interfaces (COVIRDS) utilizing haptic, speech, and eye modes while dealing with specific CAD tasks. To provide an immersive VR-CAD environment, a projection based system called Visual Design Studio was used, which was similar to a Responsive Workbench [9] and Immersadesk [4].

Gupta et al. [6] demonstrated a multimodal virtual environment called the Virtual Environment for Design and Assembly (VEDA). They provided a haptic interface coupled with force feedback so that the designer can feel the virtual objects. The system also was coupled with auditory feedback, so the designer could hear sounds of events such as collision of parts. They also conducted experiments with human subjects to compare handling and insertion assembly times in virtual and real environments. The experiments showed that the virtual environment is able to replicate experimental results in which increased task completion times correlated with increased task difficulty.

Jayaram et al. [8] used the Cyber Glove, HMD, and electromagnetic tracking devices to create a Virtual Assembly Design Environment (VADE) for addressing the assembly issues of a mechanical system in virtual environments. HMD's were used to generate a high-resolution real-time stereo view of the assembly process.
The CAD system used was Pro/Engineer. The system facilitated two-way data transfer between the CAD system and VR environment, and had the capability of collision detection, multiple part manipulation, and dynamic simulation for assembly evaluation.

Bouzit et al. [1] developed a glove interface that provided force feedback for dexterous interaction with virtual environments. Other research to enhance the realism of VR also can be found in the literature [3, 4], including various methods for hand gesture recognition [10, 15, 18, 21].

Weissmann et al. [21] used hand gestures as a means of human-computer interaction. He used neural networks for gesture recognition using data glove devices. Several other attempts have been made for gesture recognition using different kinds of gloves [15, 10].

It is evident from the literature that deploying the 3D interface systems requires highly specialized and costly equipment such as CAVE, Immersadesk [3, 4], and HMDs, which are not easily affordable. Configuring and using such systems also require a high level of technical skill in VR technology. Above all, very few of these approaches address the problem of quick and easy transfer of CAD data from conventional CAD systems to their VR-CAD systems. In addition, modern CAD systems such as Pro/Engineer, AutoDesk Inventor, and Solid Works etc., are still using the traditional 2D keyboards and mouse interface to interact with complex 3D CAD models. All prior approaches stress on building new VR-enabled CAD systems, while few of them focuses on providing a VR interface to an existing commercial CAD system. This prevents the widespread acceptance of VR interfaces in design communities, and VR thus is limited to only specialized research applications.

This paper demonstrates a prototype of a low-cost VR CAD model-viewing interface that imports CAD models created in systems like Pro/Engineer and
displays the stereo views on a computer monitor. To make the object manipulation more intuitive and efficient, a natural hand interface using a data glove device is included. A human subject study is conducted to determine the ease of use of the interface and its intuitiveness, and to study the responses of users of the interface.

The aim of the research conducted in this paper is to provide the designer with a more efficient and naturally intuitive interface for CAD model viewing and manipulation with the assistance of a data glove device. The main philosophy behind the application design is to keep the interface user-friendly so it can be used by people with basic technical computer skills and limited resources. Figure 1 shows the prototype presented in this paper, which allows the designer to interact with CAD models with the help data glove device and provides a real-time stereo view of the CAD model for enhancing the realism of visualization. The VR interaction device helps the user to perform normal interactions in a more natural way. Such types of VR interfaces for CAD systems not only will provide the users with a powerful tool to interact with the CAD models in a more intuitive and natural way, but it also will be helpful for designers for reviewing product designs in the design process.

Stereo vision provides depth cues, which carry the spatial information about the parts in a complex assembly, thus providing a better visual feedback to the user.
3 VR-CAD Viewer

The VR interface provided in the application for interacting with CAD models consists of two parts: the visualization part and the 3D interaction part. For enhancing visualization, real-time stereo viewing is provided. A computer monitor and a pair of LCD shutter glasses are used to present the virtual world. As the human hand interface provides the most intuitive and efficient form of 3D interfaces in performing special tasks in virtual environments [3], a data glove device is used for model manipulation in the virtual environment. The main purpose of providing a 3D interface is to enable a designer to manipulate CAD models with the same number of degrees of freedom as the environment in which the actual part exists in.

3.1 Importing CAD models from CAD Systems

The proposed VR CAD model viewer system imports CAD models using the Open Inventor (.iv) ASCII file format supported in Pro/Engineer. The application opens an inventor file (.iv) and searches for the unit of the part. The value of the variable, called a conversion factor, is set according to the unit found. The design space is automatically resized according to the unit of the part. The conversion factors for the different units are as follows:

<table>
<thead>
<tr>
<th>Conversion Factor Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inches</td>
<td>25.4</td>
</tr>
<tr>
<td>Feet</td>
<td>304.8</td>
</tr>
<tr>
<td>Meters</td>
<td>1000</td>
</tr>
<tr>
<td>Decimetres</td>
<td>100</td>
</tr>
<tr>
<td>Centimetres</td>
<td>10</td>
</tr>
<tr>
<td>Millimetres</td>
<td>1</td>
</tr>
</tbody>
</table>

This conversion factor is used by the application for performing several functions. Whenever a CAD model is imported, the application calculates the size of the virtual
design space needed for viewing the part by the help of the conversion factor. Accordingly, the light locations in the space and the size of the axes are also altered.

The vertex points of the triangulated CAD data are read from the Inventor file, and the system calculates the face normal and provides smooth rendering of the model using OpenGL graphics library [22]. The application also counts the number of parts in the assembly and keeps the information in a data structure that is needed when the part is displayed. The color information for each part is also read and stored, and each part is displayed in the color in which it was fabricated earlier. Color information becomes more important when the number of parts in the assembly increases and the assembly becomes more complicated.

The entire system is implemented in C++ and a Microsoft foundation class graphics user interface is provided. The CAD models created in the Pro/Engineer CAD system can be imported successfully to the viewer as shown in Figure 2.

3.2 Stereo View

To enhance the visualization part of the interface, the system provides the user with menu options to toggle between stereo and mono views of the CAD model. Stereoscopic views provide the user with a higher degree of immersion in the virtual design space.
For viewing an imported CAD model in stereo, images for the left and the right eye need to be generated separately. The left and right image frames carry the depth information in the form of several monocular and binocular depth cues. These left and right images need to be viewed independently by the left and right eyes in order to create the stereo effect by fusing together and providing the depth information to the user.

A positive parallax as shown in Figure 3 is achieved by keeping the left image on the left and the right image on the right. Because the images are on the same side as the respective eyes, this type of parallax is called a positive parallax. A positive parallax keeps the stereo image of the model behind the projection plane i.e. computer screen. The maximum positive parallax condition occurs when the object is at infinity. At this point, the parallax is equal to the interocular distance. Figure 4 shows a negative parallax which is achieved by placing the right image frame on the left side and the left image frame on the right side on the computer screen. In such a situation, the CAD model is located in front of the computer monitor, i.e., the projection plane. In the zero parallax condition, both the left and the right eye images overlap each other and the object appears to be on the projection plane.
In mathematical terms, the parallax angle ($\theta$) can be defined as

$$\theta = 2 \tan^{-1} \left( \frac{D}{2S} \right)$$

where $D$ is the horizontal distance between the left and right projections of a point and $S$ is the distance of the eye from the object as shown in Figure 5. The value of parallax angle $\theta$ is positive for objects behind the scene and negative for objects in front of the screen. Exceeding the parallax after a certain limit will result in a blurred image; i.e., the user will see separate images for the left and the right eye.

### 3.2.1 Stereo viewing method

This paper uses the sync-doubling method to display the stereo images of the models on the computer screen. The sync-doubling method uses two subfields for the left and right frame of the image that are arranged above and below each other as shown in Figure 6. The images in the above and below subfields are squeezed in the vertical direction by a factor of two. An external circuit (called sync doubler) is used, which allows the left and right eye images to stretch to normal size. The sync-doubler increases the refresh rate of the monitor to 120 frames per second, and thus the left and right images appear on the screen alternately, every 1/120th second. Wearing proper shuttering glasses, the user will be able to see 60 frames of image per second for either eye. Thus, each eye sees an image for a period of 1/120th second followed by 1/120th second of darkness, which results in a flicker-free stereo
image [11]. The main advantage of the sync-doubling method is that it does not require any specific computer hardware such as a quad-buffered graphics card, which again make the system unaffordable and inhibits its use in masses.

Figure 6 Sync-doubling Method

Here, shutter glasses from Eye3D (http://www.iart3d.com/product/eye3d/eye3d.htm) were used for stereo viewing. The shutters in the LCD glasses are synchronized with the images on the monitor with the help of an infrared emitter, which provides a signal to the glasses for triggering the shutters precisely. At a vertical resolution of 1280x1024 pixels, the sync-doubling method will result in about 1280x500 pixels per eye (some lines are lost to blanking), which is considered to be a good quality image. The stereoscopic views provide depth-cues, which are helpful in understanding the spatial relationship of the different parts of a complicated CAD model.

3.3 A Data Glove Interface

Among all available 3D interaction devices, the data glove and exoskeletons are considered the most intuitive, because using these devices, the user can relate in a manner closer to natural human interaction methods [12, 20]. These types of interfaces allow the designers to use the dexterity of their hands for performing the
desired task, while interacting with the application, and thus enhance their creativity. Apart from this, glove devices are capable of producing a wider range of information by measuring some or all of the finger joints, and this information can be used in interacting with virtual objects. Thus, data glove devices are used in a number of fields, like scientific visualization, VR, medicine, telemanipulation, puppetry, music, and video games [17].

A data glove as shown in Figure 7 consists of a lightweight lycra glove with fiber optic sensors embedded along the backs of the fingers. When the user starts moving his or her fingers, finger flexure bends the optical fibers along the fingers. This results in variation in the signal strengths of each of the fibers. These signals are sent to the processor that determines the joint angles of each finger. The data glove used in the research was a 5DT Data Glove from the 5DT Corporation (http://www.5dt.com) having 5 sensors for sensing the finger flexures. Apart from the optical fibers for measuring finger flexure values, the 5DT data glove also has a tilt sensor for measuring the orientation of the hand by reading the pitch and the roll values.

### 3.4 Gesture Recognition and Mapping

A gesture can be defined as a particular configuration of the finger joint angles. For each gesture, a finger flexure value for each finger is predefined. When the Open Data Glove command is issued, the application starts locating the data glove at the 9
pin RD 232 (COM1) port of the system. After the glove is found, it checks for the glove model details, i.e., the number of sensors, left hand, or right hand, etc. After the glove is connected, the object manipulation controls are transferred to the glove. The 3D object then can now be manipulated by using the glove instead of a mouse. To recognize a gesture, the angular flexure values from each finger joint are collected. These values are then converted to angular values representing hand and finger movements of the user.

As it is difficult for the user to keep his/her hand at a stationary position after making a gesture, we provide some allowance for angular hand movements which is around 10 degrees on either side of the horizontal hand position.

![Hand Gestures](image)

(a) Grasp   (b) Translate   (c) Zoom   (d) Top/Side View   (e) Reset

Figure 8 Hand Gestures

A complete gesture value consists of predefined angular flexure values of all five fingers. If the collected flexure value lies in the predefined range for all fingers, then the particular gesture is recognized by the system. A lot of research has been done in the area of gesture recognition using various types of gloves [10, 15, 18, 21]. To keep the system simple, hand movement is not considered as a part of gesture, and only static gestures are recognized by the system.

The VR CAD model viewer uses the glove interface for performing fundamental navigation tasks like zoom-in, zoom-out, viewpoint translate, rotate, and reset. Some views such as top-view and side-view, which are required frequently by the designers, also are mapped to different gestures to facilitate the designers orienting
the model along those views directly without going through the intermediate transformations.

To perform a navigation task, the user has to make the assigned gestures as shown in Figure 8a-e, and once a gesture is recognized by the system, the object can be manipulated by changing the orientation of the hand i.e. by varying the pitch and roll values. For performing rotation tasks, the user has to grasp the model and then vary the pitch and roll values for rotating the object along any arbitrary axis. The index and middle finger point gesture as shown in Figure 8c, was used for initiating the zoom mode; and once the gesture is recognized, the roll value was responsible for zooming in and out transformations. A flat hand gesture was used to release the object. Object translation was mapped to the index finger point gesture, which is shown in Figure 8b, and the roll, and pitch values made the object translate. Three-finger point gesture as seen in Figure 8d along with the roll values were used for toggling between the top and side views of the model. The index and little finger point gesture seen in Figure 8e, was used for resetting the model to bring it back to its original start position.

4 The Experiment

An experiment was performed to evaluate the VR CAD model-viewing application interface. Altogether sixteen subjects participated in the study. All subjects had previous experience in performing CAD model manipulations using commercial CAD applications. The subjects were asked to perform a set of object manipulation tasks using the data glove interface and the same tasks using the traditional keyboard and mouse interface. While interacting with a keyboard and mouse interface, the participants could rotate the model by pressing the left mouse button. Translate and zoom transformations could be performed by using the left
mouse button in conjunction with the “ctrl” and “shift” key, respectively. The time required for performing each task was registered carefully.

The desktop system used for the tests consists of an Intel Pentium IV processor at 2.0 GHz, 512 Mega Bytes of RAM, 17-inch monitor, and running on Windows 2000 operating system. Same CAD model assembly was used for performing the assigned tasks in both interfaces. Before the users were asked to perform the specific tasks, all users were given a demonstration about the working of the glove, and they were asked to make themselves familiar with the interface by using it for some time.

The task was to manipulate the CAD model so that it appears in the computer screen in required orientation. To test how the users adapt to the tool, the first three tasks were to achieve the bottom view, side view, and top view of the model. Specific gestures were assigned to achieve the side view (task 2) and top view (task 3), while for seeing the bottom view (task 1) and an arbitrary position of the side view (task 4); the users had to plan the set of transformations themselves. After each task, users had to reset the model and bring it back to the initial orientation. All the subjects were observed carefully during the experiment. After the tests, the subjects were required to fill out a questionnaire providing their opinion about the new interface for CAD model viewing. The four final object orientations required to complete the tasks are shown in Figure 9.
5 Results

Both qualitative and quantitative questions were asked of the participants. The questionnaire used for the study can be seen attached in the appendix. Questions 1, 2, 3, 4, and 5 were multiple-choice questions and questions 6 and 7 were open-ended to elicit spontaneous responses from the subjects. The distributions of responses to the multiple-choice questions are provided in the histograms shown in Figure 10.

Q1 How intuitive in your opinion is data glove interface, for manipulating CAD models?
Q2 Will you prefer this interface over conventional mouse and keyboard?
Q3 How easy do you think is the interface to use?
Q4 Do you think any gestures you used for manipulation were unnatural?
From the responses to question one, it is clear that none of the subjects found the Data Glove device to be non-intuitive. The mean of all responses for answer one is 2.25, which is very close to the second choice, i.e., “intuitive”. Thus it can be concluded that most of the subjects found the device to be intuitive while handling CAD models. Responses from the second question indicate that 50% of the subjects prefer the use of the data glove device over a mouse and keyboard while interacting with CAD models.

The histogram chart of the third question indicates that all the users except one found the use of glove device to be easy. The mean of response choices from question three is 2.1, which is close to the second choice, “easy” to use. The responses from the fourth question indicate that 56.3% (i.e., 9 subjects) of the sample reported that no gestures were unnatural, while 43.8% (i.e., 7 subjects) reported that some gestures were unnatural for object manipulation. From the responses for question five, it may be observed that 93.8% (i.e., 15 subjects) reported that the VR interface would be useful as an introductory tool in an undergraduate design class.

From the results of the one-sample t-test shown in Table 1, it can be observed that the mean response equals zero for questions 1-5. From the confidence interval values for the first question, it can be predicted that 95% of all users will have
response values with a lower bound of 1.84 and upper bound of 2.66, which supports the conclusion that users found the interface to be intuitive. Similarly, the confidence interval values from question three predict that 95% of all users will have response values with a lower bound of 1.7 and upper bound of 2.55 which demonstrate that most of the users found the use of the glove device to be easy.

Similarly, from the confidence interval values of the sixth question, it is predicted that 95% of the response values of all users will lie within the interval 0.93 - 1.20. This shows a high level of agreement by all users that the glove interface will be useful as an introductory tool for undergraduate students taking an engineering design class.

<table>
<thead>
<tr>
<th></th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
<th>Mean Difference</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>11.619</td>
<td>15</td>
<td>.000</td>
<td>2.25</td>
<td>1.84</td>
</tr>
<tr>
<td>Q2</td>
<td>11.775</td>
<td>15</td>
<td>.000</td>
<td>1.469</td>
<td>1.203</td>
</tr>
<tr>
<td>Q3</td>
<td>10.543</td>
<td>15</td>
<td>.000</td>
<td>2.13</td>
<td>1.70</td>
</tr>
<tr>
<td>Q4</td>
<td>12.199</td>
<td>15</td>
<td>.000</td>
<td>1.56</td>
<td>1.29</td>
</tr>
<tr>
<td>Q6</td>
<td>17.000</td>
<td>15</td>
<td>.000</td>
<td>1.06</td>
<td>.93</td>
</tr>
</tbody>
</table>

Table 1 One-sample test results, with 95% confidence intervals, for questions 1-5.

Question one and question two has a Pearson correlation value of 0.712; i.e., questions one and two are highly correlated. The subjects who found the glove intuitive also preferred the glove over a mouse and keyboard for manipulating CAD models. Questions one and three are also found to be fairly strongly correlated, with a Pearson correlation value of 0.587. Users who found the glove intuitive, also found it easy to use.

Repeated measures analysis of variance demonstrates that there is a significant difference among the four tasks shown in Figure 9, using the glove (F = 37.069, df = 3, 13, p < .001). Differences across tasks with the glove accounted for 71.2% of the variance in differences among subjects. With the glove, performance time is
significantly higher for Task 4 than for each of the other tasks; no other pair wise differences are significant.

In addition, there is a significant difference among the four tasks using the mouse and keyboard \((F = 11.989, \text{df} = 3, 13, p < .001)\). Differences across tasks with the mouse and keyboard accounted for 73.5% of the variance in differences among subjects. With the mouse and keyboard, performance time is significantly higher for Task 4 than for each of the other tasks; no other pair wise differences are significant.

From the results shown in Table 2 and Table 3, the mean time consumed performing Task 1 and Task 4 by the glove device is greater than the mean time taken for performing the same tasks with the keyboard and mouse interface. This conclusion is supported by the results of a repeated measures analysis of variance comparing mean completion times for each task between the glove and the mouse and keyboard interface. Time required to completion is significantly higher \((F = 7.817, \text{df} = 1, 15, p = .014)\) for glove \((M = 4.326)\) than mouse and keyboard \((M = 2.842)\) for Task 1. The use of a glove vs. mouse and keyboard accounts for 34.3% of the variation in performance from subject to subject on Task 1. A significantly greater time to completion \((F = 20.157, \text{df} = 1, 15, p < .001)\) also is found for glove \((M = 17.529)\) than for mouse and keyboard \((M = 7.435)\) for Task 4. On Task 4, the use of a glove vs. mouse and keyboard accounts for 57.3% of subject-to-subject variation in performance. One of the main reasons behind such a result is that all users who took part in the study were familiar with the conventional mouse and keyboard interface and thus were more adept interacting with those devices, while the working methodology and behaviour of the data glove device were completely new to all of them.

In contrast, the mean time for performing Task 2 and Task 3 by the mouse and keyboard interface was greater than the mean time for performing Task 2 and Task 3
with the data glove interface. These results suggest that the data glove acts as a faster interface when the tasks are assigned to the gestures directly.

One-Sample Statistics

<table>
<thead>
<tr>
<th>Task</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>TASK1</td>
<td>16</td>
<td>2.8419</td>
<td>1.25332</td>
<td>.31333</td>
</tr>
<tr>
<td>TASK2</td>
<td>16</td>
<td>2.6687</td>
<td>.99744</td>
<td>.24936</td>
</tr>
<tr>
<td>TASK3</td>
<td>16</td>
<td>2.7006</td>
<td>1.13783</td>
<td>.28446</td>
</tr>
<tr>
<td>TASK4</td>
<td>16</td>
<td>7.4350</td>
<td>3.38540</td>
<td>.84635</td>
</tr>
</tbody>
</table>

Table 2 Mean timing values for tasks using the Mouse and Keyboard interface

One-Sample Statistics

<table>
<thead>
<tr>
<th>Task</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>TASK1</td>
<td>16</td>
<td>4.3256</td>
<td>2.48388</td>
<td>.62097</td>
</tr>
<tr>
<td>TASK2</td>
<td>16</td>
<td>2.2613</td>
<td>1.67430</td>
<td>.41858</td>
</tr>
<tr>
<td>TASK3</td>
<td>16</td>
<td>2.3100</td>
<td>1.68498</td>
<td>.42125</td>
</tr>
<tr>
<td>TASK4</td>
<td>16</td>
<td>17.5294</td>
<td>9.77767</td>
<td>2.44442</td>
</tr>
</tbody>
</table>

Table 3 Mean timing values for tasks using the Data Glove interface

Although there are measurable differences between glove device and mouse and keyboard interface, a repeated measures analysis of variance shows that there are no significant differences in time to completion between glove (M = 2.261) and mouse and keyboard (M = 2.669) for Task 2, or for Task 3 (M = 2.310 for glove and M = 2.701 for mouse and keyboard).

One of the interesting observations was that many subjects started by achieving Task 2 before performing Task 4, which suggests that the subjects liked the directly mapped gestures and tend to make use of those gestures for performing the tasks.

From the communalities shown in Table 4, a factor analysis was undertaken to ascertain the construct validity of the five quantitative items used in the survey. If construct validity can be established, these survey items could be used more generally to evaluate perceptions of human-computer interaction. We see that the
five items consistently measure the same underlying dimension of perception. All five of these five items predict each other well.

From the principal components factor analysis as shown in Table 5, a single factor accounts for 57.239% of the variance in all five items. Such a high value in all five items shows that one factor does a good job of explaining variation among all five variables. Thus there is one underlying idea that the survey instrument is measuring; i.e., the survey instrument is very well constructed in getting the desired information.

Thus, the glove devices can provide a comparable option for interaction than the conventional mouse; but some practice is definitely required to get accustomed to such a device.

<table>
<thead>
<tr>
<th>COMMUNALITIES ANALYSIS</th>
<th>Initial</th>
<th>Extraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 How intuitive in your opinion is data glove interface, for manipulating CAD models?</td>
<td>1.000</td>
<td>.680</td>
</tr>
<tr>
<td>Q2 Will you prefer this interface over conventional mouse and keyboard?</td>
<td>1.000</td>
<td>.640</td>
</tr>
<tr>
<td>Q3 How easy do you think is the interface to use?</td>
<td>1.000</td>
<td>.766</td>
</tr>
<tr>
<td>Q4 Do you think any gestures you used for manipulation were unnatural?</td>
<td>1.000</td>
<td>.410</td>
</tr>
<tr>
<td>Q5 Do you think this interface will be useful as an introductory VR tool for an undergraduate student taking an engineering design class?</td>
<td>1.000</td>
<td>.367</td>
</tr>
</tbody>
</table>

Table 4 Communalities of Survey items 1-5.

<table>
<thead>
<tr>
<th>Component</th>
<th>Initial Eigenvalues</th>
<th>Extraction Sums of Squared Loadings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>% of Variance</td>
</tr>
<tr>
<td>1</td>
<td>2.862</td>
<td>57.239</td>
</tr>
<tr>
<td>2</td>
<td>.906</td>
<td>18.119</td>
</tr>
<tr>
<td>3</td>
<td>.705</td>
<td>14.095</td>
</tr>
<tr>
<td>4</td>
<td>.273</td>
<td>5.457</td>
</tr>
<tr>
<td>5</td>
<td>.255</td>
<td>5.091</td>
</tr>
</tbody>
</table>

Table 5 Total Variance Explained by Factor Analysis
5.1 Technical Issues

Subjects complained about the gesture recognition problem with the glove. Even after trying again and again, they were not able to perform some manipulations. One of the subjects could not reset the part after trying for some time. While performing the reset operation some times the object starts translating. This happens mainly because some subjects found the task of pointing the index and small finger together difficult and they could not keep the small finger straight. Thus, the glove recognized the gesture as only index finger point, and the object was translated instead of reset. These types of errors can be eliminated by redefining the finger flexure values for the gesture. One of the other reasons for this difficulty might be that the glove had only five sensors to sense the finger flexures. More sensors will be useful in precise recognition of hand gestures and will be helpful in eliminating such problems.

Almost all the subjects tried to use the “yaw” motion for translating the part right and left, i.e., pointing the index finger was more intuitive for the users than tilting their whole hand on either side for performing object translation. A glove that senses the yaw motion would be more intuitive and easier to use. Some of the subjects suggested that adding a tracker device will make the interface system better, easier and more intuitive to use. However, because of the high cost associated with tracker devices, adding a tracker device will increase the cost of the interface system and will restrict its acceptance in masses.

6 Conclusions

This paper presents a user-friendly approach for a VR-based interface for interacting with CAD models. The interface demonstrated in the paper provides a stereo view of the CAD model for enhanced visualization and enables the designer
to use a 3D input data glove device to interact with the CAD models in a more natural and intuitive manner.

The test results indicate that the glove was a little faster while performing some specific CAD tasks, i.e., Task 2 and Task 3, which were mapped directly to the glove gestures. Although the glove device was found to be slower for some tasks, it was found to be more intuitive than the traditional mouse and keyboard interface. It has been observed that after using the data glove interface for some time, subjects showed improvement in their performance and started feeling more comfortable. Most of the subjects found the interface intuitive and easy to use and learn. Almost all the subjects advocated using the data glove device in an undergraduate design class, to ensure that future designers are exposed to the applications of low-cost VR technology in CAD.
References


Appendix- Questionnaire

Q1. How intuitive in your opinion is data glove interface, for manipulating CAD models?
   1. Very intuitive
   2. Intuitive
   3. O.K.
   4. Not so intuitive
   5. No intuitiveness in manipulation.

Q2. Will you prefer this interface over conventional mouse and keyboard?
   1. Yes
   2. No

Why? Ans:

Q3. How easy do you think is the interface to use?
   1. Very Easy
   2. Easy
   3. O.K.
   4. Difficult
   5. Very Difficult

Q4. Do you think any gestures you used for manipulation were unnatural?
   1. Yes
   2. No
   Which actions were unnatural and how should they be changed?

Q5. Do you think this interface will be useful as an introductory VR tool for an undergraduate student taking an engineering design class?
   1. Yes
   2. No

Q6. What are the functions that the interface is not performing properly?

Q7. What suggestions do you have for improving the application?
GENERAL CONCLUSIONS

Low cost VR technology has become popular with the rapid developments that have taken place in the field of computer graphics hardware in recent years. Attempts have been made to implement this technology in the field of CAD. VR provides a sense of immersion in the 3D design space, which makes the analysis and interaction process more naturalistic and intuitive. The VR CAD model viewer application developed during the research is capable of manipulating CAD models with the help of a 6-dof 3D Data Glove interface. It provides the designers with the ability to import CAD models made in CAD systems like Pro/Engineer, and view them in stereo on a computer monitor using LCD shutter glasses. The application uses low cost easily available VR hardware without sacrificing the quality of the VR environment. The results from the human subject study conducted during the research; have shown that the users found the interface intuitive and easy to use. The fact that the subjects found the use of the data glove easy to learn also supports the conclusion that it is intuitive to use. This type of VR interface to modern CAD systems will be very helpful for designer to understand and analyze complex CAD models using low cost VR technology without having any background in VR.

The research conducted in this thesis can be expanded to allow several other types of active and passive stereo format support. Developing the active stereo viewing; further work can be done to provide support for using the “Page Flipping” technology for stereo viewing. The VR CAD Model viewer application can also be developed to provide stereo support for demonstrational purposes like using the application to explain geometric features of a CAD model in an engineering design class. This can be possible by providing support for passive stereo viewing using anaglyphic or polarization techniques for projecting the stereo images on a large projection screen. This would be very helpful for use in educational and academic
purposes. Support for a 3D tracking system will increase the intuitiveness of the interface significantly.
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