

PC-Based Virtual Reality for CAD Model Viewing

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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. VR refers to an immersive, interactive, multisensory, viewer-centered, 3D computer-generated environment and the combination of technologies required to build such an environment (Aukstakalnis & Blatner, 1992; Cruz-Neira, 1998). 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 3D models, 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.

Usually, however, implementation of VR technology is not easy. 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 VR 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. Thus, VR solutions are becoming more accessible.

About This Article

This article introduces the current status of VR applications in industry and the technologies involved in the low-cost VR systems. The number of companies producing low-cost VR-related hardware and software is continuously increasing. New hardware and software technical terms are confusing or meaningless to people without any prior background in VR. Thus, choosing the right VR tool for a particular application is challenging for potential users. This article introduces 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. The purpose of this article is to help CAD users and product designers have a better understanding about VR technology so that they can develop their own VR systems to increase the efficiency of design communication.

Status in Industry

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 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 VR for verifying product design (Gomes de Sa & Zachmann, 1999). They concluded that VR has the potential to reduce the number of physical mockups 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.

Passive and Active Stereo Systems

Because a person's two eyes are some distance apart, upon viewing the same object the right eye sees a slightly different image from the left eye. 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.

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 colored or polarized filters, the images become stereoscopic.

Passive anaglyphic systems create a different colored image for the right and left eye. Users then view the colored images using anaglyphic glasses made from colored filters (e.g., blue for the right eye and red for the left eye). Anaglyphic glasses used for passive stereo cost about 80¢ per pair (VRex, <http://www.vrex.com>). However, image quality in passive anaglyphic systems is relatively poor, and colored views are not possible. The lack of colored 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 colors can also be viewed. The theory behind polarized viewing systems is based upon the vibration characteristics of light (Barco, n.d.). Nonpolarized 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. Nonpolarized 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

Figure 1. Polarizing light using a polarizing filter.

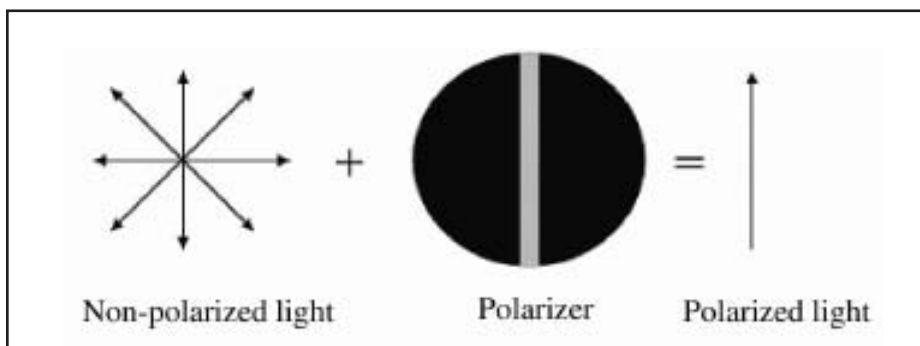


Figure 2. Double projector system with opposite polarizers.



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 significantly degrade image quality because human eyes are largely insensitive to polarization. The cost for a polarized projector system is around \$20,000 (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 (Barco, 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, for circularly polarizing right-eye and left-eye images (StereoGraphics Corporation, <http://www.stereographics.com>). The cost of a Monitor ZScreen system is \$2,345. Polarized glasses range in cost from \$3.95 to \$50 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.

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, 1997):

- Interlacing
- Page flipping
- Sync doubling

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.

Figure 3. Interlacing.

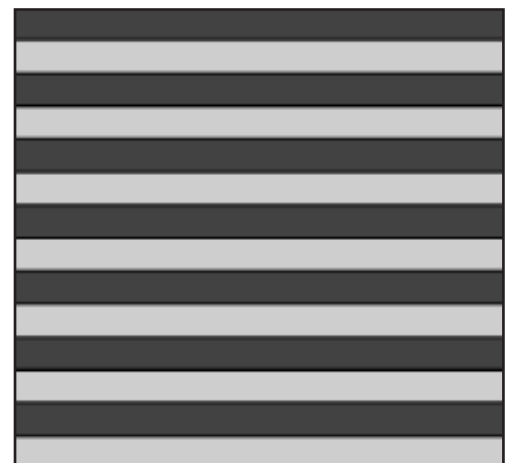
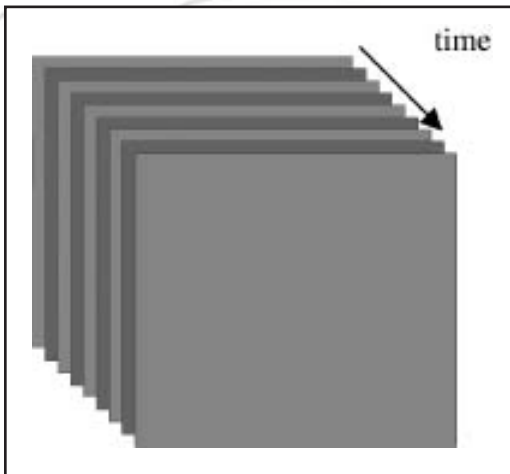


Figure 4. Page-flipping.**Page-Flipping**

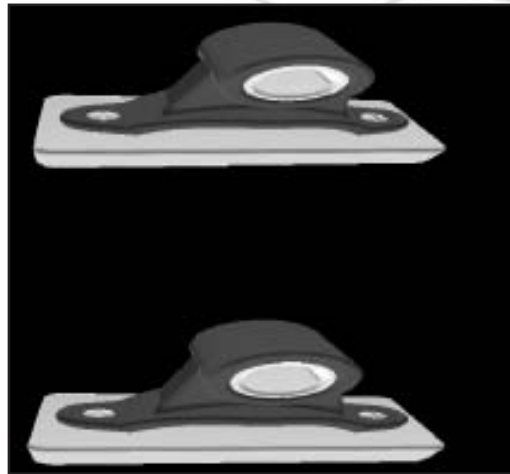
In page-flipping mode, the right- and the left-eye frames are shown alternately on the screen (see Figure 4). When the right-eye frame is shown on the screen, the left eye is covered by the shutter glasses, and when the left-eye frame is shown on the screen, the right eye is covered by the shutter glasses. 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. A monitor that supports a 120 Hz or higher vertical scan frequency and specially designed hardware are 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.

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 flip-

Figure 5. Sync-doubling.

ping 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.

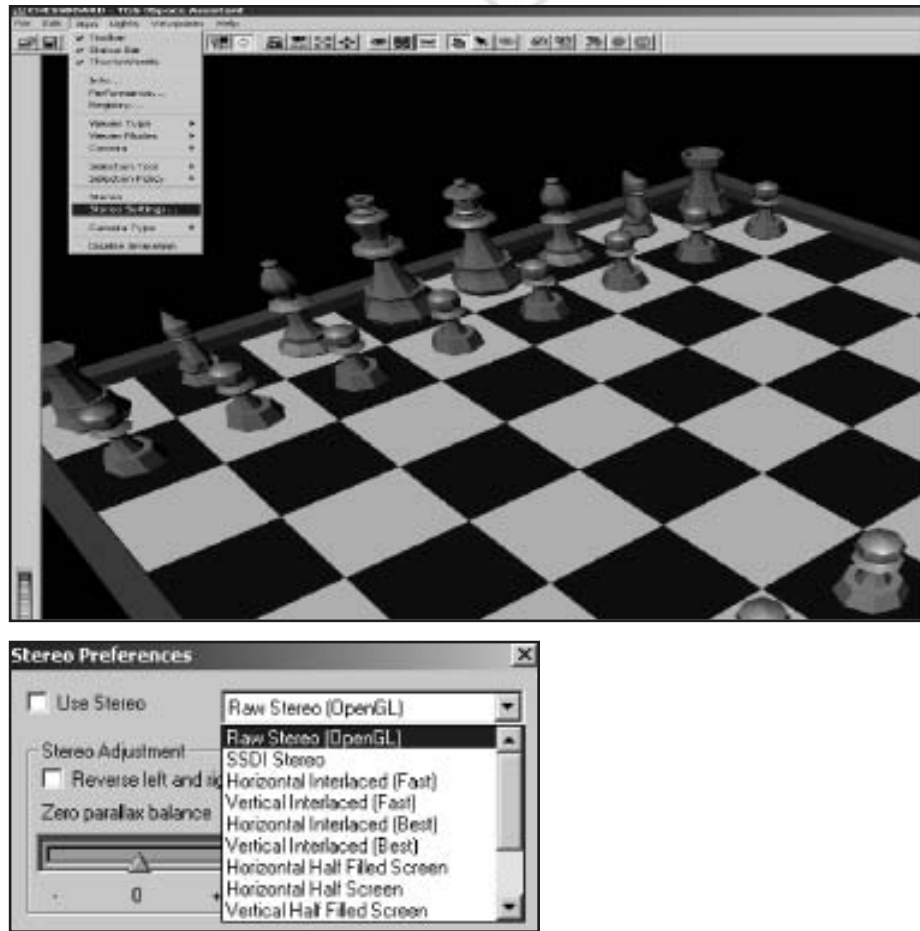
Available Software

Presently, there are a number of VR software tools available for stereoscopically viewing CAD models. For example, 3Space Assistant by Template Graphics Software (<http://www.tgs.com>) and Quadro View by Nvidia Corporation (<http://www.nvidia.com>) are well developed and very user-friendly.

For the available software tools, the computer system must have an OpenGL driver installed to activate stereo modes. OpenGL is a cross-platform, high-performance standard library for 3D graphics applications. 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 SciTech Software Inc. (www.scitechsoft.com), provides a solution to the above problem. After the software is installed, whenever any stereo application (e.g., TGS 3Space Assistant or Quadro View) starts, SciTech GL Direct will automatically start.

TGS 3Space Assistant

3Space Assistant from Template Graphics Software, Inc., is a stand-alone CAD model viewer. The advantage of 3Space Assistant is that it allows stereo viewing in a number of

Figure 6. Stereo settings in the view menu of 3Space Assistant.

stereo modes such as Raw OpenGL, Horizontal Interlaced, Vertical Interlaced, Red-Cyan Anaglyphic, and Blue-Yellow Anaglyphic (see Figure 6). If the active stereo mode is used, LCD shutter glasses are required. If the anaglyphic stereo mode is enabled, passive colored filter glasses (red/cyan, blue/yellow, or green/magenta) are required.

Nvidia Quadro View

To use Nvidia's Quadro View, users need to purchase a quad-buffered graphics card or a computer system that already has a quad-buffered graphics card installed (Nvidia Corporation, <http://www.nvidia.com>; Redmond, n.d.). The stereo quality provided by Quadro View is very good, but the part handling features are not very user-friendly. Using Quadro View, 3D CAD models can be viewed using passive as well as active stereo modes. One of the unique features in Quadro View is its compatibility with other CAD design packages (e.g., AutoCAD, AutoCAD Architectural Desktop, and Mechanical Desktop), which makes it different from all other stereo viewers.

Future Directions

PC-based VR, in the future, will incorporate haptic and audio devices to give a better sense of immersion in the computer-generated environment and to provide a more intuitive interaction with design models. Haptic devices could provide realistic force feedback so users could feel objects that they touch or move. Audio devices could provide realistic sound effects for collisions between objects. In addition, because of the restrictions associated with manipulating 3D virtual objects with a keyboard and mouse, data gloves will be used to increase manipulation efficiency in low-cost VR systems. Handling computational workloads while providing real-time response is also a critical issue for realizing future low-cost VR systems.

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