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Low Cost Virtual Reality and its Application to Chemical Engineering - Part One

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Virtual reality, (VR), is an important emerging technology in computer visualization. While the concept of virtual reality has been around since the early 1960s, until recently the capabilities of VR have been limited, and only available to those institutions with large computing budgets. Recent developments have greatly increased the capabilities of this technology and have brought the price to within the range of the average researcher and even home hobbyist. This paper will provide a brief overview of this rapidly growing field, with emphasis on entry-level implementations, and will finish with a discussion of how it can be and is being applied to chemical engineering.

Background

The underlying concept behind virtual reality is to produce a computer generated environment which is as lifelike as possible; To make the user believe that he[1] is actually present in the computer generated world. In a perfect implementation, the user would be completely unable to distinguish the virtual world from the real one. As Ivan Sutherland put it, in one of the founding quotes of the field, "The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal."[2] StarTrek fans will instantly see this as a description of the holodeck. Much of the current research in virtual reality involves striving to attain this pinnacle of realism.

In addition to the real world, other environments can also be modeled using virtual reality. For example, VR can be used to explore the inside of a catalyst pellet or an operating nuclear reactor. With VR an engineer can pick up a distillation tower and move it to a better location. Abstract concepts such as entropy, safety, or flexibility can be visualized and manipulated. In fact, the virtual world does not have to bear any resemblance to the real world, and is not constrained by gravity, the laws of physics, or even any sense of reasonableness. In addition, multiple users can enter into the same

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[1]. Please read he/she, him/her, etc. wherever pronouns are used.

[2]. Sutherland, Ivan E., "The Ultimate Display", Proceedings of the IFIP Congress, 1965.

virtual world and interact with each other, even though they may be physically located thousands of miles apart.

Virtual reality is commonly considered to be an expensive operation, involving fast expensive computers and lots of specialty hardware. This hardware includes head-mounted displays and head tracking devices, which, in combination, allow the user to look in all directions and have his view change in accordance with his head position. While VR *can* be quite expensive, this does not have to be the case. If one is willing to accept a slightly lower performance level, virtual reality can be implemented on an ordinary personal computer with less than $500 worth of additional equipment. The progression of this paper will be to start with the minimum cost alternatives, and then to move on to more complex and expensive solutions. This is a normal path of progression for new entrants into this field.

Increasing Immersion = Increasing Cost

The question of exactly what is and isn't virtual reality is still a topic of much heated debate. However the key concepts which separate virtual reality from other forms of computer interfaces are immersion and believability. A VR participant should be completely immersed in the virtual environment, and should believe, as much as possible, that the environment around him is "real". There are many different degrees to this immersion, with higher levels of immersion requiring more sophisticated hardware and software, and having appropriately higher costs.

If one could produce a scale with which to measure the degree of immersion, at the low end of the scale would be a simple table of numbers. Next would come charts, graphs, and then three-dimensional graphic images. None of these are, of course, virtual reality, because in all these cases the user is an external observer looking in on the data, and is not immersed within the scene. The closest interfaces to be almost, but not quite, virtual reality are video games, some of which take a first-person perspective and contain quite realistic graphics. What separates these games from true virtual reality is that the video game graphics are all pre-computed and stored, (which may take man-years to complete), and are then presented to the user as appropriate. True virtual reality maintains a database of objects, and calculates for each frame update which objects are visible and what they look like from the users current viewpoint. The functional difference is that in VR you can look at the world from any viewpoint and perspective you wish, whereas the video games can only show you views for which the graphics have been stored. (Conversely, video game graphics are generally of much higher quality, as the time required to generate them is not a concern, whereas virtual reality must re-compute all the graphics images several times per second, thereby limiting feasible graphics quality.)

As the immersion level increases, the simulation becomes more and more realistic, and the user believes to a greater and greater extent that they are actually within the computer generated environment. Obviously higher screen resolution and faster, more detailed images increase the immersion level. This is accomplished using faster, often specialized, computers and high speed graphics boards. In some cases, multiple computers work together to handle different portions of the overall task. Other common features of VR which add to the immersion level and hence the experience are 3-D (stereoscopic) vision, 3-D audio (the user can sense the direction of the sound), wired gloves, and most notably the head mounted display.

Minimum Cost Virtual Reality

The lowest cost level of virtual reality is commonly referred to as "homebrew VR", or "garage VR". This level of hardware and software has been developed by hobbyists literally working in their basements and garages, using parts and techniques scavenged from whatever source is available. Prices for homebrew VR start at essentially free, assuming one already has a personal computer.

The least cost software implementation of virtual reality would have to be Rend386, a public domain program which runs on ordinary personal computers, and is tuned to run efficiently without requiring a lot of computing power. (Using only integer math, Rend386 does not require a floating point math co-processor, and will ignore one if present.) Rend386 is available via anonymous ftp, but a better source is the floppy included with the book "Virtual Reality Creations", by Roehl, Stampe, and Eagan. Bernie Roehl and Dave Stampe are the original creators of Rend386, and their book provides the best documentation for the program, as well as some good tutorials concerning the basics of virtual reality, a number of support utilities which are useful for building virtual worlds, and numerous sample worlds.

Rend386 allows the user to construct their own virtual worlds, merely by describing the geometry of their objects in simple data files. Numerous sample worlds and extensive documentation make this a relatively simple task, depending of course on the level of complexity of the geometry involved. Numerous utility programs are available for constructing simple geometrical shapes, such as cylinders, spheres, and objects of revolution, and for manipulating the resulting objects (combining, stretching, inverting, etc.) No programming skills are required, though a firm grasp of three dimensional geometry is helpful. (An appendix in the aforementioned book provides a good refresher for those who are rusty in this respect.)

In addition to simply defining objects, (including their color, material, and other properties), Rend386 also supports animation, i.e. moving objects. An early prototype for a virtual chemical plant developed with Rend386 included a CSTR with a moving stirrer. If the user got too close, the stirrer would grab on and spin the user around the tank! Although Rend386 does not require any special hardware, a number of peripheral devices are supported, including the Sega LCD shutter glasses and Nintendo PowerGlove described below.

Additional Software Choices

There are a number of other software packages available for implementing virtual reality, and an increasing number of them run on ordinary personal computers. Most of these do not require any particular special hardware, but do support various items of low-cost hardware if you have them. In general, the more costly the software, the more costly the hardware supported by that software. Some of the more popular low-cost virtual reality programs are VREAM, Virtual Reality Studio, Vistapro, Virtus Walk Through, and Superscape VRT. For full descriptions of these and other programs, including purchasing information and a number of free demo versions, see the books listed in the bibliography. One program not covered in the books, but available via anonymous ftp to qualified individuals is MR Toolkit. Contact lloyd@cs.ualberta.ca for more information concerning this package, or better yet, visit the web site http://web.cs.ualberta.ca/~graphics/MRToolkit.html.

The software development package which we have chosen for most of our VR development work is WorldToolKit, (WTK), from Sense8 corporation. The main factor influencing that decision was the wide range of platforms supported. There are versions of WTK available for MS Windows, DOS, Silicon Graphics, and numerous platforms in between. The Windows version only requires a math co-processor, i.e. a 486 or above. The DOS version also requires a special graphics board, the SPEA Fire RISC board, available for $1800 from Sense8. This graphics card and its associated monitor are **in addition to** the regular VGA card and monitor which a PC would normally have.

WorldToolKit is actually a library of C language routines, along with a few support files and demo programs. In order to use WTK, one must have C programming skills and an appropriate compiler / linker. Other supporting programs, such as AutoCAD and photo management utilities, can be very useful for developing the objects and images necessary to populate a virtual world.

Additional Hardware Options

Other than a sufficient personal computer, and the special graphics card required for the DOS version of WTK, most low-cost VR development packages do not require any special hardware. On the other hand, most of them do support various hardware items if you happen to have them or are willing to buy them. Some of these additional peripherals include LCD shutter glasses, other 3-D viewing devices, 3-D audio cards, and head mounted display units.

Alternate Input Devices

Recall that the driving force behind virtual realty is to produce a world as realistic as possible, into which the user can become so immersed as to forget that it is just a simulation. Using a keyboard to navigate such a world is completely counterproductive to this underlying goal, even if the keyboard commands are simple and straightforward. To produce a truly immersive environment requires a navigation device which is as intuitive as possible, one the user can implement without thinking about or even realizing what they are doing. This is especially true when head mounted displays or other devices are being used which restrict access to the outside world. To this end, mice make better navigation tools than keyboards, but joysticks are better yet. At $13 for the joystick and $10 for the game card, there is no reason not to have this peripheral for VR applications. (Don't let their resemblance to a child's toy inhibit you on this point; Joysticks add immensely to the navigability and thereby the effectiveness of a virtual world.)

There are a wide variety of other input devices which have been used with virtual reality, either extensively or experimentally. Two of the more common ones are 6 DOF mice and forceballs. 6 DOF mice have six degrees of freedom, three translational and three rotational, which allow the user to pick the mouse up off the table and manipulate objects in three dimensional space. (A variation, the wand, resembles the light pen used by many public speakers.) Forceballs are similar to joysticks, but like 6 DOF mice, they also respond to three translational and three rotational degrees of force, and are generally ball shaped. Special purpose devices are widely varied, such as bicycles, golf clubs, and wheelchairs. A more common and well known virtual reality input device is the wired glove.

Wired Gloves

A wired glove is a device worn by the user which contains sensors for measuring hand location and position, and finger and thumb movement. This allows the computer to track users' hand and finger movements, thereby allowing users to point to objects, pick up and move objects, and in general interact "manually" with the virtual environment. Rend386 supports the Nintendo PowerGlove, which was once manufactured by Mattel, but is unfortunately no longer manufactured. PowerGloves have been available in scattered Toys-R-Us stores, (often in a back room, not on display), for around $30 or so. Alternatively they are occasionally sold on the Internet for negotiable prices, typically between $30 and $100. In true homebrew fashion, you must rig up your own wiring for the PowerGlove, (Eglowstein, 1990), or there are connection boxes available from various sources. (Jacobson, 1994) Higher quality wired gloves are also available, at a cost of thousands to tens of thousands of dollars. These high quality gloves track finger movement via fiber-optic technology, or for even greater accuracy, mechanical linkages (Eglowstein, 1990). Extremely expensive virtual reality setups may incorporate entire suits of wired clothing.

3-D Viewing Devices

There are many different cues which indicate to the human mind how far away something is, including size, parallax, level of detail, relative motion, and others. By far the most important depth cue is stereoscopic vision, produced by the left eye having a slightly different viewpoint from the right. Good software can handle all of the first items mentioned, but true stereoscopic vision also requires the use of special hardware.

An inexpensive stereoscopic option is the Cyberscope at $80. This device, which attaches to the front of the monitor, splits the screen image in two, and presents the left half to the left eye, and the right half to the right eye. Because the human eye has a wider range of vision horizontally than vertically, the Cyberscope also rotates the images 90° using mirrors, and the software must, of course, produce the proper screeen images for the device. More elaborate and generally more effective stereoscopic vision is produced by LCD shutter glasses and stereoscopic head-mounted display units, as described below.

It should be noted that stereoscopic vision is not always required for effective VR. There are many other ways to make the user believe what they are seeing is real, and in virtual reality, as in magic, it is what the viewer believes that counts, not what they actually see. With head mounted displays in particular, most users will report seeing stereoscopic 3D images, even when using a monoscopic device.

LCD Shutter Glasses

Rend386 supports stereoscopic vision through the use of low-cost LCD shutter glasses. The basic principle behind shutter glasses is that the computer alternates displaying the left-eye image and then the right-eye image on the same screen, while at the same time the glasses use LCD shutters to alternately block the vision of the right eye and then the left eye in sync with the changing screen images. The net result is that the left eye sees only the left-eye image and the right eye sees only the right-eye image.

In the case of Rend386, the LCD glasses which are supported are known as Sega glasses, since they were originally manufactured by Sega, or Toshiba glasses, who also manufactured them for awhile. The problem is that neither manufacturer is still making them, which means the thing to do is to find a supplier who still has some. Over the last few years the going price for these goggles has risen from $70 to $250, as their popularity has increased and supplies have dwindled. At last report 3DTV corporation, (P.O. Box Q, San Rafael, CA 94913-4316, (415) 479-3516), still had some of these glasses available.

There are some pros and cons of the Sega glasses as opposed to alternative LCD shutter glasses which are currently being produced (Crystal Eyes glasses described below.) The advantages of the Sega glasses are that they are inexpensive, use an ordinary computer/monitor combination, and happen to be the only ones supported by Rend386. The disadvantages are the dwindling availability, the fact that they cut the effective frequency in half, thereby producing a noticeable "flicker", (hence the other name for these glasses - flicker glasses), and the fact that you must wire your own circuit to connect them to a serial port. The circuit is fairly simple and entails about $30 worth of Radio Shack parts and some simple soldering skills. Instructions for building this circuit are available from many sources, including (Stampe, 1993).

A higher quality though more costly implementation of LCD shutter glasses are Crystal Eyes from StereoGraphics corporation in Sausalito, CA. While the principal is the same, there are a few critical differences between the Crystal Eyes and Sega glasses. First of all, the sycnhronization of the Crystal Eyes glasses is handled via an infra-red signal rather than a serial wire. This means that 1) there is no circuit to be wired up by the user, 2) the user is unencumbered by a tether wire, and 3) multiple participants can view the 3-D effect simultaneously, limited only by the number of pairs of eyewear purchased and the number of people who can simultaneously crowd around the same monitor. (StereoGraphics also sells products for displaying 3-D images to large audiences, via special projectors and polarized eyewear.) Crystal Eyes glasses work by *doubling* the vertical refresh rate of the video signal, which has the advantage of reducing the distracting flicker sometimes associated with LCD glasses, and the disadvantage of requiring a more expensive monitor, capable of handling the higher vertical sync frequency. Crystal Eyes glasses normally run from $1000 to $1300 for the PC platform, though a recent show special had them priced below $500.

Head Mounted Displays

As the name suggests, the head mounted display, (HMD), is a display unit which the user wears on their head. The immediate benefits of this are that the user is no longer confined to the computer monitor, and the sensory deprivation factor - when the user can no longer see the real world, they become much more immersed in the virtual one. In addition, HMDs are generally used in conjunction with a head tracking device which informs the computer of the current position and orientation of the user's head. Then, whenever the user turns their head to look in a new direction, the computer adjusts the displayed image to show whatever is in that direction in the virtual world. The net result is a highly believable cause-and-effect relationship between the user's movements and the displayed image.

Head mounted displays can be either monoscopic or stereoscopic, and generally range in price from $3000 to $8000, though at the low end there are a few HMDs available for under $500, and at the high end the military has some which cost over a million dollars. HMDs generally take a television (NTSC) type signal instead of a computer video (VGA) signal, which necessitates the use of a RGB to NTSC converter of some kind. This usually results in some loss of image quality, as the TV standard does not support either the color depth or the resolution of today's modern computer video signals. (The HMDs use a TV signal because they are based upon the screens developed for camcorder viewfinders.) HMDs are limited by the weight which can be worn comfortably by the average user. Boom-mounted displays do not have this problem, and offer much better image quality at a correspondingly higher price. Monoscopic HMDs can be used with any software, (including non-VR applications), since the converter box will convert the ordinary VGA signal, or they can be used to watch television signals. Stereoscopic HMDs require two separate video signals, such as produced by a computer with two video cards, or two computers working in parallel. HMDs are most effective when used in conjunction with a head tracking device.

Head Trackers

Head trackers are devices which keep track of the position and orientation of the users head, so that the computer can update the video image accordingly when the user looks around. The three methods most commonly used for head tracking are mechanical, acoustical, and electromagnetic. Mechanical trackers are generally incorporated into expensive boom-mounted display devices. The low-cost option is the acoustic approach for about $700 from Logitech. This method places three small speakers, emitting ultrasonic pulses, in a triangle above the user, and three small microphones attached to another triangle on the users head. By measuring the relative intensity of the three sound sources from the three microphones, the system is able to determine the position and orientation values. Drawbacks are the intrusive nature of the speaker unit, and the low accuracy and range of the system.

Electromagnetic trackers are preferable, but carry a higher price tag. These devices work using three mutually orthogonal wire coils in a baseball sized transmitter, and three similarly arranged coils in a receiver about the size of a cherry. Current is pulsed alternately through the three transmitter coils, and the current induced in the three receiver coils by the resulting magnetic pulses is measured, yielding nine measurements which are used to determine the position and orientation values. This system was originally developed by Polhemus, who make an alternating current version, though the direct current version manufactured by Ascension Technology is purported to be more accurate and have fewer interference problems.

Other head tracking methods which have been used, include gyroscopic devices and the monitoring of blinking LEDs via multiple cameras, where either the LEDs or the cameras are mounted to the user's head and the other to the ceiling. The advantage of the latter system is that it provides the user with complete mobility within a room sized area, at a rather high cost. Head trackers can, of course, be used to track other moving objects, such as the users hand when using a wired glove.

Coming in Part Two

Part two of this paper will look at applications of virtual reality, starting with general applications, and then addressing specifically applications of virtual reality to chemical engineering. In particular, Vicher, the virtual reality based educational simulation being developed in the Chemical Engineering department at the University of Michigan will be covered. The article will conclude with a discussion of the additional sources of virtual reality information which are available, (besides the bookstore).

Additional Information

Obviously there is much more to virtual reality than can be included in a report of this size. The products, applications, and research efforts which have been mentioned are only a few of the hundreds available. There are many good sources of additional information available, starting with those listed in the bibliography.

For those who have access to the Internet, or Usenet, there is much information on-line. First of all, there is a news group sci.virtual-worlds. This newsgroup includes active discussions of current topics by active members in the field, as well as helpful questions and answers. Secondly, there are several active ftp sites, where interested parties can anonymously download hundreds of Megabytes of useful information.

One such ftp site is ftp.u.washington.edu. One of the host computers for the sci.virtual-worlds newsgroup, this ftp site contains an archive of several years worth of news messages, as well as several faq (frequently asked questions) files, and other information. For beginning searchers, faq files are generally the best first step. Highly recommended as a starting point is "Meta-FAQ", in the public/virtual-worlds directory on ftp.u.washington.edu. The University of Washington is also home to the Human Interface Technology (HIT) Laboratory, one of the leading sites for virtual reality development.

Another excellent ftp site is sunee.uwaterloo.ca. Rend386 was developed by Bernie Roehl and Dave Stampe of that institution, and so it is the logical archive site for the Rend386 programs as well as many utilities and worlds developed by others and submitted into the public domain. Get the readme files first, to avoid downloading unnecessary files. Other VR information can be obtained from sunsite.unc.edu (UNC Chapel Hill info), and wuarchive.wustl.edu (Washington University in St. Louis, a generally good VR site.) Reading the faq files and other information available at these sites will lead to other sources of information as well.

For Web surfers, there are WWW sites on virtual reality too numerous to mention. An excellent starting point is http://www.hitl.washington.edu/project/knowledge_base, and in particular, follow the thread from there to "On The Net: Internet Resources in Virtual Reality." That alone will provide an overwhelming amount of information.

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