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An Investigation of Current Virtual Reality Interfaces

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Abstract

Virtual Reality hype is becoming a large part of everyday life. This paper explores the components of actual virtual reality systems, critiquing each in terms of human factors. The hardware and software of visual, aural, and haptic input and feedback are considered. Technical and human factor difficulties are discussed and some potential solutions are offered.

Introduction

Virtual reality is a new technology for simulation, design, entertainment, and many other pursuits. The purpose of our paper is to identify weaknesses in virtual reality interfaces. To accomplish this task, we have divided the typical virtual reality interface into four specific areas: audio, visual, tactile, and navigation. We will point out the limitations of current solutions to problems in these areas, possible areas of improvement, and those problems that remain completely unsolved at this point.

Visual Aspects of Virtual Reality

The main tradeoffs in this area are image detail versus rendering speed, and monoscopic vision versus stereoscopic vision. In most applications of virtual reality, visual feedback is required. In fact, visual cues are perhaps the most important feedback in the virtual reality system. To achieve a sense reality, the pictures sent to the display have to be real-time to avoid discontinuity. Therefore, we investigate the trade-off between the rendering time and the graphic resolution for the 3-dimensional graphic scene and the 2-dimensional graphic scene from both the software and hardware perspective.

Types of Visual Display

LCD Flicker Lens

The LCD (liquid crystal display) flicker lens has the appearance of a pair of glasses. A photosensor is mounted on these LCD glasses with the sole purpose of reading a signal from the computer. This signal tells the LCD glasses whether to allow light to pass through the left lens or the right lens. When light is allowed to pass through the left lens, the computer screen will be showing a left eye scene, which corresponds to what the user will see through his left eye. When light passes through the right lens, the scene on the computer screen is a slightly offset version of the view from the left eye. The glasses switch between the two lenses at 60 Hertz, which causes the user to perceive a continual 3D view via the mechanics of parallax [3].

LCD flicker lens' are light weight and cordless. These two features makes them easy to wear and to remove. Unfortunately, the user has to stare only at the computer screen in order to see the 3-D scene. Since the field of view is limited to the size of the computer screen, the surrounding real world environment can also be noticed. This does not provide an immersive effect.

Head Mounted Displays

Head mounted displays place a screen in front of each of the viewer's eyes at all times. The view, the segment of the virtual environment generated and displayed, is controlled by orientation sensors mounted on the ``helmet''. Head movement is recognized by the computer, and a new perspective of the scene is generated. In most cases, a set of optical lens and mirrors are used to enlarge the view to fill the field of view and to direct the scene to the eyes (Lane). Four types of Head Mounted Displays (HMDs) will be discussed below.

- LCD display HMD

This type of HMD uses LCD technology to display the scene. When a liquid crystal pixel is activated, it blocks the passage of light through it. Thousands of these pixels are arranged in a two dimensional matrix for each display. Since liquid crystals block the passage of light, to display the scene a light must be shone from behind the LCD matrix toward the eye to provide brightness for the scene [1].

The LCD display HMD is lighter than most HMDs. As with most HMDs, it does provide an immersive effect, but the resolution and the contrast is low. The problem associated with low resolution is inability to identify objects and inability to locate the exact position of objects. Since the crystals are polarized to control the color of a pixel, the actual polarizing of the crystal creates a small delay while forming the image on the screen. Such a delay may cause the viewer to misjudge the position of objects [4].

- Projected HMD

  This type of HMD uses fiber optic cables to transmit the scene to the screen. The screen is similar to a cathode ray tube (CRT) except the phosphor is illuminated by the light transmitted through fiber optic cables. Ideally, each fiber would control one pixel. But due to the limitation in cost and manufacturing, each fiber controls a honeycomb section of pixels [11].

  The projected HMD provides better resolution and contrast than LCD displays. This HMD is also light weight. Higher resolution and contrast means that the viewer is able to see an image with greater detail. The downside of this type of HMD is that it is expensive and difficult to manufacture [4].

- Small CRT HMD

  This type of HMD uses two CRTs that are positioned on the side of the HMD. Mirrors are used to direct the scene to the viewers eye. Unlike the projected HMD where the phosphor is illuminated by fiber optic cables, here the phosphor is illuminated by an electron gun as usual [11].

  The CRT HMD is in many ways similar to the projected HMD. This type of HMD is heavier than most other types because of added electronic components (which also generate large amounts of heat). The user wearing this type of HMD may feel discomfort due to the heat and the weight of the HMD [**4**].

- Single Column LED HMD

  This type of HMD uses one column of 280 LEDs. A mirror rapidly oscillates opposite from the LEDs, reflecting the image to the user's eye. The LEDs are updated 720 times per oscillation of the mirror. As the LED column updates for each column of the virtual screen, the mirror redirects the light to the viewers eye, one column at a time, to form the image of the entire virtual screen [**1**].

  Single Column LED HMDs allow the user to interact with a virtual world and the real world simultaneously. This type of display can be used to create a virtual screen that seems to float in the real world.

One of the common problems of HMDs is that the cable connecting the HMD and a computer restricts the mobility of the user. The user can only move as far as the cable allows. If the cable is not properly managed, the user could trip over it or become entangled in it. In addition, switching frequently between a virtual world and the real world is tedious and tiresome.

Binocular Omni-Orientation Monitor (BOOM)

The binocular omni-orientation monitor (for example **http://techinfo.jpl.nasa.gov/JPLTRS/SISN/ISSUE36/COHEN1.htm**) is mounted on a jointed mechanical arm with tracking sensors located at the joints. A counterbalance is used to stabilize the monitor, so that when the user releases the monitor, it remains in place. To view the virtual environment, the user must take hold of the monitor and put her face up to it. The computer will generate an appropriate scene based on the position and orientation of the joints on the mechanical arm [**1**].

Some of the problems associated with HMDs can be solved by using a BOOM display. The user does not have to wear a BOOM display as in the case of an HMD. This means that crossing the boundary between a virtual world and the real world is simply a matter of moving your eyes away from the BOOM.

3-D Audio

The main research area in audio is the simulation of sound origin. ``It has been demonstrated that using sound to supply alternative or supplementary information to a computer user can greatly increase the amount of information they can ingest'' [**1**]. This is no less true in the virtual world. In addition to visual output, a complete virtual world must incorporate a three dimensional sound field that reflects the conditions modeled in the virtual environment. This sound field has to react to walls, multiple sound sources, and background noise, as well as the absence of them. This requires massive computational power and speed because hearing is a complex system which uses the shape of the outer ear and microsecond delays in the arrival of sound to the two ears to determine position and location of the source of the sound. To simulate a virtual sound environment, a computer must first determine the position of the source relative to the listener. It also must calculate the effects of the environment. For example, to simulate an echo due to a wall, the computer must first determine the source's location relative to the subject and the wall, then place another source the at the appropriate distance and location on the opposite side of the wall [**17**].

The main problem with producing sound is that it is impossible to replay previously recorded sound in a manner that moves a sound from behind the user to in front of the user as they turn their head. **Crystal River Engineering** has developed a process for producing a sound such that it seems like it is coming from a particular direction. Since these sounds are computed and produced in real time, there is no problem with playback.

The evolution of 3D sound starts with monophonic sound. ``Mono'', the latin word for ``one'', sends one signal to every speaker. It appears that all of the sounds of the environment are coming from each individual speaker. If there is only one speaker, then all sounds seem to be coming from that point.

Stereophonic sound allows for sound to seem as if it is coming from anywhere between two speakers. This is accomplished by delaying the signals between the two speakers by a few microseconds. The smaller the delay, the closer to the center the source appears to be located.

Surround sound, used in many theaters, uses the idea of stereo, but with more speakers. The delays can be set so that a sound can seem to move from behind the listener to in front of the listener. One problem with this system is that a plane taking off behind the listener will appear to go by the listener's elbow instead of overhead [**15**].

A solution to the problem of creating a three dimensional sound field comes from production of sound which is tuned to an individual's head. When sound reaches the outer ear, the outer ear bends the sound wavefront and channels it down the ear canal. The sound that actually reaches the eardrum is different for each person [1]. To resolve this problem of personalization, the computer must create a sound that is custom designed for a particular user. This is done by placing small microphones inside the ear canal, then creating reference sounds from various locations around the listener. Then the computer solves a set of mathematical relationships that describe how the sound is changed inside the ear canal. These mathematical relationships are called Head Related Transfer Functions (HRTFs) [15].

HRTF measurements can not accurately simulate the acoustical environment when used alone. The problem lies in trying to non-intrusively make measurements. When the microphone is placed in the ear canal, it changes the acoustical track, thereby changing the HRTF. Also, this method does not attempt to take into consideration the middle or inner ear [14].

Realistic Sound

An additional computational burden is the production of background noise. This is very important if the person in the virtual environment wishes to be immersed in a ``believable'' world. However, since the noise is background, it does not need to take advantage of 3D sound technology. This limits the interactivity of the user with the virtual environment. In the real world, a person can pick out sounds from the background. This ability is commonly called the ``cocktail party affect'', because of the ability of a person to focus on different conversations from the background noise. This can only be done in a 3D acoustic field [14] and background noise in the virtual world does not use a 3D field.

Some researchers suggest the use of prerecorded sounds so that all computational power is devoted to determining the location and direction of the source. This, however, can not work in a 3D sound field. Although the sounds can be accurately placed in a 3D sound field, the listener can not interact with the environment--they can only observe it. In a 3D acoustic field played through headphones, when the listener turns around, the sounds that were behind the listener should now be in front. However, with prerecorded/playback methods, the sounds that were behind the listener are still behind the listener [1].

A realistic sound environment has great potential to be an interface for visually impaired or blind people. For example, a virtual environment can be created where the objects in it are application software. Then the users can learn their way around the environment, much like they can learn their way from home to the store without ever having to see.

Tactile and Force Feedback

One of the biggest complaints about top of the line virtual environment packages is the ``lack of tangibility.'' Although the area of tactile feedback is only a few years old, it has produced some impressive results. These solutions are critiqued below. There is no single interface currently built that will simulate the interactions of shape, texture, temperature, firmness, and force.

Being able to produce a realistic interface means having to produce tactile and force feedback to correspond to the objects in the virtual world. Dr. Fred Brooks of the University of North Carolina at Chapel Hill is noted for introducing the problem of ``shin-knockers'' [5]. This was originally in reference to modeling of a submarine: ``How are you going to let the person know when he knocks his shin on a pipe that is sticking out in his way?''

The area of touch has been broken down into two different areas. Force feedback deals with how the virtual environment affects a user. For example, walls should stop someone instead of letting them pass through, and pipes should knock a user in the shin. Tactile feedback deals with how a virtual object feels. Temperature, size, shape, firmness, and texture are some of the bits of information gained through the sense of touch.

Force Feedback

There are several different types of devices that allow a user to ``feel'' certain aspects of the virtual environment. Motion platforms for simulators and simulated rides, force feedback gloves, exoskeletons, and butlers are all forms of force feedback.

- Motion Platforms

The motion platform was originally designed for use in flight simulators which train pilots. A platform is bolted to a set of hydraulic lift arms. As the motion from a visual display changes, the platform tilts and moves in a synchronous path to give the user a ``feeling'' that they are actually flying. However, this platform has serious limitation in its range of movement. If the user's visual cues are that the plane is upside down, the hydraulics can not simulate this. However, it can usually give the middle ear sensations that correspond to the visual scene, making the simulation more realistic. For examples of motion platforms, see **http://www.vetl.uh.edu/Equipment/motion.html** or **http://ccad.uiowa.edu/media/still/index.html**.

- Gloves

  For interaction with small objects in a virtual world, the user can use one of several gloves designed to give feedback on the characteristics of the object. This can be done with pneumatic pistons which are mounted on the palm of the glove, as in the Rutgers Master II [**8**] (see **http://www.caip.rutgers.edu/~dgomez/rm2.html**). When a virtual object is placed in the virtual hand, the user's actual hand can close around it. When the fingers would meet resistance from the object in reality, the pressure in the pistons is increased, giving the sensation of resistance from the virtual object.

- Exoskeletons

  Exoskeletons are also employed to simulate the resistance of objects in a virtual world. An exoskeleton is basically a robotic arm strapped to a person. At the University of Utah, researchers have developed a robotic arm which has 10 degrees of freedom (for a picture, see **http://www.cs.utah.edu/projects/robot/IMAGES/jon_small.gif** or **http://www.cs.utah.edu/~jmh/sda-master-tom.gif**). The robot continuously updates the force to each of its ten joints, and can make it appear that the 50 pound arm is weightless. ``However, when the operator touches something, the virtual forces become actual forces felt through the exoskeleton'' [**10**]. This would make the operator's arm stop when it hit a virtual wall or feel the weight of a virtual object.

- Butlers

  The butler is a robot that basically gets in the way whenever you try to move through an object. If a user reaches out his/her hand to touch a wall, desk, or any other virtual object, the butler robot will place a real object at the location where the virtual object is supposed to be. This technique is currently being researched at the University of Tokyo by Susumu Tachi [18]. The butler being worked on ``provides mechanical impedance of the environment, i.e., inertia, viscosity and stiffness'' [18]. The major drawback of the butler robot is that it can only present these properties for a single point at a time.

The butler robot under development can give the impression of stiffness and viscosity, but it can't present the information needed by a human to know what the object feels like. The temperature and texture are totally unknown to the user.

Texture

The texture of a surface is probably the hardest feature of tactile feedback to simulate. The closest documented attempt is the Sandpaper system. This system, developed by a research group which includes members from MIT and UNC, can accurately simulate several different grades of sandpaper [1]. Other systems, like the Teletact Commander, use either air-filled bladders sown into a glove, or piezo-electric transducers to provide the sensation of pressure or vibrations. These systems have problems with the unreliability of compressors and interference between the piezo-electric transducer electromagnetic fields and the electromagnetic field used by a Polhemus tracking system [16].

Any attempt to model the texture of a surface faces tremendous challenges because of the way the human haptic system functions. There are several types of nerves which serve different functions, including: temperature sensors, pressure sensors, rapid-varying pressure sensors, sensors to detect force exerted by muscles, and sensors to detect hair movements on the skin. All of these human factors must be taken into consideration when attempting to develop a tactile human-machine interface.

Navigation

Tracking Devices

The purpose of a tracking device is to determine the x, y, and z position, and the orientation (yaw, pitch, and roll) of some part of the user's body in reference to a fixed point. Most types of virtual reality interaction devices will have a tracker on them. HMDs need a tracker so that the view can be updated for the current orientation of the user's head. Datagloves and flying joysticks usually have trackers so that the virtual ``hand'' icon will follow the position and orientation changes of the user's real hand. Full body datasuits will have several trackers on them so that virtual feet, waist, hands, and head are all slaved to the human user.

When designing or evaluating a virtual reality system that will receive tracking information, it is important to pay attention to the latency (lag), update rate, resolution, and accuracy of the tracking system. Latency is the ``delay between the change of the position and orientation of the target being tracked and the report of the change to the computer'' [**2**]. If the latency is greater than 50 milliseconds, it will be noticed by the user and can even cause nausea or vertigo. Update rate is the rate at which the tracker reports data to the computer, and is typically between 30 and 60 updates per second. Resolution will depend on the type of tracker used, and accuracy will usually decrease as the user moves farther from the fixed reference point [**2**]. Six-degree- of-freedom tracking devices come in several basic types of technology: mechanical, electromagnetic, ultrasonic, infra-red, and inertial.

- Mechanical Trackers

  A mechanical tracker is similar to a robot arm and consists of a jointed structure with rigid links, a supporting base, and an ``active end'' which is attached to the body part being tracked [**12**], often the hand. This type of tracker is fast, accurate, and is not susceptible to jitter. However, it also tends to encumber the movement of the user, has a restricted area of operation, and the technical problem of tracking the head and two hands at the same time is still difficult.

- Electromagnetic Trackers

  An electromagnetic tracker allows several body parts to be tracked simultaneously and will function correctly if objects come between the source and the detector. In this type of tracker, the source produces three electromagnetic fields each of which is perpendicular to the others. The detector on the user's body then measures field attenuation (the strength and direction of the electromagnetic field) and sends this information back to a computer. The computer triangulates the distance and orientation of the three perpendicular axes in the detector relative to the three electromagnetic fields produced by the source [2].

Electromagnetic trackers are popular, but they are inaccurate. They suffer from latency problems, distortion of data, and they can be thrown off by large amounts of metal in the surrounding work area or by other electromagnetic fields, such as those from other pieces of large computer equipment. In addition, the detector must be within a restricted range from the source or it will not be able to send back accurate information [12], so the user has a limited working volume.

- Ultrasonic Trackers

  Ultrasonic tracking devices consist of three high frequency sound wave emitters in a rigid formation that form the source for three receivers that are also in a rigid arrangement on the user. There are two ways to calculate position and orientation using acoustic trackers. The first is called ``phase coherence''. Position and orientation is detected by computing the difference in the phases of the soundwaves that reach the receivers from the emitters as compared to soundwaves produced by the receiver. ``As long as the distance traveled by the target is less than one wavelength between updates, the system can update the position of the target'' [2]. The second method is ``time-of-flight'', which measures the time for sound, emitted by the transmitters at known moments, to reach the sensors. Only one transmitter is need to calculate position, but the calculation of orientation requires finding the differences between three sensors [2].

  Unlike electromagnetic trackers that are affected by large amounts of metal, ultrasonic trackers do not suffer from this problem. However, ultrasonic trackers also have a restricted workspace volume and, worse, must have a direct line-of-sight from the emitter to the detector. Time-of-flight trackers usually have a low update rate, and phase-coherence trackers are subject to error accumulation over time [2]. Additionally, both types are affected by temperature and pressure changes [12], and the humidity level of the work environment [2].

- Infrared Trackers

  Infrared (optical) trackers utilize several emitters fixed in a rigid arrangement while cameras or ``quad cells'' receive the IR light. To fix the position of the tracker, a computer must triangulate a position based on the data from the cameras. This type of tracker is not affected by large amounts of metal, has a high update rate, and low latency [2]. However, the emitters must be directly in the line-of-sight of the cameras or quad cells. In addition, any other sources of infrared light, high-intensity light, or other glare will affect the correctness of the measurement [12].

- Inertial Trackers

  Finally, there are several types of inertial tracking devices which allow the user to move about in a comparatively large working volume because there is no hardware or cabling between a computer and the tracker. Inertial trackers apply the principle of conservation of angular momentum [2]. Miniature gyroscopes can be attached to HMDs, but they tend to drift (up to 10 degrees per minute) and to be sensitive to vibration. Yaw, pitch, and roll are calculated by measuring the resistance of the gyroscope to a change in orientation. If tracking of position is desired, an additional type of tracker must be used [2]. Accelerometers are another option, but they also drift and their output is distorted by the gravity field [12].

Interaction Devices

Virtual reality and virtual environments go far beyond typical interfaces in the realism of the visual metaphor. Point and click with a table-top mouse is wonderful in some situations, but not nearly sufficient for an immersive environment. So instead of a keyboard and mouse, researchers are developing gloves, 3D mice, floating joysticks, and voice recognition. This paper will not attempt to cover voice recognition because it is such a large domain.

Gloves

For sensing the flexion of the fingers, three types of glove technology have arisen: optical fiber sensors, mechanical measurement, and strain gauges. The Dataglove (originally developed by VPL Research) is a neoprene fabric glove with two fiber optic loops on each finger. Each loop is dedicated to one knuckle and this can be a problem. If a user has extra large or small hands, the loops will not correspond very well to the actual knuckle position and the user will not be able to produce very accurate gestures. At one end of each loop is an LED and at the other end is a photosensor. The fiber optic cable has small cuts along its length. When the user bends a finger, light escapes from the fiber optic cable through these cuts. The amount of light reaching the photosensor is measured and converted into a measure of how much the finger is bent [1]. The Dataglove requires recalibration for each user [9]. ``The implications for longer term use of devices such as the Dataglove--fatigue effects, recalibration during a session--remain to be explored'' [20].

The Powerglove was originally sold by Mattel for the Nintendo Home Entertainment System but, due to its low price, has been used widely in research [1]. This Powerglove is less accurate than the Dataglove, and also needs recalibration for each user, but is more rugged than the Dataglove. The Powerglove uses strain gauges to measure the flexion of each finger.

> *A small strip of mylar plastic is coated with an electrically conductive ink and placed along the length of each finger. When the fingers are kept straight, a small electrical current passing through the ink remains stable. When a finger is bent, the computer can measure the change in the ink's electrical resistance [1].*

The dexterous hand master (DHM) is not exactly a glove but a exoskeleton that attaches to the fingers with velcro straps. A mechanical sensor measures the flexion of the finger. Unlike the Dataglove and Powerglove, the DHM is able to detect and measure the side-to-side movement of a finger. The other gloves only measure finger flexion. The DHM is more accurate than either of the gloves and less sensitive to the user's hand size, but can be awkward to work with [9].

The main strength of the various types of gloves is that they provide a more intuitive interaction device than a mouse or a joystick. This is because the gloves allow the computer to read and represent hand gestures. Objects in the environment can therefore be ``grasped'' and manipulated, the user can point in the direction of desired movement, windows can be dismissed, etc [20]. ``Gestures should be natural and intuitive in the particular virtual environment. Actions should be represented visually and be incremental, immediate, and reversible to give a person the impression of acting directly in an environment'' [6]. Wilson and Conway [20] say that a basic set of command gestures for gloves has been developed, but that more work is needed to expand the set beyond the current simple mapping. Another area of improvement is feedback for the user to aid hand-eye coordination and proprioceptive feedback to let a user know when an object has been successfully grasped [20].

3D Mice

There are several brands of 3D mice available, all with basically the same technology: A mouse or trackball has been modified to include a position and orientation tracker of some kind [1. This modified mouse is fairly familiar and intuitive to users--simply push the mouse in the direction you want to move. However, these mice are not very useful for interactions other than navigation and selection of objects [9].

Joysticks

The final category of interaction device is the wand or floating joystick. Basically, this device works exactly the same as a conventional joystick, but it is not attached to a base that sits on a table top. Instead, the joystick is equipped with an orientation tracker so the user simply holds it in their hand and tilts it. Most flying joysticks also have some buttons on the stick for ``clicking'' or selecting, similar to a mouse [9].

Human Factors in Virtual Environments

Kay Stanney [13] has written an excellent critique of the areas that still need to be researched in order to make virtual environments a safe place to work. These include health concerns such as ``flicker vertigo'' which can induce a seizure, auditory and inner ear damage from high volume audio, prolonged repetitive movements which cause overuse injuries (for example, carpal tunnel syndrome), and head, neck, and spine damage from the weight or position of HMDs. Safety factors also need to be considered. For example, when a user's vision is restricted by an HMD, they are likely to trip and fall over cables or other real world objects. Also, how safe is the user from harm in the event of system failure? Hands and arms might be pinched or over extended if a haptic feedback device fails; the user might be disoriented or harmed if the computer crashes and suddenly dumps the user into reality, disrupting the sense of ``presence''.

Conclusion

Virtual reality holds promises of being the ``ultimate human-computer interface''. This would incorporate a natural, intuitive interface between a human and a machine generated work environment.

> *An intuitive interface between man and machine is one which requires little training . . . and proffers a working style most like that used by the human being to interact with environments and objects in his day-to- day life. In other words, the human interacts with elements of this task by looking, holding, manipulating, speaking, listening, and moving, using as many of his natural skills as are appropriate, or can reasonable be expected to be applied to as task [16].*

This paper has overviewed the technology currently in use, in addition to the open areas of research. Visual display devices, graphics display techniques, 3D audio, haptic feedback, navigation, and interaction devices are all in need of more development. Large areas of concern about the health and safety of the user are still in focus, not to mention the unsolved technical problems standing in the way of an intuitive immersive environment. As the public market for virtual reality grows in the coming years, more money will be spent on quality interface improvements and some of these problems may be solved.

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