Virtual reality

A real world review on a somewhat touchy subject

Virtual Reality (VR) is an advanced, human-computer interface that simulates a realistic environment. The participants can move around in the virtual world. They can see it from different angles, reach into it, grab it and reshape it. There is no little screen of symbols for manipulation nor commands to be entered to get the computer to do something.

The term "virtual reality" is credited to Jaron Lanier, who was the founder of VPL Research. The term *cyberspace* was coined by William Gibson in his 1984 science fiction novel, *Neuromancer*. Cyperspace is thought of as the ultimate virtual reality environment. It is an alternative computer universe where data exists like cities of light. Information workers use a special virtual reality system to enter cyberspace and to travel its data highways. This gives them the experience of being physically free to go anywhere.

Virtual reality feeds off a variety of fields. It is more a convergence of previously disparate disciplines than a whole new branch of technology. Virtual reality involves electronic and mechanical engineering, cybernetics, database design, real-time and distributed systems, simulation, computer graphics, human engineering, stereoscope, human anatomy and, even, artificial life. The many challenges for creating virtual reality systems include: software, hardware, human factors and VR over high-speed networks.

The basics

The core ideas are immersion and interactivity. Immersion means to block out distractions and focus selectively on just the information with which the participant wants to work. Interactivity means the ability for humans to interact with the events in the virtual world. A virtual reality system should have three characteristics: response to user actions, real-time 3-D graphics and a sense of immersion.

Virtual reality takes on various forms such as cab simulation, projected reality, augmented reality, telepresence and desktop virtual reality. Cab simulation is used for training airplane pilots. Projected reality uses projection technology to achieve a system that matches the quality of workstation screens in terms of resolution, color and flicker-free stereo. In augmented reality, see-through Head-Mounted Displays (HMDs) superimpose virtual 3-D objects on the real world. The outside world is visible along with the computer-generated graphics. With telepresence technology, when users manipulate objects in the virtual world, the results occur in a remote place of the real world.

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Desktop virtual reality is a subset of traditional virtual reality systems. It uses conventional, computer input and output devices such as a keyboard, mouse and monitor, instead of a head-mounted display. Although the same level of spatial awareness is missing, it is a popular choice for business users due to the inadequacies of existing head-mounted displays.

The architecture

Virtual reality's central objective is to place the participant in a virtual environment that gives the participant a feeling of "being there." This requires linking the human perceptual and muscle systems with the "virtual environment."

A VR system consists of three types of hardware: 1) sensors, 2) effectors and 3) the reality simulators. The sensors—such as head position sensors, which detect the operator's body movement, and data glove sensors, which measure the bend and flex of fingers—capture the user's actions and instruct the computer to generate new images and sound signals. The effectors, such as stereoscopic displays, stimulate the operator's senses. The reality simulator links the sensors and effectors to produce sensory experiences that resemble those in the physical environment. The reality simulator continuously churns out sensor and effector information in order to keep the virtual illusion alive.

Latest developments

Virtual reality has a wide range of uses from recreation to communication to scientific and medical research. Currently, its situation is similar to the early stages of computer graphics in the 1960s through the early 1970s. For example, the prices for producing a realistic, personal simulation are still expensive. The resolutions for 3-D displays are still poor. Outside of flight simulation, only a few VR applications have progressed beyond the laboratory to real business or popular uses. This is because achieving the performance specifications required for practical applications has been very expensive, costing tens of thousands to millions of dollars. Some VR products have matured in the field of technology, but their commercial value is still uncertain. For example, using a data-glove and HMD, the user can make small adjustments for the virtual object. The glove records 28 degrees-of-freedom of the hand. Also, another key problem in interacting with objects in a virtual environment is the lack, or limitation, of tactile and force feedback.

Industry is not viewed as having sufficiently long-term strategies to advance the field in many necessary

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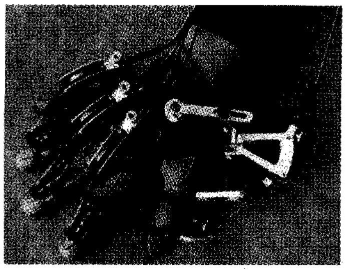
areas. But virtual reality's importance is clearly understood all over the world. Governments in Europe, Asia and US have appropriated funds to support research. Current research and applications may be divided into two general groups: 1) work done to advance particular professions or interests, such as virtual product design and surgical simulation, and 2) efforts to develop and perfect the technology itself, such as haptic-feedback devices, high-quality, comfortable displays and fast, accurate 3-D trackers.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The perceptual model

Psychological immersivity is the most important performance measure of effectiveness for media experiences. How does the human brain receive information from the real world and react to it? How can virtual reality software and hardware make the human brain form the same messages as from the real world? Knowing the working principles of the human perceptual system is essential for designing a virtual reality system.

Virtual reality device

The stereoscopic mode is one key advancement that will make virtual reality much more realistic. The aim is to produce images from a location that dynamically tracks the viewing orientation of the viewers. Thus, a convincing 3-D illusion is created. However, despite the potential demand for high resolution and the ability to track events, there is no hardware breakthrough currently. The HMDs and Binocular Omni-Orientation Monitor (BOOM) displays are still the most common virtual reality display devices.

For head tracking, the choices are mainly 1) ultrasonic, such as the Logitech tracking device or 2) magnetic, such as the Polhemus 3SPACE or "The Bird" by Ascension Technology Corp. Trackers, based on the magnetic approach, can be more accurate than ultrasonic devices but are substantially more expensive. The current, main, unsolved problem for tracking is the substantial lag time, or latency. (Latency is the delay between the time the user moves his or her head and the time the modified image is displayed.) The delay contributed by tracking and registration depends on the instrument and complexity of the graphics. The image rendering is based on the polygon rendering. The more accurate the polygon rendering, the slower the image display.

Nevertheless, scientists have presented many algorithms or approaches to increase the realness of virtual reality. For example, Michael Deering has a way to increase the high resolution accurately for a headtracked stereo display on a workstation Cathode-Ray Tube (CRT). This includes the steps in predicting headtracking, the dynamic optical location of the viewers' eyepoints, physically accurate stereo perspective viewing matrices and corrections for effective and curvature distortions of glass CRTs.

Ronald Azuma, Department of Computer Science at the University of North Carolina (Chapel Hill), has offered two methods to improve static and dynamic registration in an optical, see-through HMD. First, an optoelectronic tracker is used to provide the required range and accuracy. The viewing parameters are calibrated by three steps so the user can register a wide variety of viewing angles and positions.

Second, the inertial sensors mounted on the HMD assist in predicting the user's head motions. As a result, the dynamic errors are reduced. Azuma claims that prediction with inertial sensors produces two to three times fewer errors than prediction without inertial sensors, and five to 10 times fewer errors than using no prediction at all.

The haptic concept (touch) is as essential to immersion virtual reality as the visual and auditory concepts. For example, in the telepresence technology, a user needs intuitive force and tactile feedback from a remote robot griper. However, research on the tactile senses has lagged behind the visual and auditory senses.

There are different types of force and tactile feedback devices. However, there are only two major haptic device types. One is the glove-like device, such as the Dextrous Hand Mastera, developed by the Laboratoire de Robotigue de Paris; the Arts Glove, developed by the Arts Lab of the Scuola Superiore Santa Anna in Pisa, Italy, and the glove-like device developed by ARRI and Airmuscle Ltd. of Cranfield, UK. Its main feature is the glove structure that wraps around the hand and the fingers to support kinesthetic sensors from the fingers and the hand. The glove consists of resistors, or air pockets, distributed across the finger or the underside of the hand. Sequential inflation and deflation of the pockets convey virtual objects feedback to the wearer.

The other haptic device type is called a surface display. This allows users to directly manipulate an object in a virtual environment by touching a physical model of the object's surface as represented by an intermediate device outside the computer. When the user touches a physical model of the object's surface or moves the object, the display can simulate the object's behavior.

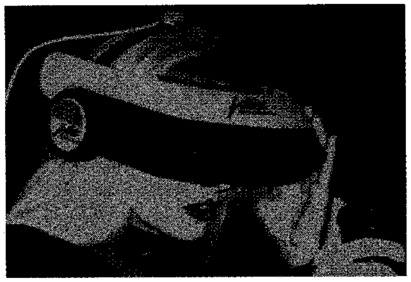
Both haptic devices may not allow a user to grasp a virtual object in the same way he or she would grasp a real object. This is because the virtual objects are defined in the computer while the user exists in the real world.

Simulation

Although virtual reality shows great promise as a research tool in computational science and engineering, its price can be much higher than ordinary graphics workstations. The Electronic Visualization Laboratory (EVL), at the University of Illinois at Chicago, has a hardware-independent, virtual reality development system. Its main focus is to provide a programming environment that facilitates practical applications. Various virtual reality system features are simulated with an interface that runs on an ordinary workstation. Application developers can use keyboard and mouse controls to manipulate the tracking sensors in the virtual space. These devices can track the position and orientation of the user's head. They also can be used to simulate virtual reality control devices, such as buttons on a wand or 3-D mouse, joysticks and data gloves.

Research over high-speed networks

There are many large-scale, scientific and technical problems that require a lot of distributed and heterogeneous computations. Some even require multi-site collaborations. Traditional computational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tools are not adequate for this purpose. Virtual reality over a high-speed network shows great promise as a research tool. The technique for this purpose includes: 1) distributed, real-time, heterogeneous computing, 2) large data sets, 3) remote instrumentation, 4) collaboration and 5) advanced, graphical devices.

The applications of supercomputing-to-virtual reality and virtual reality-to-virtual reality communication over high-speed networks were demonstrated at the annual ACM/IEEE Supercomputing Conference in San Diego (December 1995). The National Center for Atmospheric Research's (NCAR) Climate Simulation Laboratory example had the Global Information Infrastructure (GII) Testbed running over the Information Wide Area Year (I-WAY). The demonstration showed that large-scale problems can be decomposed into distributed and heterogeneous computing for scientists at multi-sites. Scientists also can convey parts of their laboratory to the site; or, they can contact other scientists to exchange their experiment data and learn from one another over the so-called cyberlaboratory.

Applications in engineering and medical fields

The previous examples describe virtual reality research activities for developing and perfecting the technology, itself. However, many engineering applications have already been developed.

Virtual product development. Because market competition is rigorous, lengthy product development cycles are not suitable. The sooner a company provides a new product to the market, the better its chances to obtain a large market share and higher profits. Virtual reality technology is considered a promising tool for this purpose. Areas it can help include compressing design time, reducing costs, improving product quality and improving performance. The products can be modeled, analyzed and designs refined right in the computer's virtual environment.

For example, the Chrysler Corp. and Ford Motor Co. have used the Virtual Design Environments to design and visualize all the development stages of their products. The time for product development was reduced from approximately 36 months to under 24 months.

There are many research activities on virtual design systems. For example, Fraunhofer Institute for Computer Graphics, Darmstadt, Germany, has developed a virtual reality tool set, called Virtual Design II, to support virtual product design applications. The system lets users import data from various sources, preprocess and enhance data, interact with and manipulate data in real time, and present the application using various audiovisual facilities.

Surgical simulation. Surgical simulation allows medical personnel to practice or to perform a complex task using an interactive computer environment. The multiple image modalities, such as Magnetic Resonance Imaging (MRI) and Computer Tomography (CT) are used to construct a 3-D model. This allows medical personnel to obtain information about tumor volume, bone, blood vessels, nerves and a patient's surrounding environment.

Many techniques, such as stereotactic frames and anatomical landmarks, are adapted to register these images. A large, deformation, finite-element model is used for the surgical simulation. The surgical virtual environment can be an aid to surgeons during operations and be used for training via simulation. Now scientists are trying to use augmented reality technology to overcome the difficulties in the telepresence technology for surgeons. The augmented reality technology allows an image to be overlaid consistently onto objects. This helps surgeons plan exact locations for incisions, define margins of tumors and precisely locate critical structures.

Future challenges

Virtual reality is a technology that feeds from a variety of other fields. Yet, as a field in its own right, it is characterized by a tight coupling of human factors and enabling technologies. The crucial challenges concern hardware, software, human factors and delivering virtual reality over high-speed networks. Hardware challenges include: 1) haptic-feedback devices, 2) high-quality, comfortable displays and 3) fast and accurate 3-D trackers. Software challenges include: 1) the computer graphics programming for virtual reality, 2) difficulties of 3-D interaction, 3) languages model (speech recognition), 4) operating system design, 5) time-critical computation and render support and 6) development system design. Human-factor challenges include: 1) determining how to use 3-D input and output effectively, 2) incorporating sound and speech in the user interface and 3) performing the cognitive research necessary to understand human interaction within virtual environments. Virtual reality over a high-speed network includes the problem of distributed, real-time and heterogeneous computing in large-scale parallel processors. Standards are of paramount importance for linking dissimilar player nodes and for content definition and human interaction.

Hardware. At present, the HMD systems are cumbersome, uncomfortable and have low resolution. The latency in tracking is still one of the most difficult problems. The ultimate, virtual reality tracking systems may be based on the nervous system. For example, hand tracking can be detected by sensors strapped across the outer skin (electromyography). The retinal display is the most far-reaching idea in virtual reality display technology right now. It draws pictures directly on the retina using a laser. The advantages are extremely high resolution and a precise eyetracking ability—knowing exactly what direction the user's eyes are looking at all times.

Software. The software should have the following functions: process the data from various input/output devices, such as tracker, glove, HMD, sound, speech recognition; provide a very convenient way for users to interact with the 3-D virtual world, and rapid, accurate modeling and rendering methods for the virtual environment.

The object-oriented graphics programming language may help to simplify the process of interacting and creating a 3-D simulation. The standard class mechanisms of the previous object-oriented programming languages provide a static, singly polymorphic form of inheritance. This is not adequate for designing a virtual environment because it requires the system to share information and communicate in dynamic ways on an object-by-object basis. What is needed for this purpose are dynamic, multiple-polymorphic systems that allow objects to collaborate to determine what action to perform.

The method for reducing the latency

depends on the hardware tracking sensors. However, it is also determined by the software generating the virtual world. "Time-critical computation" is essential for virtual reality systems to give real-time performance. Most current approaches for virtual reality focus on polygon rendering, which involves approximating the shape of each object with a various number of polygons. This algorithm can give real-time performance for only simple virtual worlds; to handle richer worlds, improved algorithms must come from somewhere else.

Creating 3-D objects is the primary task of mechanical and industrial designers involved in product development. Virtual reality can provide a direct manipulation method for users to work with 3-D graphics. Because 3-D computer objects have a high level of complexity, further improvements are required. The interaction should let the system users feel like they are holding or manipulating the actual object.

Human factors. Naturalness is the goal for any virtual reality interface. Thus, it is necessary to understand how the human biological system responds to and interacts with the virtual environment. Virtual reality developers are advised to befriend perceptual psychologists, the experts in understanding these issues. How human muscles and bones work, the way humans interpret stimuli and their psychological reactions need to be studied by engineers.

Over the high-speed network. There are still many obstacles and challenges faced in translating virtual reality technology into the high-speed networks. For example, large-scale problems that are decomposed into distributed, heterogeneous computing in parallel, compatibility of equipment in the remote sites (such as sensitivity to the number of processors) should be further studied. We should exploit the best way for networked computers to meet the real-time requirements for multiple interacting users and applications. The communication mechanism in the I-WAY should also be studied more.

Conclusion

Virtual reality is still in its infancy. However, many contemporary applications already have proven virtual reality to be indispensable to everyday life. For instance, the technology of virtual product design and manufacturing makes the new products better and cheaper. The applications of VR in medicine allow doctors to diagnose a disease more accurately. Without a doubt, it has and will foster more innovative research and applications.

High-resolution, low-lag and low-price systems will be the focus of future virtual reality research. The technology has been infiltrated into many application fields, involving training, medical, engineering, space exploring and communication.

Read more about it

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