VIRTUAL REALITY: A PRIMER
A DISCUSSION OF DEFINITIONS AND POSSIBLE APPLICATIONS FOR MILITARY TRAINING SYSTEMS

Dr. George C. Barcus
NAVTRASYSCEN
Orlando, Florida

Mrs. Theresa T. Barcus
NAVTRASYSCEN
Orlando, Florida

Mr. Richard R. Dunn-Roberts
Institute for Simulation and Training Technology
Orlando, Florida

Abstract

This paper reviews the latest developments in and traces the background of the "new" technology of Virtual Reality. Concepts covered will include the AIP cube, physical and geometric modeling, dead reckoning and behavioral modeling. Intended as a primer, through this article the reader will be introduced to the field of Virtual Reality by explaining common terms, theoretical concepts, enabling technologies and by presenting present and future applications of virtual environments.

Introduction

In the last few years, a significant amount of attention has been directed towards interactive simulations that take advantage of technical developments in human-computer interface technology. The popular name used to describe this type of simulation is Virtual Reality (VR). Other names include virtual environments and virtual interfaces. While advocates of the interface model claim extensive and far-reaching applicability for the paradigm, the current state of the technology is crude and intrusive. In spite of this, there is significant excitement about VR in academic research establishments, our military training communities, and the commercial entertainment industry.[1]

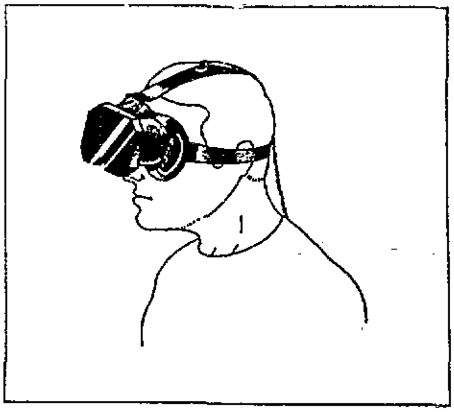
Background

The term "virtual reality" has been described as a collective term for a family of computer technologies that are capable of generating apparent three-dimensional space (referred to as cyberspace) where a person can achieve the "sense" of moving around and doing things within this space. Computer graphics visionary Ivan Sutherland first introduced the concept of virtual reality within the computer in 1965 when he described a computer monitor screen as a window through which one sees a virtual world. Even earlier, in his doctoral thesis, "Sketchpad", Sutherland described the first complete system for making drawings with a computer. Virtual reality has existed for over twenty years as a research tool first used by the Air Force in jet flight simulation and by NASA in preparation for the Apollo moon missions. The technology exists today and is being advanced by many university computer science departments, government and civilian research labs, and military projects.[2] It also exists in the field of computer-aided design (CAD), in which a designer and end user can observe, explore, and manipulate computer-generated objects. To a very limited degree virtual reality also exists in the entertainment world in the form of "space" games. As an educational tool, VR has been used to bring the student within a model or conceptual environment to be studied to better explain its content, structure or purpose.

While at the University of Utah in 1968, Sutherland developed a 3-D display system that reacted to the user's head movements. This system provided a wrap-around virtual environment. In 1974, Myron Kruger, then a graduate student at the University of Wisconsin at Madison and now a Connecticut computer scientist, coined the phrase "artificial reality" while conducting research and experiments to test his belief that humanity's relationship to technology can be a positive experience. Presently, one of his environments, VIDEOPLACE, installed at the Connecticut Museum of Natural History in Storrs, Connecticut, continues to be used to further this research in man-machine interaction.[3]

The Department of Defense in 1978 invested over a million dollars to develop a 3-D display simulator as part of the project called Visually-Coupled Airborne Space Simulator (VCASS) for pilot training. The outgrowth of this work eventually produced the Super Cockpit. This was one of the earliest military applications of virtual reality and arose from work carried out at the Wright Patterson Air Force Base. The goal of this work was to develop advanced avionics and cockpit management systems to permit the screening of pilots of future military aircraft from direct visual contact with the outside world.[4]

In 1984, the Human Interface Research Laboratory at NASA's Ames Research Center developed the first lightweight stereoscopic head mounted display based on miniature Liquid Crystal Display (LCD) monitors, and funded a small California computer company, Virtual Programming Languages (VPL) Research, Inc., for development of the DataGlove. [5] The DataGlove consists of a glove fitted on the back with a network of fiber-optic cables connected to a light-emitting diode at one end and an array of photosensors at the other. Flexing a finger reduces the flow of light where a fiber-optic cable is bent at a knuckle or joint; the resulting change in light intensity is translated into positioning data that can be transmitted in digital form to a computer. The most common version of this type of input device, although admittedly crude compared to its possible potential, is Mattel Inc.'s Power Glove.[6] This is a joystick substitute used for controlling Nintendo games. Subsequent research has produced VPL EyePhone goggles which is a display *mechanism comprised of two small color LCD* video monitors in a counter balanced head-mount. An example of this type of system is shown in Figure 1. Wide angle optics in front of the eyes give the user an approximately 120 x 60 degree field of view. This system uses two National Television System Committee (NTSC) composite video signals. Presently, VPL Research Inc. founder, Jaron Lanier is directing the development of an expermental computer network, known as RealityNet, that will attempt to make virtual reality transmittable over standard telephone lines. Partners in this system will include the University of Washington Human Interface Technology Laboratory, the Computer Science Department at the University of North Carolina, and the Massachusetts Institute of Technology (MIT) Laboratory in Cambridge, Massachusetts.



Head mounted virtual reality display mechanism

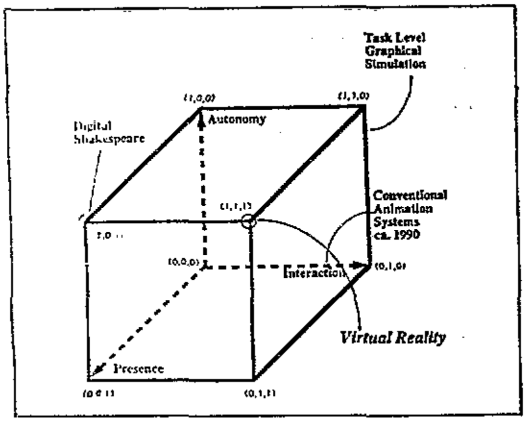
FIGURE 1

International interest in the field of virtual reality is evidenced by the work of the Advanced Telecommunications Research Institute, a consortium of 150 firms, mostly Japanese, which are devoting in excess of 5 million dollars per year for ten years to explore "communications with realistic sensation." A related area of research comprising virtual reality is involved with tactile feedback. The TELETACT Virtual Tactile Feedback System (a registered Trade Mark name of Airmuscle Limited manufactured under licence by the Advanced Robotics Research Limited Company) was designed to investigate the lack of tactile and force feedback when interacting with objects in a virtual environment. By using a glove-based stimulation device, this system assists in permitting experimenters to generate simple tactile and *force patterns* for a variety of objects. These can be stored on computers and recalled to identify "contact" with virtual objects.[7] Current efforts in virtual reality include work at the Aerospace Human Factors Research Division of NASA's Ames Research Center where an interactive Virtual Interface Environment Workstation (VIEW) has been developed to aid design, simulation and evaluation of advanced data display and management concepts for operator interface design. The VIEW system will provide a virtual auditory and stereoscopic image surround that is responsive to inputs from the operator's position, voice and gestures. As a low-cost, multipurpose Input/Output (I/O) device, this variable interface configuration will allow the operator to virtually explore a 360 degree synthesized environment. It can also be used to remotely explore hazardous environments or control robotic devices at a distance.[8]

Efforts known as Telerobotics and Telepresence are examples of VR technology that help remove man from hazardous environments. The Advanced Robotics Research Limited Human Factors Program called Virtual Environment Remote Driving EXperiment (VERDEX) addresses the design of advanced human system interfaces which permit intuitive interactions between a human operator, a robotic vehicle and a remote environment. VPL Research, Inc. has recently developed a system that allows more than one user to share a virtual space. Known as Reality Built for Two (RB2), it is a development platform for *designing and implementing* real-time virtual realities.[9] Additional VR interests involve 3-D sound, advanced development platforms and improved tracking mechanisms such as the Polhemus Isotrak.[10]

In spite of the flood of development of virtual reality systems, VR is in serious danger of being oversold by the media. To understand the problems facing VR developers we will look at some theoretical work and concepts arising from that work. The AIP cube proposed by David Zeltzer of MIT's Media Laboratory is a qualitative tool for evaluating virtual realities. The AIP cube, as displayed in Figure 2, provides for a taxonomy of virtual environments based on three components Zeltzer considers to be salient. These components are autonomy, interaction, and presence, hence the name of the cube.

Each of these components represent an axis of the cube, and can be considered to have a value between zero and one. The autonomy axis represents the sophistication of the computational model underlying the simulation. If there is no model, we have a static geometric model that can be rendered as a picture, but has no capability for autonomous behavior. This is represented as an autonomy value of zero. An autonomy value of one would indicate a very sophisticated model, supporting a high level of autonomous and emergent behavior in the simulation. The interaction axis represents our ability to affect the simulation during the runtime cycle. An interaction value of zero would be indicative of a graphical simulation that could not be affected once started. An interaction value of one represents allowing the user to modify any and all model parameters during runtime. It is not desirable, however, to require the user to maintain control over all model parameters, because the user could easily be overwhelmed.



AIP CUBE: Autonomy, interaction and presence

FIGURE 2

The final axis of the AIP cube is the presence axis. This refers to the degree to which the user actually feels immersed in the virtual reality. Presence is supported by the I/O peripherals (such as a Helmet Mounted Display (HMD)) through which the user perceives the VR. This can also be expressed as the success with which the I/O channels of the virtual reality map into the I/O channels, or senses, of the human user. Again, a value of 0 represents the least amount of presence, such as a keyboard and text based monochrome monitor, while a value of 1 would represent a VR in which the user feels completely immersed.

Modeling, introduced above under autonomy, is an area of great interest in VR research. Modeling can be broken down into three areas: geometric modeling, physical modeling, and behavioral modeling. The geometric model represents what the object being modeled looks like ... its shape, color, texture, etc. The physical model represents the mechanics of the object's behavior. The behavioral model represents higher level abstract behaviors.

Definitions

Before continuing, it may be helpful to review and explain a few of the more common terms relating to the field of virtual reality. Although presently definitions are not stable, many being coined or trademarked as new applications and products are discovered and produced, quite a few have attained "common usage" status. A sampling of these include:

- <u>Convolvotron</u>
  A signal processor that coordinates a target location and the position of the listener's head and "places" the signal in the perceptual 3-D space of the user.
- <u>Cyberspace</u>
  While there is more than one definition listed, for this paper, the first definition more closely describes our use of the term "cyberspace".
  -(John Walker of Autodesk) Cyberspace is a system that provides the user a three-dimensional interaction experience that provides the illusion he is inside a world rather than observing an image. At the minimum, a cyberspace system provides stereoscopic imagery of three-dimensional objects, sensing the user's head position and rapidly updating the perceived scene. In addition, a cyberspace system provides a means of interacting with simulated objects.
  -(William Gibson) First coined the term cyberspace in the 1982 trilogy NEUROMANCER, COUNT ZERO, and MONA LISA OVERDRIVE. This referred to a 3-D representation or model of information. This representation could be used to access or modify the underlying data. Cyberspace "tricks" participants into believing they are within a place, real or imaginary, apart from their location in physical space.
- <u>Cybernetics</u>
  The science of communication and *control theory that is concerned* especially with the comparative study of automatic control systems (as in the nervous system and brain and mechanical-electrical communication systems).
- <u>Distributed Virtual Reality</u>
  A VR program running on a distributed network of computers.
- <u>Virtual Reality</u>
  While all definitions listed are correct, Mr. Dunn-Roberts' definition is the one the authors used in this paper.
  - (Dunn-Roberts) Denotes a multi-sensory real-time simulation that immerses the user in 3-D graphical space through the use of innovative I/O (Input/Output) technology, such as head-mounted displays. VR allows freedom of movement within the space, and supports complex interactions including the modification of features of the space itself. Other terms used are artificial reality, cyberspace, virtual environment and virtual world.
  - (Emery) Virtual reality is described as a collective term for a family of computer programs that are capable of

generating apparent 3-D space where a person can achieve the "sense" of moving around and doing things within this space.

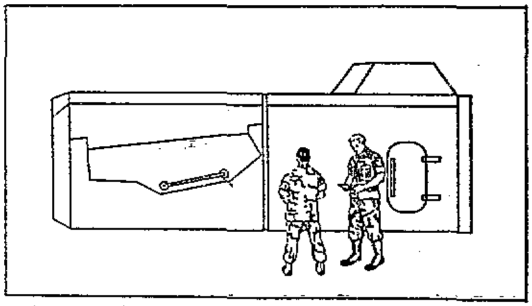
- (Stone) Virtual Reality broadly refers to the generation, using computer graphics, of realistic three-dimensional visual, audio and tactile worlds in which a suitably-equipped user can explore and interact with virtual objects using natural human skills.

Present Military Applications

Based on Zeltzer's taxonomy, no current systems are complete virtual realities. However, there are many research efforts that are moving us towards virtual reality. Many of these research efforts have been and are being conducted under the auspices of military research, although not always with the specific intent of furthering our virtual reality capabilities. As mentioned above, Tom Furness's VCASS project was one of the first military projects to use head-mounted displays in association with computer generated three-dimensional worlds. This system was developed to look at the use of advanced interface technologies to improve pilot situational awareness in fighter aircraft. Project scientists realized that a fighter pilot must operate his aircraft in a 3-dimensional space while the information necessary to that operation is presented to the pilot came from highly coded two-dimensional representations of the world. Often, in order to obtain that information, the pilot must lower his head from the real world in which he must operate. Furness wanted to take advantage of the human capacity for handling properly presented spatial information. The Super Cockpit used a helmet-mounted video display system to either overlay the real world with imagery, or to completely replace the real world with a synthetically generated representation of the real world. Information that had a spatial context for the pilot, such as threat information, was conveyed in spatially relevant positions. Three-dimensional audio also conveyed directional information. Both head and eye position were tracked to facilitate selection of virtual switches. Voice and gestural command input was also allowed.

However, the Super Cockpit is not the only military research project that has VR applicability. The Visual Technology Research Simulator Laboratory (VTRS) at the Naval Training Systems Center in Orlando, Florida, has worked on many aspects of simulators that may have future impact on VR systems. Projects done at VTRS looked at questions involving motion bases on training simulators and the use of head and eye-tracking equipment in dome based simulators.

SIMNET, a large scale networked team training simulation system, is not considered a virtual reality system; however, it is another important forerunner to a virtual reality system. SIMNET, as shown in Figure 3, actually provides many of the characteristics of a virtual environment and adds at least one important possible component of future VR systems. SIMNET provides a multi-sensory (sight and sound) immersion in a synthetic environment where users can interact with many other participants. While the user's windows into the virtual world are small, a shell representing an M1A1 Abrams tank helps improve the sense of presence. Some of the participants the user interacts with are other humans, as well as others being autonomous enemies controlled by a computer. One of the most important contributions made by SIMNET is the concept of dead reckoning. Dead reckoning allows each participant in the networked simulation to keep track of the location and state of all other participants while reducing the network traffic. Each participant stores location and velocity information for all other participants, and updates their locations during each time slice in the simulation. If a player's real location deviates from the location determined by dead reckoning, the player sends out an update to the other participants to correct their perception of the player.[11]



SIMNET: A large scale networked team training simulation system

FIGURE 3

However, as stated, SIMNET falls short of virtual reality. Interaction in SIMNET is limited to interactions between players. The database representing the world in which a SIMNET exercise takes place is static, and cannot be affected by the players. Also, presence is limited by the small size of the user's viewports into the world. In order to address these issues, the Army Project Manager for Training Devices (PMTRADE) has funded several research projects at the University of Central Florida's Institute for Simulation and Training (IST).

The first of these projects is looking at the integration of low cost head-mounted displays with several image generators, including SIMNET and an Evans and Sutherland ESIG-500. This project is looking at the feasibility of using head-tracking capability and HMD's to improve the user's access to the world modeled in training simulators, including head-out-of-the-hatch operation and dismounted infantry capabilities. This work explores technologies that may improve a trainee's sense of presence in the virtual world in the training simulator. [12]

Another project underway at IST is exploring the algorithmic requirements to increase the level of interaction with the virtual world at runtime in a training simulation. This project has modeled a virtual bulldozer that can dig trenches and tank defilades, as well as a water flow model that simulates the flow of water in the virtual world. These capabilities are representative of physical models that are not currently available in real-time image generators, and will be necessary to provide interaction and autonomy in a virtual reality.

Also underway at IST is a project to develop a laboratory testbed for evaluating new VR technologies. The Virtual Environment Test Bed (VETB) is based on an IST developed networking protocol to support virtual environments running on a distributed heterogeneous network of computers.[13]

In addition to projects that are advancing the enabling technologies of virtual reality, some projects take advantage of VR technology to support other efforts. At NASA Ames Research Center, the Crew Station Research and Development Facility (CSRDF) is using a simulator to assess proposed designs for the LHX light attack helicopter. The simulator is built around a General Electric Compuscene 4 image generator driving a CAE Electronics HMD. This is an example of the use of virtual reality technology for design. The Army expects to save about $1 billion by not building prototypes of the LHX.[14]

The CSRDF simulator is similar to several other simulators based on CAE HMDs. These include an F16 pilot trainer at the Air Force Human Resource Laboratory at Williams Air Force Base and Army Research Institute Helicopter simulator at Fort Rucker.

Future Military Applications

Future applications of VR in support of training are limited only by how far we have progressed in moving systems along the three axes of Zeltzer's AIP cube. As stated earlier, the current state of the technology is not sufficient to support all of the applications we can imagine supporting. However, research into display technology, force feedback, computational modeling and algorithms is improving our capabilities. The virtual worlds we can build will improve.

Perhaps the most obvious use of virtual reality technology in support of training is the idea of a virtual simulator. In the morning, a team of army aviators might use the virtual simulator to practice flying attack missions just above tree level. After lunch, a crew of Navy aviators practice carrier landings. Later, a group of human factors scientists may test cockpit configurations. To support the virtual simulator and allow for different kinds of controls, improvements will be required in HMD resolution and tactile and force feedback capabilities.

Training simulators could be enhanced through networking to provide for large scale training exercises. They could also be enhanced through the use of autonomous enemy forces to provide training in strategy and tactics. VR technology may provide for the inclusion of dismounted infantry in the combined arms training exercise, although there are some difficulties associated with this. For a long-range view of the prospects for seamless integration of dismounted-infantry into combined arms simulations, see the work of D.K. McBride.[15]

An interesting variant for dismounted infantry training in VR involves the use of Personnel Amplification Systems (PAS), such as the ones studied at Los Alamos National Laboratory in the PITMAN project. This engineering study examined issues ranging from force feedback and servo design to visual displays. Such a suit could actually provide the interface through which a soldier would be immersed in the virtual world, complete with force feedback.[16][17]

Finally, we wish to look into the not so near future and expand on the possibilities in the use of VR for training commanders in strategy and tactics. We can imagine a virtual war college, where commanders could visit simulated battles that had either been fought or were under planning. In observing virtual battles, commanders could take advantage of the ability to scale time and space to gain a God's eye view of the battle while jumping through time to interesting moments in the course of the battle. The spatial correspondence of the virtual battlefield to the real battlefield would aid commanders in placing units on the virtual battlefield to test what-if hypotheses about battles. This virtual war college is far in the future, if it can be attained at all. However, this is the type of application that helps maintain the excitement that virtual reality is creating.

Conclusions

Although the material presented here is by no means exhaustive, the intent is to introduce the reader to the field of virtual reality and suggest a starting point for learning more about the subject. As VR applications and related computer technologies advance, the use of virtual reality and its associated techniques will become more common place in the future development of military training systems.

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ABOUT THE AUTHORS

Dr. George C. Barcus is the Project Director for Advanced Technology within the Program Director, General Education Methodology and Technology at the Naval Training Systems Center, Orlando, Florida. He holds a Doctorate Degree from the University of Central Florida in Education, a Master's Degree from the Ohio State University in Instructional Media and an additional Master's Degree from the University of Florida in Curriculum and Instruction.

Mrs. Theresa T. Barcus is an Education Specialist in the Strategic Planning Group at the Naval Training Systems Center, Orlando, Florida. She holds a Master's Degree in Education from the University of Florida and is presently pursuing a Specialist Degree from the University of Central Florida.

Mr. Richard R. Dunn-Roberts is a Visual Systems Scientist at the Institute for Simulation and Training at the University of Central Florida, Orlando, Florida. He is currently working in the Visual Systems Laboratory on projects exploring the use of advanced display technology with real-time image generators and training simulators. He has a B.S. degree in Computer Science from the University of Central Florida, and for his Master's Degree is exploring design and integration requirements of virtual reality.