VIRTUAL REALITY: THEORETICAL AND PRACTICAL IMPLICATIONS

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ABSTRACT

The concept of virtual reality and the wave of research and development accompaning it are creating new forms of simulation that may lead to fundamental improvements in simulation-based training. However, because virtual reality is a relatively new concept within the training community, there seems to be a few misconceptions concerning what virtual realities are, how they are created, and how they can be used. In an effort to clarify readers' understanding concerning virtual realities, this paper examines three dimensions that will describe virtual reality's role and effectiveness in simulation-based training.

INTRODUCTION

Virtual reality refers to both the experience of residing in an artificial environment and the medium that makes such an experience possible. As an experience virtual reality offers a strong sense of "presence" (Zeltzer, 1990) in a synthetic environment, unlike a movie which may portray an alternate reality but cannot give viewers the compelling sense that they are actually present within it. As a medium, virtual reality is a type of interactive computer-based simulation controlled in part by the user (Walsher, 1991). In a virtual reality, the user is included as part of the simulation. This represents a break from traditional computer-based games and simulations which provide interactive components but do not include the user as part of the simulation.

Virtual reality is a loosely defined concept, represented so far by a number of rather simple prototypes (Helsel & Roth, 1991). Yet, the concept holds promise for applications in military training and other types of computer-assisted instruction. Virtual reality research is leading to new insights in modeling, simulation, and multisensory human-computer communication (Burg et al., 1991). However, there are indications that virtual reality technology is often misinterpreted as a single technological innovation associated with helmet mounted displays, or sometimes with input devices such as DataGloves. The technology is also mistaken for particular hardware and software implementations in much the same way that particular computer processors (e.g., lisp machines) and languages (e.g., Prolog) were mistaken for artificial intelligence technology. In an effort to clarify readers' understanding of virtual reality's potential for training applications, this paper describes three components that will determine its role and effectiveness in simulation-based training. The theoretical and practical implications of "verity," "degree of integration," and "natural vs. artificial interface" are defined below.

VERITY

The verity dimension of a virtual reality refers to the degree that our natural environment is simulated. The word verity is derived from a Latin term, "veritis," which means "true to life." It is used here to denote a continuum of simulation experiences that range from simulating, as much as is humanly possible, the physical world as we know it to simulating a totally invented world.

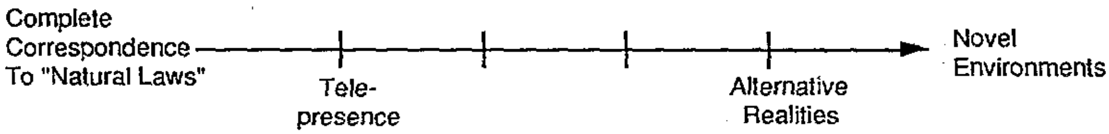

Figure 1. The Verity Scale

Figure 1 depicts the verity of virtual realities ranging from "telepresence," the representation of the real world in real time, to "alternative realities," which are completely novel environments . An example of telepresence is depicted by remote-controlled, undersea robots that provide a view and a way to manipulate objects in sea environments (Spring, 1991).

NASA's Ames Research Center, has developed a helmet mounted display which, when worn by astronauts inside a space station, enables them to see through a robot's "eyes" outside the station. As an astronaut's head turns, the robot's camera eyes simultaneously swing in the same direction (Foley, 1989). Astronauts can make repairs without leaving the safety of the space station. Telepresence literally allows users to be in more than one place at the same time.

Further toward the novel environments end of the continuum are simulations that go beyond reality. These virtual realities model, in a tangible form, abstract information such as mathematical equations, vortices, shock systems, and flow patterns. In their visual form such information is commonly represented by lists of or matrices of numbers, but when converted into graphic images, the information undergoes a qualitative change that brings the human visual system into play. Our ability to recognize, categorize, and analyze visual and aural patterns goes far beyond our ability to deal with purely numeric data (DeFanti, Brown & McCormick; 1989). This form of virtual reality may empower human users to overcome problems of scale in studying and manipulating objects such as atoms, molecules, DNA, brain maps, or entire galaxies (Foley, 1989).

Finally, at the far end of the verity scale lie those simulations which have little basis in physical reality. These virtual realities are represented by environments that have no physical counterparts and are governed by laws originated by the developers. In such virtual realities, the laws that govern the universe as we know it may be modified, suspended, or contradicted (Spring, 1991). For instance, mathematicians create computer-based models of curved, or hyperbolic, space, where the rules of geometry differ from those we normally encounter. As an example, in hyperbolic space the sum of the angles within a triangle is less than 180° (whereas the sum is exactly 180° in ordinary Euclidian space). Despite the fact that these "realities" exist only in the minds of physicists and mathematicians, they are useful in comprehending how objects act in curved space. Guided by carefully crafted instructions, computers can simulate familiar objects, display abstract concepts, and create new worlds beyond the confines of human experience - occasionally with surprising results. (Peterson, 1990)

INTEGRATION

Virtual realities are a type of interactive simulation which includes the human user as a necessary component. Virtual realities are fundamentally different from other interactive simulations in the way that the user is integrated within the computer simulation.

Viewed historically, there are three broad eras of human-computer integration. In early systems, the interface consisted of batch processing where the computer and user acted as completely separate entities. The user's job was to set up mathematical tasks to be performed in a linear sequence, code the information in a format that was interpretable by the computer (i.e., the computer program), start the program, and wait for the output. In this type of interface the user and the computer had very distinct and different roles. Those roles called for little, if any, human-computer integration.

The second era of human-computer interface came about when computers were developed that were capable of carrying on a dialogue with the user. For example, context sensitive help systems enabled the computer to assess users' error patterns and provide correct information to help them complete unfamiliar tasks. In the training arena computer-assisted instruction and computer-based training simulations were developed that made computers capable of assessing students' needs and providing feedback and other instructional assistance based upon student performance.

In the dawning era of human-computer interface, simulation technology makes it possible to go beyond simple assessment of user behavior. In such a system the dialogue is replaced by simultaneous interaction of the user and the computer within the simulation. Such interface designs can be typified by an interactive simulation where user input is simply one data source. In such systems, the simulation is less of a sequence of preprogrammed events. Rather, the simulation is created by constructing a computer world of animate and inanimate objects, defining the world's laws, and populating the world with consistently behaving characters. According to Burg et al. (1991), the idea is to create not just one sequence of events that replays itself every time the simulation is turned on, but to create a virtual world of objects which act and interact in an independent but emergent manner. In such a simulation, the computer defines what an object is and then insists that it remain true to its definition as it reacts to the evolving situation. Burg et al. states:

> The point here is that the programmer need only describe (declaratively) the objects in his world, without prescribing (procedurally) what each object will do at every turn. Written into the ... system are the laws which govern the virtual world, and behavior emerges naturally from object descriptions and the [virtual] world's natural laws. (p.5)

It is at this level of human-computer interaction where virtual reality is directed. Figure 2 graphically depicts the integration dimension of virtual reality.

Walsher's (1991) depiction of cybernetic simulation represents an appropriate description of an inte-

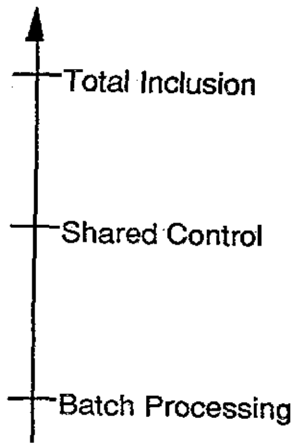

Figure 2. Integration Dimension of Virtual Reality

grative simulation. According to Walsher, a cybernetic simulation is a dynamic model of a world filled with virtual objects that behave the same as their physical counterparts. In addition, certain objects (Walsher calls them "puppets") are controlled by the actions of human users (termed "patrons"). The patron's movements are monitored by sensors installed in DataGloves or DataSuits. When the patron moves, the puppet moves in direct relation. According to Walsher, the principle function of the cybernetic simulation, besides simulating a virtual world, is to maintain a tight feedback loop between the human user and the puppet. This will give the user "...the illusion of being literally embodied by the puppet (i.e., the puppet gives the patrons a virtual body, and the patrons give the puppet a personality)." (Walsher, 1991; p.35)

Figure 3 depicts the relationship between the patron and the puppet. The puppet monitors the patron through such sensors as data gloves, data suits, joystrings, or head trackers and acts on the patron through various effectors such as video displays, sound generators, resistance controllers, motion platforms, force feedback devices, and so on.

What makes Walsher's explanation of cyberspace useful is the way one thinks about sensors and effectors. Most interactive simulations are designed extrinsically, that is, from the user's point of view. Typically users conceive of themselves as standing outside the system and using "input devices" to put information in and "output devices" to get information out. A *cybernetic simulation*, on the other hand, is defined intrinsically, that is from the puppet's point of view. Under an intrinsic point of view, the sensor in Figure 3 refers to a device through which a puppet acquires knowledge of events in the physical world. The same device would have been formerly called an input device. A puppet's effectors, on the other hand, are output devices in the old way of speaking. Walsher states:

> Generally, a patron affects virtual space through a puppet's sensors and learns of events in virtual space through a puppet's effectors. That is, a puppet's sensors are a patrons effectors, and a puppet's effectors are a patron's sensors. This can be confusing until you shift your thinking to the intrinsic viewpoint, and realize that discussion is always centered on a point of view from within the virtual space (the term patron, as another example, is used to suggest an actual visit to a place, such as a museum).

The ultimate form of this kind of human-computer integration will not require the use of a puppet. Instead the patron will be integrated directly into the simulation. A fully integrative system is depicted by the "Holodeck" simulations from the television series Star Trek: The Next Generation. The "Holodeck" views each patron as only one data source among many within the simulation (Spring, 1991). In addition, the patron needs no artificial sensors (e.g. DataGloves) to interact with the simulation.

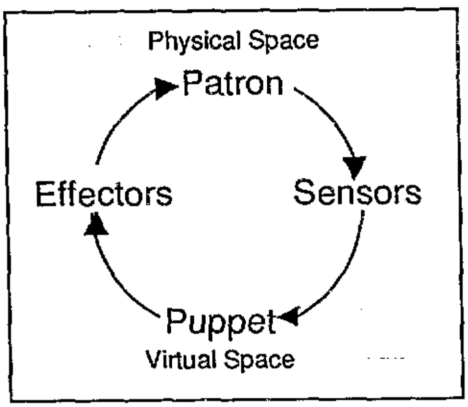

Figure 3. The Cybernetic feedback loop (adapted from Walsher, 1991).

NATURAL VS. ARTIFICIAL INTERFACE

The third dimension we have used to characterize virtual reality is the form of interface that enables the user and computer to interact within the simulation. On the low end of this continuum are artificial input/output devices such as a keyboard, mouse, or trackball. Moving up the continuum are body-mounted sensor/effector systems such as helmet mounted displays and datasuits. These systems represent a more direct and natural way of interfacing with the simulation. On the high end of the continuum the virtual reality system is capable of monitoring users' behavior, including voice commands and body position, without the use of body-mounted external input devices. Thus the computer and user interact quite naturally.

A good example of the interface dimension can be found in the field of oceanographic research. Because oceanographic researchers are dealing with an environment that, at times, can be quite inhospitable to humans, they have invented many devices to interface with our oceans and seas. These interface devices, like the human-computer interface, form a continuum ranging from the very artificial to the quite natural. At the artificial end of the continuum lie remotely piloted vehicles. These vehicles allow a researcher to "see" the underwater environment from the relative comfort of a computer terminal. The researcher need never get his feet wet! At the other end of the continuum, the natural end, researchers can completely immerse themselves in the medium by scuba diving. Somewhere in the middle of the continuum lies the use of underwater submarines which have remotely controlled robotic arms.

Likewise, on the low end (the artificial end) of the interface scale, a virtual reality may use some form of an external input device to control a "puppet" in a virtual space or, on the high end of the scale, the user may participate directly.

THE CUBE

Figure 4 shows that the three dimensions - verity, integration, and interface - when combined, form a three dimensional coordinate system which can be used to classify virtual reality systems*. All the

* The idea of depicting virtual reality in cube form and the classification system used here was inspired by Spring's (1991) and Zeltzer's (1991) articles.

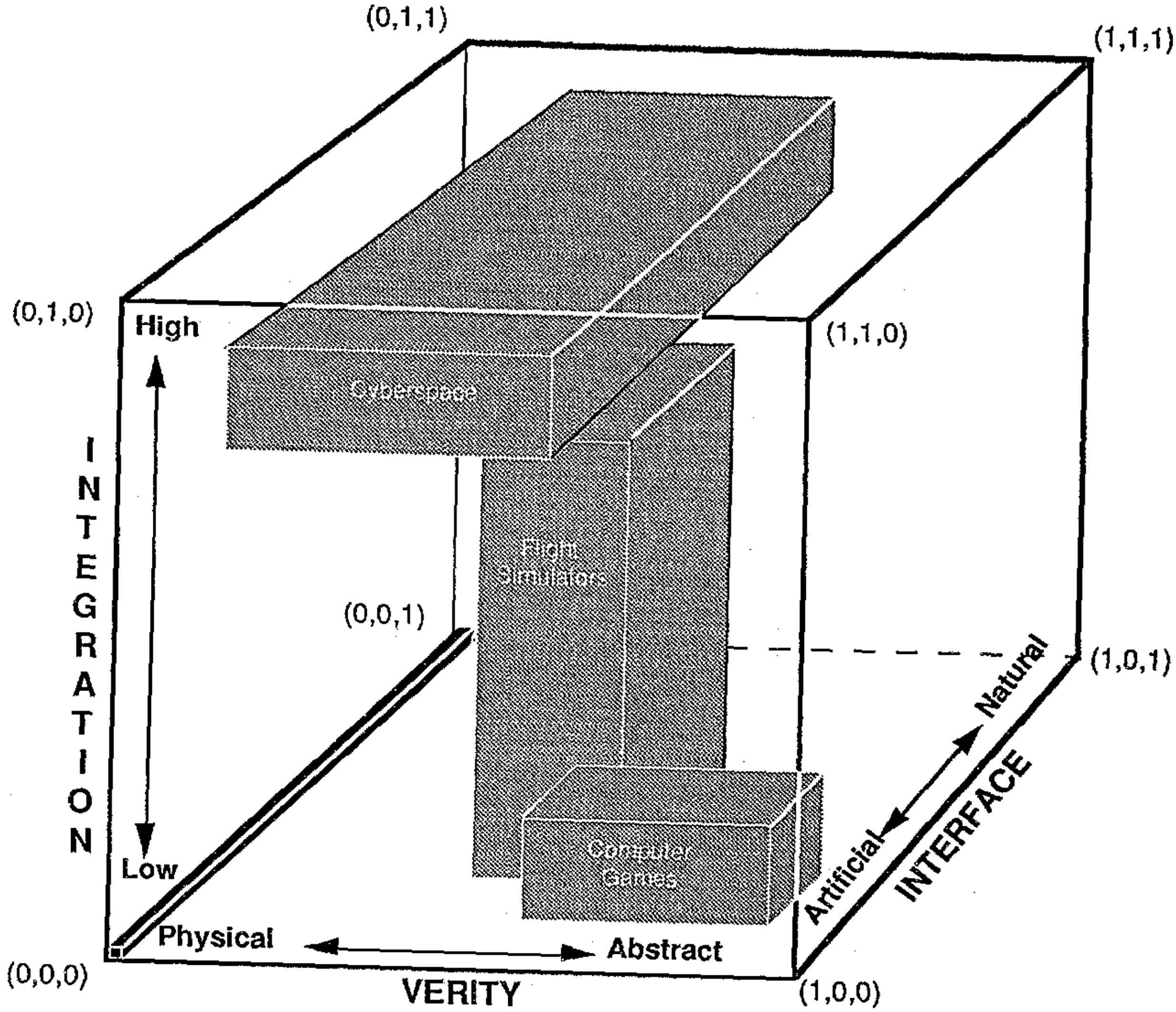

Figure 4. Dimensions of Virtual Reality

corners of the cube in Figure 4 have three numbers. Each number corresponds to the verity, integration and interface dimensions, respectively. For ease of interpretation the range for each dimension is scaled from zero to one. This lends itself to quantifying a virtual reality's salient characteristics. For example, one could describe a particular simulation by assigning a value of .33 for verity, .89 for integration and .65 for interaction.

At the origin (0,0,0) simulations are strictly numerical exercises, probably done in batch mode, where the user does not participate (except to read the printout when it is done). While computational simulations are very valuable to business and/or research, they are hardly virtual realities.

Position (1,0,0) is not much better from a virtual reality standpoint. This position exhibits the same limitations discussed above with the exception that this represents a situation where physical laws, as we know them have been sufficiently changed so as to represent an entirely new reality. For example, physicists sometimes write simulations which attempt to portray worlds which exist in five or more dimensions. Such work is very valuable to researchers who are trying to understand hyperbolic space (Peterson, 1990). Often they are able to print out graphic depictions of these artificial realities which are really quite stunning in their visual and emotional impact. However, these simulations do not constitute a virtual environment. Actually, these simulations are straightforward in terms of input and output, require a minimum of interface with the simulation, and are little more than "batch mode" computations.

In contrast, positions (1,1,1) and (0,1,1) represent full implementations of virtual reality. At position (1,1,1) we have interactive simulations which are based on completely new laws of physics. In addition, users are completely immersed in such simulations, and have become another data point in the artificial world. They are completely free from any artificial means of experiencing the reality (e. g., DataGloves or helmet mounted displays). Position (0,1,1) represents simulations which are highly integrated and at the same time have a natural interface. In addition, simulations at position (0,1,1) are capable of fully simulating the laws of physics. At position (1,1,1) users could take a "pretend trip" to an imaginary moon, while at position (0,1,1) users would be able to walk on a fairly convincing representation of our own moon. Is such a system feasible? Is it doable? Probably not in the near future, but this concept brings home an important idea - if our virtual reality systems have enough data about the environment we wish to simulate, have enough data about the participant, and can process this data quickly enough, we can create new realities.

At position (0,1,0) simulations are accurate representations of physical reality where users are fully integrated with the simulation through artificial means. This position represents the telerobotic aspect of virtual reality - the command and control of remote physical devices by simulating a robot's view. Virtual robots would let users work in environments ranging from giant automated construction equipment to microsurgery. Users would operate in a virtual environment scaled to their real world, and the system would translate the user's actions to the scale of the application's real world via the computer's virtual world. The telerobotics aspect of virtual reality may very well have its greatest impact on situations where humans will need to operate safely and effectively in hazardous environments such as the ocean or outer space (Fisher, 1991).

At position (1,1,0) we find an interesting combination where simulations are based on alternate sets of physical laws but exhibit a high degree of integration through artificial interface devices. This position represents, among other things, the entertainment/gaming aspect of virtual reality. For example, computer games often place participants in a world of strange creatures where alternate laws of physics prevail. Virtual reality systems will expand the gaming concept to include the participant's entire body, rather than simply providing a joystick or keyboard as today's computer games do.

Finally, positions (0,0,1) and (1,0,1) represent situations that are familiar to all of us. At (0,0,1) we have simulations which are based in reality, with natural interfaces and with very little integration with the system. This point represents classic social and business simulations where participants play particular roles. This position also represents live theater. Simulations at position (1,0,1) have the added feature of being based in an alternate reality. Perhaps the best way to represent this position is by conceiving a precomputed conventional animation sequence viewed on a large screen where the user just sits back and enjoys the show. Currently there are a few amusement park rides which fit the description found in this corner. 'Tour of the Universe' in Toronto and 'Star Tours' at Disneyland were among the first entertainment applications of simulation technology and virtual display environments where approximately 40 people sit in a room on top of a motion platform that moves synchronously with a computer-generated display to simulate a ride through another universe (Fisher, 1991).

THE RELATIONSHIP BETWEEN VIRTUAL REALITY AND OTHER "SIMULATIONS"

The cube with its three dimensions - verity, integration, and interface - can be used as a tool for structuring our conceptualization of other kinds of simulations found in the entertainment and training arenas. Take for example the area of computer-based entertainment called "games and simulations." Figure 4 shows that most of these products fall into the lower right quadrant of the cube. These "simulations" are usually found on desk-top computers, dedicated entertainment systems, or in some cases, low-end work stations. Because of the lack of computing power of these hareware configurations, most of the simulations are fairly anemic in the verity dimension. They simply cannot model to any degree of reasonable fidelity, the actual items they are attempting to simulate. In addition, computer-based games often deliberately try not to imitate "reality." After all fantasy is an important part of the appeal of computer-based games (Malone, 1981). In terms of interface, these "simulations" are usually limited to keyborad, joystick, or mouse inputs. The output is usually limited to a single CRT. In almost all cases, these are extremely artificial interface devices. In terms of inclusion, computer-based games and simulations have been almost always programmed by conventional methods. Users are no more a part of the simulation than if they were using a spreadsheet program.

Figure 4 also shows where flight simulators may fit into the cube. Notice that the space representing flight simulations takes up more volume within the cube. These simulations range from pc-based simulations on up to high-fidelity, full-mission simulators. As flight simulators become more sophisticated, in terms of programming techniques, attention to functional, physical, and psychological fidelity, and use of innovative interface techniques, they begin to take on more of the characteristics of virtual realities.

The cyberspace dimensions of virtual reality are depicted in Figure 4 as well. As discussed above, cybernetic simulations are designed from the simulated object's point of view (Walsher, 1991), may or may not require external (artificial) input and output devices, and model to a greater or lesser degree - depending on the application - real world objects.

As can be seen, the cube in Figure 4 allows us to conceptualize, and to some extent, quantify a simulation's qualifications as a virtual reality. The simulations represented in the cube are by no means exhaustive, the reader is invited to fill in the rest of the 'empty' space.

VIRTUAL REALITY AND SIMULATION RESEARCH

The cube, with its three dimensions, can also be used as a conceptual tool for structuring our understanding of virtual reality research. The verity dimension includes research and development of scientific visualization tools (DeFanti, Brown, & McCormick, 1989; Peterson, 1990), simulation fidelity (Alessi,1988), physics based modeling of objects (rigid and nonrigid), including anthropomorphic and jointed figure motion (Lee, Wei, Zhao & Bradler,1990; Wilhems, Moore & Skinner,1988; Carrington, Hughes, Burg & Xin,1991), and reactive planning (Gonzalez, 1991; Le, 1991). In terms of integration, ongoing research includes, among other things, object oriented, as well as constraint-based programming (Burg, Hughes, Moshell & Lang, 1990; Pentland , 1990).

The interface dimension consists of work to further define and increase our understanding of how to develop complex, yet intuitive and natural controls to make virtual reality systems more responsive to human participation. Accordingly, we need to improve our understanding of human sensory mechanisms to be able to design and implement tactile feedback, binaural hearing, and autosterioscopic vision. We also need to improve our understanding of human perception for several reasons. As Zeltzer (1990) indicated:

> . . . it is important to develop a taxonomy of tasks in terms of sensory input; for a given task, what sensory cues are necessary, and which cues are dispensable but improve performance? Are there sensory cues which do not affect performance per se, but which enhance the aesthetics of the operations or the work place? Are there sensory cues that interfere with performance and which should be avoided? (p. 5)

VIRTUAL REALITY AND TRAINING R&D

It would seem that a computer-based learning system that includes the user in a naturally participative and physically realistic setting would be more instructive than conventional computer-based systems. Similarly, the explosion of "high tech" media in the last two decades lured many trainers into mistakenly assuming that increased learning would result from improved delivery systems (Clark, 1991; Clark, 1983). Accordingly, an overemphasis on the more salient aspects of simulation and a lack of emphasis on instructional principles led to the development of simulation devices that produce compelling experiences but are not optimally effective for training (Andrews, 1988). Consequently, most researchers and developers have learned that mere exposure to even the most motivating experiences do not guarantee the acquisition of knowledge or skill.

It is only natural for people to focus on virtual realities that are the most exciting and unusual. However, the most fruitful training research and development is likely to result from a systematic examination of military training activities that require an experiential approach. Three generic areas, defined by Wiggers et al (1989) and by Monet, et al. (1990), come readily to mind: combat mission training, mission preview, and mission rehearsal.

Combat Mission Training

According to Wiggers, et al. (1989), combat mission training occurs when "Tactical forces/crews conduct training scenarios, to which some factors, including a moderate level of uncertainty, have been realistically applied with the intent of training for a particular type of mission." The purpose of the training is to increase crew's effectiveness in a variety of situations and not just the one specifically represented by the training scenario. In such training situations, the mission, terrain and opposing force(s) can be generic rather than specific. It is irrelevant then, whether the computer database contains 'real' or generic terrain information since learning a specific scenario is not the training objective. Crew members view the scenario either through helmet mounted displays or within a dome. Movements (head and eye as well as hand and body) are detected and responded to appropriately by the system without discernible lag. The crew member can interact with other members of the team as they perform the simulated mission. Opposing forces, which can be either manually controlled, semi-automated, or fully automated are also included in the scenario. Individuals' actions usually occur in real time, but time may be compressed or expanded in order to enhance training effectiveness. (Knerr, 1991)

Mission Preview

Wiggers, et al. (1989) defined mission preview as "Tactical forces/crews conducting initial familiarization for a specific mission. This can be performed using personal computers or similar equipment." The purpose of such preview activities are (a) to develop and refine, through the use of a simulated environment, a plan for a specific mission, and (b) to insure that crew members understand their role in the plan (Knerr, 1991). Mission preview calls for crew members to understand when and where to perform, not necessarily how to perform. That is, the emphasis is on cognitive, rather than psychomotor aspects of mission performance. In such scenarios, the database should represent the actual terrain over which crew members will conduct their mission, and the opposing forces (and other aspects of the mission) should represent the actual situation. In addition, actions take place in real or faster-than-real time. Feedback should be designed to provide information necessary to improve the plan and does not necessarily need to be given to individual crew members. (Knerr, 1991)

Mission Rehearsal

Monette, et al. (1990) defines mission rehearsal as "Tactical forces/crews conducting trial performances, to which all factors . . . have been realistically applied to a situation with the intent of preparing for a specific mission. Mission rehearsal requires that the simulation represent to the highest degree possible, the terrain, mission, and opposing force(s) of a specific situation. The training which occurs in such simulations is intended to directly transfer to a specific, real world situation. Crew members' actions occur and the simulation responds in real time. Feedback is used to to increase mission success, rather than improve generic combat skills. (Knerr, 1991)

In addition to the above mentioned experiential tasks, enhanced training research and development is likely to result from a systematic examination of learning domains where abstract information is made more "concrete" through virtual reality. Can, for example, air combat maneuvering techniques become more obvious if energy management can literally be seen or felt? And how "real" do virtual realities need to be to accomplish their purpose?

Nearly 20 years ago James Batter (as reported by Foley, 1989) noted that some students studying graphic displays of two-dimensional force fields gained a better understanding of the concepts involved if they could not only see the force vectors but also feel them. Batter's study, using a very simple, two-dimensional, force-feedback device, illustrates at least one way research can be conducted to determine the training value of making abstract information more concrete through virtual reality.

CONCLUSION

The description of virtual reality given above shows that there is no one technology that creates a virtual reality. Virtual realities are more than helmet mounted displays, sensor gloves, or robotic devices. They are, instead, a fundamentally new way of looking at and developing interactive, computer-based simulations. Now that we understand the virtual reality experience and the medium that provides it, it's time to get to the real task at hand. That is, to research, design, and develop virtual reality-based simulations which provide effective training for the end user.

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