THE ROLE OF VIRTUAL REALITY TECHNOLOGY IN EMERGENCY MANAGEMENT

Giampiero E.G. Beroggi[1], Laurie Waisel[2], and William A. Wallace[2]
[1]Systems Engineering, Policy Analysis, and Management
Delft University of Technology, Delft, The Netherlands
[2] Decision Sciences and Engineering Systems
Rensselaer Polytechnic Institute, Troy, New York, USA

ABSTRACT

Virtual reality is a popular term that refers to a variety of computer-generated virtual experiences. The core is an advanced interface to a human-machine simulation system. Virtual reality consists of virtual sensations, feelings, visions, sounds, or any other kind of artificial perception. Technical components used in virtual reality range from mouse and voice input devices to motion detection systems and artificial skin. The user lives and acts in cyberspace - the virtual world that could also be connected to the real world through telepresence.

The field of virtual reality is still in its infancy. Moving, feeling, and acting in cyberspace is still a primitive technology. However, it is in this early stage of development that potential applications in emergency management should be investigated.

The purpose of this paper is twofold: (1) to provide the emergency management community with a pragmatic overview of virtual reality technology; and (2) to propose where the technology, as it emerges, could support problem solving and decision making in emergency management from prevention and mitigation to response and recovery.

INTRODUCTION

The domain of virtual reality (VR) is not clearly defined. Moreover, similar terms are used for different kinds of concepts. Examples are artificial reality, virtual environments, telepresence, virtual instrumentations, virtual interfaces, virtual worlds, virtual experiences, architectural walkthroughs, etc. Common to all these concepts is that they aim at giving humans artificial or synthesized views, feelings, hearings, smells, or tastes, or any combination of these senses. The more realistic the surrogate or artificial perception, the more "virtual" is the approach. However, only the genuine stimulation of human senses is considered VR; the creation of "artificial feelings" by ingestion, injection, or inhalation does not belong to the domain of VR.

If one attempts to bound the domain of VR, analogous philosophical questions arise as with the definition of artificial intelligence (AI) about 30 years ago. The question then was "When is AI achieved?" i.e., when is a machine intelligent? An answer to this problem, provided by A. Turing, was that AI is achieved when a human working with such an intelligent machine believes to be working with another human [Tanimoto, 1987]. We can ask an equivalent question for VR: "When is a synthesized perception real?" To answer this we would have to define "reality." For some senses we can use the same definition as for AI: artificial environments are real if we cannot tell that they are computer generated. This certainly holds for hearing, feeling, tasting, and smelling. To use the same stringent definition for vision, however, would disqualify everything what up to now has been called VR.

Not surprisingly, pioneer work in VR originates from the entertainment industry. However, Morton Heiling's Experience Theater and Sensorama never got the credit they deserved [Rheingold, 1993]. Consequently, the entertainment industry did not promote VR concepts beyond Cinescope movie theaters.

VR, as we know it today, emerged from the field of computer science. Generally speaking, VR can be seen as the ultimate human-machine computer interface to an advanced simulation system. In fact, today's notion of VR consists of a human-computer interaction at various levels of reality, primarily focusing on visual perception. It is only recently that audio and tactile perception are being addressed in VR.

VR is an immersive, synthetic, or computer-generated environment that provides the experience of being there [Rheingold, 1991]. Ideally, VR is intuitive as well, allowing he user to communicate with the system via familiar and obvious actions [Wells, 1992]. In discussing VR, it is important to distinguish between natural and synthetic experience. In a natural experience, the user directly perceives the properties of something that is physically present before the perceiver. By contrast, in a synthetic experience, the user perceives a representation of something physically real rather than the thing itself [Robinett, 1992]. Examples of synthetic experience include flight simulation, robot tele-operation, everyday telecommunication, and, of course, virtual reality. Synthetic experience may be generated by the physical world, as in telepresence (using virtual reality to perceive and manipulate a objects remote in space from the user) or it may be generated by computer, as in architectural walkthroughs (using a VR version of an architechtural blueprint, the user can walk through a building that does not exist in the physical world). We have identified three levels of virtual reality: virtual space, virtual image, and virtual environment. Virtual space uses pictorial cues to represent a 3D portrayal on a flat (2D) display. These displays commonly use perspective, shading, and textual gradient to create a 2 1/2D image. Virtual images are perceived by adding various stereoscopic cues to produce 3D displays. Virtual environments add other sources of information with audio and tactile images [Wallace, 1992].

COMPONENTS OF VIRTUAL REALITY

The basic component of VR is the human-machine interaction in a virtual space, also called cyberspace. In addition to the above mentioned output capabilities of VR systems, input devices through which the human conveys information to the machine add significantly to the sensation of VR. The ultimate goal for input devices is certainly to reach the same realism as aspired for output devices; i.e., voice, motion, and facial expression could be understood by the machine as they are by another human.

Virtual Worlds and Cyberspace

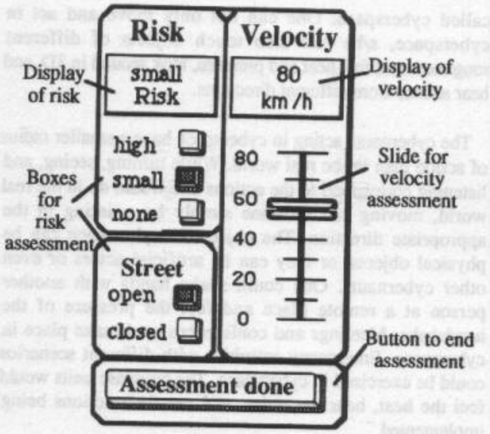
A virtual world is a place that generates events that never really happen. It consists of a computer generated environment that a user interacts with. In more advanced systems, the user can even see him/herself acting in this environment. The use of computers coupled with automatic machinery to control and carry out complex operations is called cybernation. Consequently, virtual worlds are also called cyberspace. One can not only move and act in cyberspace, s/he can also touch objects of different roughness and feel heat and pressure, look around in 3D, and hear sounds from different directions.

The cybernauts acting in cyberspace have a smaller radius of action than in the real world. While turning, seeing, and listening correspond to the actions one would do in the real world, moving can be done simply by pointing in the appropriate direction. The objects in cyberspace can be physical objects, or they can be artificial actors or even other cybernauts. One could shake hands with another person at a remote place and feel the pressure of the handshake. Meetings and conferences could take place in cyberspace. Emergency activities with different scenarios could be exercised in cyberspace. The response units would feel the heat, hear the noise, and see their actions being implemented.

Although these VR scenarios sound quite visionary, the technology to make them happen is becoming accessible, and time has come to investigate the potential use for emergency management. Many concepts of VR are already being implemented in emergency management.

Technology in VR

A major breakthrough in visual interactive input devices was reached in 1984 with the computer mouse system by Macintosh. The desktop represents a work place with disks, folders, and files as virtual objects. The mouse represents the virtual hand or finger which is used to point to those objects on the desktop. Single pointing to the objects selects the object and double-pointing opens the object. Objects can be moved around on the desktop and also be inserted into other objects. Since 1984, the mouse-pointing interface has been further developed to include virtual instruments, such as slide bars, knobs, toggles, and radio buttons. The input has become increasingly intuitive because the user knows from experience in the real world how to handle those virtual devices. Instead of using his/her hands and physical instruments, s/he uses the mouse as the virtual hand to work with the computer generated virtual input device, as illustrated below.



Still at the front of commercial microcomputers, a major new breakthrough in input devices has been reached just this year. The new Macintosh Centris and Quadra systems are equipped with remarkably effective voice recognition and voice synthesis features. Although there are not yet many software packages that can handle voice input, it will be only a matter of time until software houses start taking advantage of this novel input device. Soon we will be talking to our word processor and spreadsheet programs.

The devices most frequently associated with VR in these days are head mounted 3D displays and gloves. Three dimensional vision can only be achieved by providing the two eyes with different pictures that can be merged by the human brain to one 3D picture. This artificial 3D vision is called stereoscopic viewing.

More important than 3D perception from a motionless source, as is the case with 3D cinemas, is 3D vision that follows the user s head movements. This allows one to look around (or even walk around) the corner of an object in cyberspace. This 3D vision is achieved by head mounted cameras that keep track of the head position in space. In a somewhat more restricted way, this effect can also be achieved by 3D glasses, coupled with an appropriate simulation system.

Gloves are used as advanced input devices. Sensors attached to the glove determine the relative position of the fingers and the glove in space. One can use the glove to move around in cyberspace, but also to pick up and move around objects. Advanced gloves include the possibility of tactile perception; i.e., the glove can simulate pressure, heat, and the feeling of touching a rough or smooth surface. The ultimate goal in tactile output devices are suits that can act as artificial skin.

More advanced input devices are currently subject of research. They include lip reading devices, gestural input devices, eye-movement detectors, and facial motion detectors. Anything the user does in front of the computer will be detected by sensors, used as input, and processed in the program. While so far only active inputs such as a mouse click can be perceived by the system, advanced computer systems will also be able to recognize and process passive input, such as the facial expression for sadness. These advanced input capabilities coupled with the sophisticated 3D output systems will ultimately create what is known as mind amplifying computer technology - virtual reality.

The Role of Information Technology

The key to VR is advanced computing and communications technology. For every move or other kind of input, the simulation generates new graphs. Advanced microcomputer-based VR systems can generate from a couple of thousand texture-mapped polygons up to several thousand flat-shaded polygons per second. Power is provided today by the most advanced microcomputer systems, and in the near future it will be provided by RISC-based (reduced instruction set computers) microcomputers developed by Apple and IBM.

Data transfer between remote and mobile actors can be achieved by satellite-based phone systems, such as Iridium by Motorola. Eventually at least 60 satellites will provide world-wide communications capability. In addition, fibre optics systems will transmit data at a speed equivalent to 50,000 typed pages per second. The Global Positioning System (GPS) and other satellite tracking and communications systems such as OmniTrac, EutelTrac, and Inmarsat C provide accurate positioning and real-time data transfer between any two locations on earth.

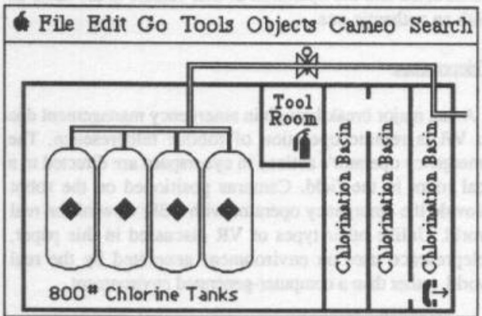
IMPACT ON EMERGENCY MANAGEMENT

VR has already had significant impact on emergency management, including advanced data visualization systems within geographical information systems (GIS). Many advanced decision support systems (DSS) for emergency management rely on GIS technology and virtual instrumentations. Dispersion plumes are depicted on digitized backgrounds of areal pictures and the growth of the plume is simulated and visualized in real-time. Concepts more closely related to today's notion of VR are virtual world navigation, tele-virtual conferencing, telepresence, and simulation in cyberspace.

From CAMEO to Virtual World Navigation

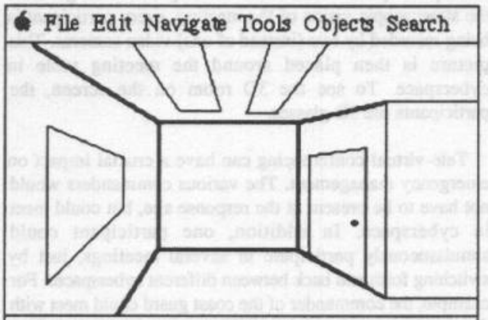
A widely used emergency response DSS is CAMEO, developed by the U.S. National Safety Council. It originally was developed on a hypermedia system on a Macintosh computer. The advantage of hypermedia is that its object oriented graph structure that allows easy navigation through the system. In addition, hypermedia systems are often used as authoring tools for multimedia systems. Objects can be text, graphics, drawings, figures, or even environments. Hypermedia systems are used for all kinds of applications. Besides multimedia applications, they are also used for simulation. An example is the decision support system for hazardous material transportation and emergency response in hypermedia [Beroggi and Wallace, forthcoming].

The concept of hypermedia has recently been used in conjunction with VR [Smith and Wilson 1993]. Instead of navigating through map displays as embedded into CAMO (see first figure below), the emergency managers would navigate through virtual environments (see second figure below). These virtual environments give a better comprehension of the facility one is walking through. This is another example of architectural walkthrough. However, emergency managers working with a hypermedia system would have the capability to "jump" to any other piece of the facility or the environment.



Navigation through Design Maps

Adding 2D monoscopic or 3D stereoscopic vision and 2D or even 3D sound has the potential to improve significantly the user s perception of the situation. Emergency managers who have to enter a burning or contaminated building could first analyze the lay-out and the escape routes of the building.



Navigation through Virtual Environments

For most tasks, a slide view of the virtual environment might be sufficient. However, some emergency management situations could call for continuous real-time simulation. Commercial software systems are available for continuous VR simulation. An example is the Windows application WorldToolKit from SENSE 8 Corporation, which has a library of over 400 functions to create real-time interactive 3D simulations. The user can create stand alone applications that use Excel or Lotus files.

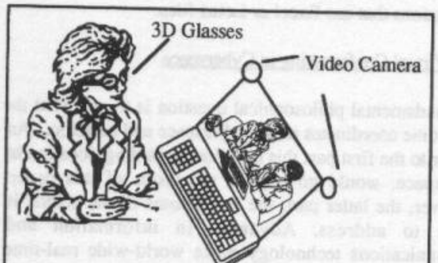
Tele-Virtual Conferencing in Cyberspace

A fundamental philosophical question is to ask what the space-time coordinates are of cyberspace and its actors. An answer to the first part this question, regarding location in cyberspace, would go beyond the scope of this paper. However, the latter part, the coordinates of the actors, is easier to address. Advances in information and communications technology make world-wide real-time communications possible. Information highway systems, satellite communications systems, and increasing computing power allow remote and mobile actors to join a communication meeting at any time in cyberspace.

Commercial tele-conferencing systems provide each participant with a view of all the other participants in different windows. However, despite the availability of this artificial tele-conferencing environment, real world meetings still seem to be preferred. Consequently, only environments that closely emulate real world scenarios might have a chance to be preferred to face-to-face meetings: tele-virtual conferencing [Ramanathan et al. 1992].

In tele-virtual conferencing, each participant sees the other participants in the same meeting room. To generate the stereoscopic vision of the meeting, every participant is being recorded by two (instead of one) video cameras. This picture is then placed around the meeting table in cyberspace. To see the 3D room on the screen, the participants use 3D glasses.

Tele-virtual conferencing can have a crucial impact on emergency management. The various commanders would not have to be present at the response site, but could meet in cyberspace. In addition, one participant could simultaneously participate in several meetings, just by switching forth and back between different cyberspaces. For example, the commander of the coast guard could meet with the on-site response team and instantaneously switch to his/her on-scene commanders to implement further actions. Furthermore, a commander would not even have to be positioned at a headquarters for a meeting in cyberspace. S/he could be travelling on a plane and working with a notebook with two small cameras attached at the corner of the notebook. Putting on his/her 3D glasses and ear-phones puts him/her, via satellite communications, right on the scene. The figure below shows the concept of mobile tele-virtual conferencing.



Mobile Tele-Virtual Conferencing

Training in Cyberspace

The success of an emergency operation depends to a large extent on the training the emergency responders have had. Training today means exercise with real situations, such as in nuclear power plants, fire-fighter training, emergency responder training, driver of HazMat training, and many more. Although the objects, trucks, roads, hydrants, etc. are real, the sensation of a real emergency situation is difficult to imitate.

Training in cyberspace would not focus on handling devices, shutting down engines, or applying first-aid techniques to people. It would focus on finding ways to get through a building, finding the location of hydrants, locating sensitive devices, and finding a way through smoky rooms.

Different scenarios could be devised, focusing on different types of emergency situations, such as emergency responses in contaminated nuclear plants and environments or fire-fighting under dense smoke. While the trainees act under difficult conditions such as restricted visibility and breathing problems due to smoke, the trainers could stand next to them in a "clear" cyberspace (i.e., without the artificially generated impacts due to the smoke) and control their actions and advice them. At any time of the simulation, the trainers can change the environment of the cyberspace; e.g., create more or less smoke, increase the temperature, make a building fall apart, or switch instantaneously from summer to winter.

Another application of VR in training is already being implemented and uses simulators similar to flight simulators. The emergency responder, usually a driver of a vehicle, moves in cyberspace. Vision, sound, and motion are simulated. The trainer can change at any time the conditions of the cyberspace to test or assess his/her behavior. For such purposes, a real vehicle is usually constructed and the operation of that vehicle is the same as with an authentic one.

Telepresence

A last major breakthrough in emergency management due to VR is remote operation of robots: telepresence. The emergency operator's actions in cyberspace are directed to a real robot in the field. Cameras positioned on the robot provide the emergency operator with a 3D view of the real world. Unlike other types of VR discussed in this paper, telepresence uses an environment generated by the real world, rather than a computer-generated environment.

An example of an advanced telepresence device is a suit that an emergency manager would wear. This suit would transform the emergency manager's actions directly into the robot's actions: the emergency managers and the robot merge in cyberspace.

Applications of telepresence include activities in environments posing physical hazards to human emergency responders, such as sinking ships, earthquake areas, or areas that have been radioactively or chemically contaminated.

CONCLUSIONS

The significance of virtual reality has been recognized. Interactions in cyberspace, telepresence, navigation in virtual worlds, and tele-video conferencing have become viable technologies. However, the role of virtual reality in problem solving and decision making must be addressed in the context of the problem at hand. This paper introduced some of the uses of virtual reality in emergency management.

Both the research community and people working in the field have begun to appreciate the potential of virtual reality. New methodologies to improve decision making and problem solving in emergency management will emerge shortly. However, any proposed analytical paradigm must be assessed by gaming or in an experimental setting. Only such a thorough assessment can provide significant insights that can be used to design virtual reality decision support systems (VRDSS).

REFERENCES

Beroggi, G.E.G. and W.A. Wallace, forthcoming. "A Prototype Decision Support System in Hypermedia for Operational Control of Hazardous Material Shipments." Decision Support Systems.

Ramanathan S., Rangan P.V., and Harrick M.V., 1992. "Integrating Virtual Reality, Tele-Conferencing, and Entertainment into Multimedia Home Computers." IEEE Transactions on Consumer Electronics, 38/2, 70-76.

Rheingold W., 1993. Virtual Reality. Cox & Wyman Ltd, Reading , Berks, UK.

Rheingold H., 1991. Virtual Reality. New York: Touchstone Press.

Robinett W., 1992. "Synthetic Experience." Presence, Volume 1, Number 2, Spring 1992, 229-247.

Smith P.A. and Wilson J.R., 1993. "Navigation in Hypertext Through Virtual Environments." Applied Ergonomics, 24/4, 271-278.

Tanimoto S.L., 1987. The Elements of Artificial Intelligence. Computer Science Press, Inc., Rockville, Maryland.

Wallace W.A., 1992. "Distributed Decision Making and Group Collaboration Over Networks Using Virtual Environments." Technical Report, Decision Sciences and Engineering Systems, Rensselaer Polytechnic Institute, Troy, New York.

Wells M., 1992. "Virtual Reality: Technology, Experience, Assumptions." Human Factors Society Bulletin, September 1992.