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APPLICATIONS OF VIRTUAL REALITY TO NUCLEAR SAFEGUARDS AND NON-PROLIFERATION

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Abstract

This paper presents several applications of virtual reality relevant to the areas of nuclear safeguards and non-proliferation. Each of these applications was developed to the prototype stage at Sandia National Laboratories' Virtual Reality and Intelligent Simulation laboratory. These applications include the use of virtual reality for facility visualization, training of inspection personnel, and security and monitoring of nuclear facilities.

1. Introduction

This paper presents several applications of virtual reality (VR) relevant to the areas of nuclear safeguards and non-proliferation. The following sections present prototype applications that utilize VR for visualization of nuclear facilities, the training of non-proliferation treaty verification inspection personnel, and the visualization of remote sensor data for both security and monitoring of facilities.

The area of virtual reality is still relatively new. It is a highly interdisciplinary field, that encompasses such diverse technologies as optics, computer graphics, and human factors. For the purposes of this paper, we will view VR as simply an advanced human-computer interface --- the next generation technology for interacting with computer-generated information. Virtual reality has at least three distinct features: First, it immerses the user in the computer-generated world. He or she should feel as though they are "inside" the data, able to look around and move through it at will. Next, VR utilizes all of the user's senses. Vision is, of course, the most important and it has received a great deal of attention. Advances in computer graphics hardware and software allow the production of virtual worlds that appear very realistic. But the user should also be able to hear, feel, perhaps even smell or taste the virtual world if that is an important aspect of the underlying application. Finally, but perhaps most importantly, the virtual world should be behavioral and interactive. If the user acts upon the VR, it should respond appropriately. Spoken requests for information should be answered. Objects lifted and dropped should fall. Each of these components presents a next level of difficulty in creating a virtual world. The applications described below incorporate these capabilities to varying extents, based upon the requirements of the application being addressed.

2. Visualization of Facilities

This section presents three different applications of VR architectural walkthrough. Architectural walkthrough allows a user to move through a three dimensional graphical model of a facility. During the design phase, walkthrough might be used to verify the design or to test certain aspects of a facility. A walkthrough of an existing facility might familiarize the user with that facility without requiring a visit. The three applications below address each of these uses.

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MRS

The Monitored Retrievable Storage (MRS) walkthrough is a virtual environment (VE) created in order to perform cost analyses and radiation exposure studies for a proposed civilian radioactive waste management system [1]. To reduce human exposure to radiation, it has been proposed that robots be used to automatically handle receiving and storing/transport of spent nuclear fuel within the facility. The VE created for this work is based upon conceptual design studies. It contains models of both the facility layout and the robots that might be used for the automated handling tasks. The MRS walkthrough is used to do timing studies (related to radiation exposure) and cost analyses for the automated vs. manually-handled facility. The user, using the VR viewer, may walk through the facility while the simulated robots are carrying out their tasks, allowing him/her to visualize not only the space but the process flow as well. Figure 1 depicts a user viewing the MRS model with a VR display device (BOOM).

Fig. 1 - A user views the MRS walkthrough

WIPP

The Waste Isolation Pilot Plant (WIPP) walkthrough is a VE initially created for public relations applications [2]. The WIPP itself is an underground facility near Carlsbad, New Mexico. It serves as a site to develop and demonstrate techniques for safe encapsulation and isolation of low-level radioactive waste, and will eventually become a repository for such waste. The facility is a large complex located approximately 2,100 feet under the ground. It consists of a series of storage rooms, shops, and experimental areas, connected by passageways. These spaces are carved out of an extensive, natural salt formation. The WIPP walkthrough was originally created for public relations purposes, to allow simulated tours of the facility in anticipation of restricted access to the actual site due to storage of radioactive waste. The VE has subsequently also been used for visualization of air flow within the facility during emergency events, such as fire.

Nuclear Laboratory Hotcell

The hotcell walkthrough is a VE created as part of an on-going research effort in applying virtual reality to situational training. The facility, which is part of Sandia National Laboratories' Reactor Engineering Technology Center, is used to carry out radiation experiments. It consists of several labs and a series of shielded hot cells where the actual experiments are performed. Robotic Master/Slave devices allow experimenters to handle radioactive materials within the cells remotely. The hotcell VE was created as part of a project to explore ways in which virtual reality might be used to train escorts and inspectors of nuclear facilities as part of non-proliferation treaty verification agreements. This application is described more fully in the next section. Figure 2 shows one view of the hotcell VE.

Fig. 2 - The hotcell VE

3. Training and Planning for Site Inspections

The hotcell virtual environment described above is also used in a project to explore the use of VR in training personnel involved in non-proliferation treaty verification [3]. Nuclear non-proliferation treaties often provide for facility inspection to allow verification of compliance. For each participating nation, this requires two types of personnel, facility inspectors and escorts. For example, U. S. inspectors must be trained to inspect foreign facilities to determine whether the hosting nation is complying with the terms of the treaty. Foreign inspectors do the same for U. S. facilities subject to such treaties. The time that an inspector is allowed within any foreign facility is limited and, therefore, training the inspector to become familiar with the facility ahead of time would make him more effective. The responsibilities of the escort are twofold. U. S. escorts of foreign inspectors inspecting U. S. sites (for example) must be familiar with the facility in order to comply with treaty regulations concerning the foreign inspector's right of access. In addition, they must ensure that the security of the facility remains uncompromised.

Training of both inspectors and escorts using VR has been explored. To address the problem of limited access to foreign sites, virtual models of foreign facilities can be created to allow an inspector to become familiar with the site before the actual inspection. Availability of information concerning foreign sites is the limiting factor.

Access to U. S. sites by escort trainees is also limited for many reasons. These facilities are geographically scattered. They are secure facilities. And they often present hazardous environments, due to the operations carried out in them. Virtual reality models of these sites can be used to familiarize an escort with the site before the arrival of an inspector. This is especially important given the fact that short notification of an upcoming inspection is possible.

While both of the above applications rely heavily on virtual reality architectural walkthrough, training of escorts presents an even more difficult problem. Not only must escorts be familiar with the facility, but they must also be aware of what the inspector may and may not do. To address these issues, a shared virtual reality platform has been developed that also contains artificial intelligent [4]. The VR contains domain-independent knowledge about how the virtual world should behave (e.g. if a virtual object is lifted and dropped, it should fall.) The VR also contains domain-dependent knowledge about which objects can be accessed by an inspector and which cannot. The system allows training in teams of two. One user plays the escort, the other inspector. Performance monitoring allows the system to provide verbal warnings when some aspect of permitted access has been violated. Users wear VR gear consisting of headmounted displays and position trackers. They have graphical bodies, called Avatars, that are slaved to their motion [5]. In this way, users see each other as full human figures within the VR and can interact with each other as well as with virtual objects. Figure 3 shows two users in VR gear. Figure 4 shows their Avatars within the hotcell VE as they train.

Fig. 3 - Users in VR gear.

Fig. 4 - Avatars in hotcell VE.

4. Monitoring and Security of Nuclear Facilities

The third application uses virtual reality as an advanced interface for remote display of data from multiple sensors [6]. Sensor data may be displayed in two different modes, real-time or play-back, depending upon the requirements of the application. Real-time mode is useful if the sensor data is going to a remote security or monitoring station. For example, a system has been developed at Sandia that displays the data from sensors located in a secure, but not isolated facility. An example of such a facility might be a nuclear laboratory where materials are routinely handled by staff during working hours, but must be accounted for and protected from unauthorized access at all times. The prototype system utilizes two types of sensors. A volumetric video motion detection (VVMD) system allows protected materials to be designated. The system will send an alarm if these materials are moved. In addition, the VVMD provides a motion detection capability that detects intruders and their positions within the facility. The VVMD utilizes three cameras and proprietary algorithms to determine if a particular position within the room is occupied. The room is divided into a grid of such positions, or volumes. As an intruder moves through the room, his motion is tracked via the changing grid positions that he is occupying. Protected materials are identified by the grid position that they occupy. Intrusion into such a designated position, or the removal of material from this position, is detected by the system. A benefit of this technology is that the resulting information is very low bandwidth, and may be sent to the remote monitoring station via a standard modem (compare this to the bandwidth required to send the full video image of the protected room.) Door sensors, which are simple switches, are also placed on the doors to the room and on several cabinets.

The advanced interface for this sensor system consists of a three-dimensional model of the remote room. The model may be viewed on a conventional flat screen, or through a full-up VR system. The information from the remote sensors may be transmitted to the monitoring station in real-time via the modem, or it may be stored to computer disk at the protected site and viewed at a later date. The former would be most applicable to security and safeguards, the latter to non-proliferation. The system provides an intuitive means to fuse and present the sensor data in an easily interpreted manner: The inherently three dimensional room is displayed in a three dimensional model, allowing the spatial relationships to be easily determined. The output of the VVMD is a set of grid positions that are currently occupied, along with an indicator of protected positions that have been violated. These are displayed at the remote monitor as a set of colored blocks (due to the current gross resolution of the VVMD.) As an intruder moves through the room, the blocks representing his motion are displayed at the remote monitoring station. Figure 5 shows the prototype display, consisting of the three dimensional model of the monitored room, along with the blocks that indicate the presence and position of an intruder. In addition, when a designated protected object is violated, the display changes the color of the object in the model and provides a vocal warning that a protected object has been intruded upon. Another benefit of such an interface is the ease with which other types of sensor data may be displayed and interpreted. For example, the door switch sensor data is displayed in the remote site as an opening of the graphical door and a vocal indication that the door has been opened. Compare this to a set of screens and displays, one or more for each sensor in the room, that must be constantly scanned, interpreted, and fused within the mind of the human operator before he can decide what the information means.

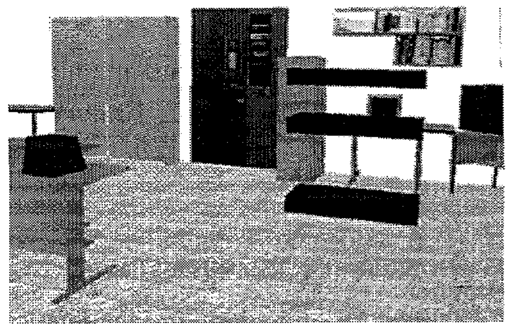

Fig. 5 - Laboratory VE with real-time display of sensor data.

6. Summary

This paper has presented three applications of virtual reality to nuclear safeguards and non-proliferation. These applications include architectural walkthrough, training, and sensor data display. Each of the applications presented has been developed to the prototype stage at Sandia National Laboratories. These applications are only a few of the potential uses of VR within safeguards and related areas, such as surety, security, transportation, and counter-proliferation.

5. Acknowledgments

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