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IH Interface

Virtual Reality for Mine Safety Training

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Introduction

Studies by the National Institute for Occupational Safety and Health (NIOSH) and the U.S. Department of Labor indicate that mining often has the highest annual fatality rate of any private industry.[1,2] Inadequate or insufficient training is often cited as a root cause for many mining fatalities. Researchers believe that the use of virtual reality-(VR) based training tools will provide the training needed to reduce these injury and fatality numbers. Accordingly, the goal of one research project undertaken by NIOSH at its Spokane Research Laboratory (SRL) (in Spokane, Washington) is to use current VR technology to develop cost-effective virtual mine environments. These environments used to train surface and underground mine workers and rescue personnel in hazard recognition and evacuation routes and procedures.

Background

Training is becoming a high priority for the mining industry due to the high injury and fatality rate. For example, in July 1999, the Mine Safety and Health Administration (MSHA) initiated a new educational program: the Educational Field Service. This program's aim is to prevent mining accidents through educational assistance. At the kick-off of the new program, the Assistant Secretary for Mine Safety and Health emphasized the importance of education and training outreach to the mining community. "Training plays a critical role in preventing deaths, injuries, and illness on the job. Only with effective training can miners recognize possible hazards and know the safe procedures to follow."[3] In addition, MSHA has recently promulgated within the Code of Federal Regulations (CFR), 30 CFR Parts 46 and 48, which establish safety training requirements for sand, gravel, surface stone, surface clay, colloidal phosphate, and surface limestone mines. These new regulations effectively prescribe training for over 120,000 previously unregulated miners.[4]

Unfortunately, while new training rules and regulations have been enacted, many training tools and techniques are not as effective as they could be in providing effective health and safety training. Recent stakeholder meetings between NIOSH and the mining industry indicate that the mining community needs improved training tools. "Mines must be more productive and they need upgraded (training) materials. Videos cannot be the only source. People get tired of listening, so they need other things, too."[5] At another stakeholder meeting, the attendees specifically requested help for developing new training material. They noted the importance of effective training and the need for updated mine safety training material.[6]

MSHA has addressed this need for updated training curriculum by publishing the "Three-Year Plan to Strengthen Capability for Production, Distribution, and Use of Instructional Materials via New Technology" on May 6, 1998. In this document, MSHA recommended the development of advanced training techniques such as VR, recognizing that VR provides "the best training by immersing students in situations that are as close as possible to the real world."[7]

As a result of this commitment to training by MSHA, and at the request of the mining industry for more effective, engaging training tools, NIOSH researchers have begun the development of accessible and affordable VR training software. The software will be used to help reduce the fatalities and injuries associated with mining accidents.

VR has already been shown to be an effective training tool in many industries. The general belief is that the information and skills acquired using VR training transfers to the real world in a more meaningful and realistic way than the information and skills acquired using more conventional, didactic training methods. The trainees will be able to see and hear the information, as well as practice what they are taught. The trainees will experience the consequences of bad choices or incorrect decisions without being exposed to any actual danger. In addition, VR allows the trainees to experience conditions that would be difficult or impossible to re-create in the real world. "Good [VR] simulations can systematically provide a wide range of possible training scenarios without incurring the high cost and risk of fielding personnel, equipment, and vehicles."[8] "Based on developed applications to date, [VR] appears to be appropriate where hazardous or unsafe conditions are prevalent, or where cost reductions in the use of fuel, manpower, or property damage can be obtained."[9]

Many private industries and businesses as well as many government agencies use VR training tools to help train employees to operate equipment, recognize hazards, and avoid accidents. For example, the U.S. Navy recently developed and implemented a VR system for training submarine officers in surface maneuvers. This VR system provided "significant learning and

skill improvement" on 11 of 15 measured ship-handling variables.[10] Motorola has developed a VR system for training employees in the safe and efficient operation of complex assembly lines. Preliminary studies indicate that those personnel who received assembly line training via a VR system with a head-mounted display significantly outperformed those who received training on a real assembly line.[11] IITRI Company has developed a VR simulator for training locomotive engineers for real-world events. IITRI has provided more than 70 of these simulators to railroads in 21 countries.[12] Ecole Polytechnique de Montreal and McGill University both of Montreal, Quebec, Canada have developed a prototype VR system aimed at training operators who work in power utility switching or distribution stations.[13] Amoco has recently completed a VR driver training simulator to train tank truck drivers how to handle road emergencies and other hazardous driving situations better.[14]

Unfortunately, many of these training systems cost $10,000, or even $100,000. However, current research by NIOSH's SRL indicates that affordable, accessible VR training tools can be developed to help train miners to work safely. By developing inexpensive, easy-to-use, accurate VR training software, NIOSH researchers will provide the mining industry with an effective method for training employees in safe and efficient work practices under a wide range of working conditions. This training will lead to reductions in the number and severity of accidents at mine sites. In addition, the intrinsic flexibility of this VR training software may lead to the development of VR safety training in other industries, such as the construction, agriculture, or petroleum industries.

Discussion

The goal of SRL's mine safety training project is to develop affordable software that runs on affordable computers and provides an immersive, realistic VR training experience for miners. To achieve this goal, researchers are focusing on two separate but parallel tasks. The first task is the development of mine evacuation training software using an existing computer graphics engine. The second task is concerned with developing a hazard recognition simulator using off-the-shelf gaming software. The training software being developed for both tasks is designed to operate on low-cost, personal computers equipped with three-dimensional graphics cards.

Task 1

To complete the first task, researchers relied upon the 3DGE graphics engine purchased from Twilight 3D, of Vantag, Finland. The graphics engine handles rendering of the scene within a virtual mine. C++ code was custom-developed to handle physics (such as gravity) and interactions within the virtual mine. This custom-designed system was necessary for the evacuation training task because it can accept actual mine geometry developed from mine maps (Figure 1). This trait is essential to provide realism for the trainees and allow evacuation routes to be practiced just as they would in an actual mine. The custom-designed system also allows user interfaces and world interactions to be tailored for the mining industry.

Various scenarios for evacuation training can be practiced, depending on the trainee's job description and how elaborate the trainer wants the simulation to be. The current program allows the trainee to start at the surface of the mine in the safety equipment room. Here, the trainee acquires the necessary safety equipment before starting to work. A hard-hat, cap lamp, and a self-rescuer are just some of the safety equipment needed (Figure 2A). The trainee then proceeds underground via a mancage (Figure 2B) to start the shift at the designated work area (Figure 2C). When the trainee arrives at the correct work area, a warning message appears on the screen that states that a mine emergency has occurred, as indicated by stench gas or blinking lights (Figure 2D). The trainee must then exit the mine while following correct procedures and routes. The scenario can be changed to test the trainee's reaction to a blocked primary escape route so that a secondary escape route must be used.

Using this program, mine workers can practice evacuating their mine without the danger and expense associated with practicing these escape routes in the actual underground mine. However, this training software has some drawbacks. The custom-designed simulator requires additional 3D modeling programs to build the mine levels as shown in Figure 1. It also requires a knowledge of a special library of functions called a TCL (tickle) library in order to define

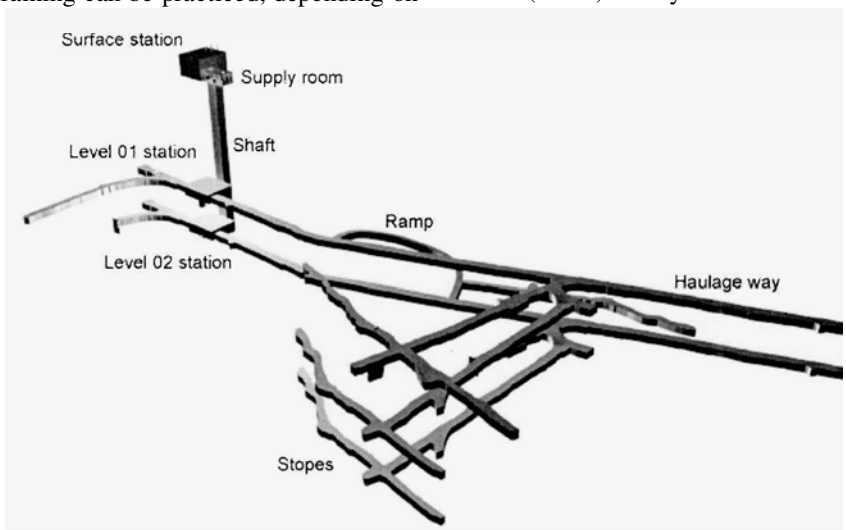

FIGURE 1

Digitized mine map used to teach evacuation routes and procedures.

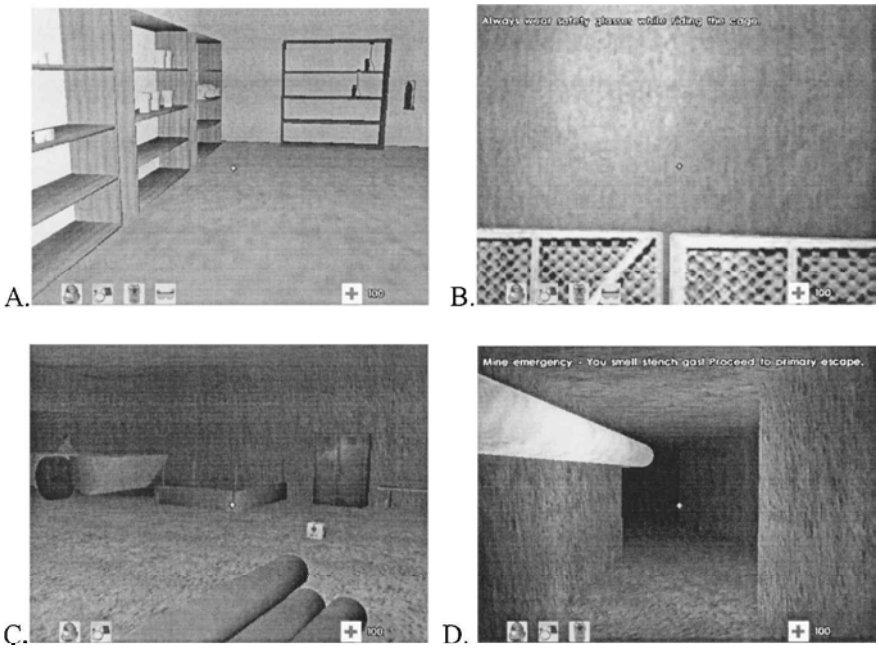

FIGURE 2
Scenes from the evacuation training simulator: A) inside the supply room; B) inside the mancage and in the shaft; C) at the station; and D) emergency message in the stope (work area).

the trainee's interaction with the virtual mine, such as the movement of the cage, the opening of doors, and the triggering of on-screen messages. The basics of both the modeling package and the TCL files can be learned fairly quickly and no programming is involved. However, it does require additional time on the part of the trainer.

Task 2

The second task under this project is to develop a simpler method of creating hazard recognition and safety training simulations for a particular mine. This task involves modification of existing personal computer (PC) game software for use as mine safety training tools.

PC gaming software has many advantages. The software is usually affordable, costing approximately $50 per copy. The software is often easy to modify; many PC games are sold with their own game editors. Finally, the software is usually designed to operate on low-cost PCs and support multiple players over a network, which allows several trainees to work together in the same training scenario.

Researchers at SRL first created prototype VR training models using the QUAKE II computer game (ID Software, Texas). Using editing software, researchers were able to create a virtual underground mine complete with vehicles, equipment, and various hazards. The user navigates this mine while identifying and avoiding the hazards. If the user fails to avoid a hazard, the user's character in the virtual mine will be severely injured. For example, one section of the virtual mine lacks any roof support. As the user navigates through this portion of the mine, cues are given to indicate no support for the roof (visible cue) or the sound of falling rock (aural cue). If the user ignores these cues and enters this portion of the mine, the user's character would be "killed" by a virtual rock burst (Figure 3). The user would then be required to start the simulation over from the beginning, hopefully with the knowledge that sections of the mine that lack roof support should be avoided.

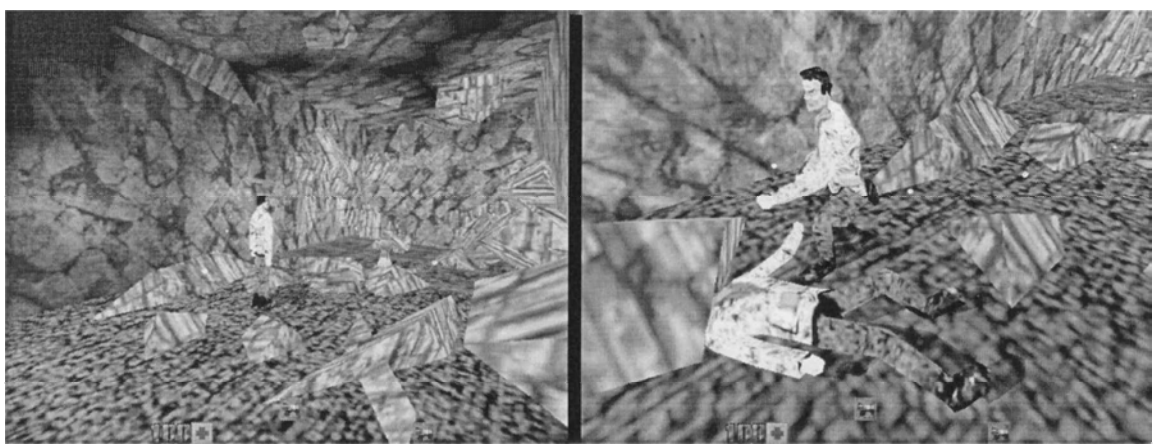

FIGURE 3
Result of failing to recognize a hazardous condition.

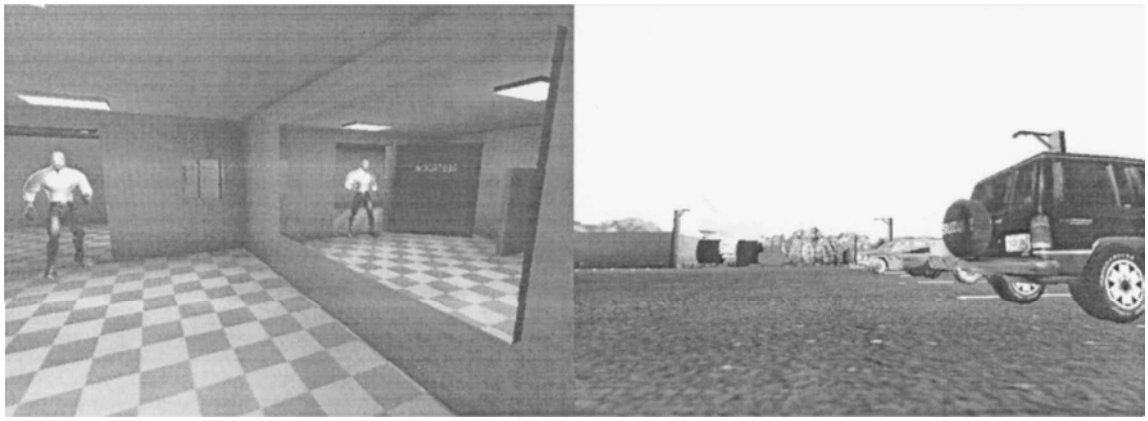

FIGURE 4
VR miner safety training using the Unreal graphics engine.

Project personnel are also evaluating unreal graphics engine (Epic Games, Inc., North Carolina) as a choice for future development of the VR mine hazard recognition program. Third-party developers have used the Unreal graphics engine to develop the Virtual Notre Dame Cathedral[15] for virtual tours of that historic site, and by real estate companies to create virtual walkthroughs of office buildings.[16] Like the QUAKE II software discussed above, this software allows for the custom creation of underground and surface mine sites (Figure 4). The Unreal engine also allows for the direct importation of digitized mine maps to create the accurate reconstruction of any mine site in a virtual world.

The virtual training scenarios created by this project each consist of four elements: surface/underground geometry, static objects, animated objects, and environment objects. These elements are combined to give the trainee a sense of presence within the artificial environment. Surface geometry can include roadways, ground surface topography, and underground openings or tunnels. Underground geometry can include drifts, stopes, and pillars. This data can be directly converted from existing computer-aided drafting (CAD) maps of the sites selected for simulation. Digital photography can be used to drape textures on the surface polygons to create a photorealistic surface.

Static objects include such items as trees, rocks, buildings, and utility poles. Animated objects include vehicles, pedestrian traffic, and animals. Computer models of these objects can be purchased from a vendor or developed using 3D modeling software or photogrametry software. Animation loops must be created and programmed to function within the VR software based on behavior algorithms and user input. Modeling and animation software is currently being evaluated to ensure that the end users have a low-cost alternative for 3D modeling. These objects can also benefit from digital phototexturing to create realistic-looking objects.

One of the difficult aspects of this project is using a minimal number of polygons to create realistic-looking characters, vehicles, and other objects. Models must be carefully crafted to maintain a specified total polygon budget with any given scenario. High-polygon

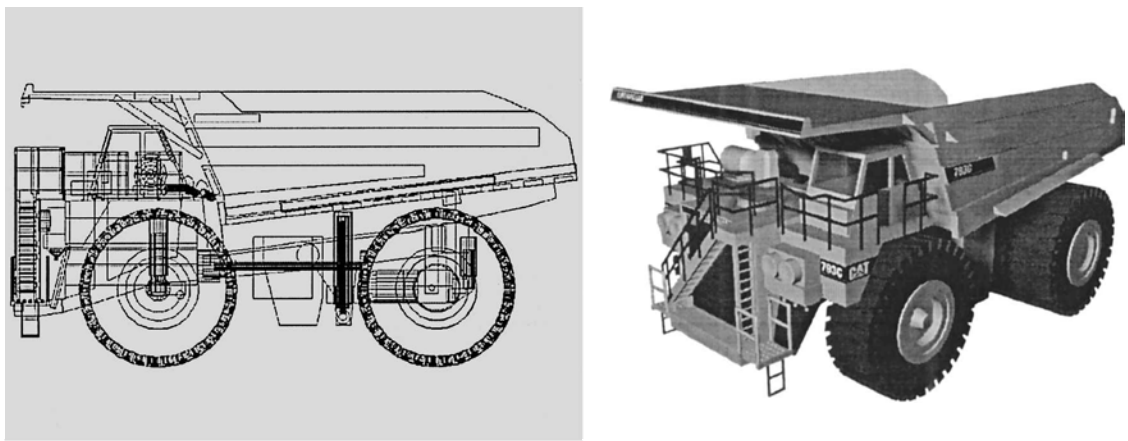

FIGURE 5
A high-polygon count model of a surface haulage truck.

models (Figure 5) are being developed to aid in developing detailed texture maps for the low-polygon versions used in the final animations. The model shown in Figure 5 contains over 54,000 polygons, but an optimized version of the same model uses less than 3000 polygons.

Environment objects primarily affect the trainee's vision within the virtual training scenario. Rain, smoke, fog, dust, and lighting conditions will be created within the training site to simulate real-world conditions accurately and to compound the difficulty of working safely within the virtual training scenario. Most of these environment objects are already available for use in the graphics engines or can be purchased as modifications.

One major challenge in applying VR is maintaining a reasonable frame-rate on the trainee's display while adding a great deal of complexity to the virtual setting. The frame-rate is a function of both environmental factors and the total number of polygons within each scene. A polygon budget should be established to help guide modelers and animators when creating the various objects and environmental factors that will populate the simulated mine site. The primary actors in the simulator (such as vehicles and pedestrians) may be afforded more polygons than a rock or shrub.

Summary

Mining has long remained one of America's most hazardous occupations. Researchers believe that by developing realistic, affordable VR training software, miners will be able to receive accurate training in hazard recognition and avoidance. In addition, the VR software will allow miners to follow mine evacuation routes and safe procedures without exposing themselves to danger. This VR software may ultimately be tailored to provide training in other industries, such as the construction, agricultural, and petroleum industries.

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