Mine Escapeway Multiuser Training with Desktop Virtual Reality

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ABSTRACT

A NIOSH study on occupational deaths between 1980 and 1989 indicated that in the United States, mining had the highest average annual fatality rate (31.9 per 100,000 workers) of any other major industry. Since "lack of training" was often cited as the primary cause of accidents, NIOSH has been investigating new methods for effective training. One such method is the use of low-cost, desktop computers to simulate a virtual mining environment. Computer-based training offers several advantages over conventional training because the computer programs provide a three-dimensional environment that allows the trainee to practice using evacuation routes, encounter mining hazards, and view mining operations without being exposed to any real danger.

One major focus of the project is mine escapeway multiuser training using desktop virtual reality programs. Researchers have imported mine maps into the software for the purpose of practicing actual evacuation routes and procedures. Various scenarios for evacuation can be practiced in a three-dimensional computer simulation of the mine in a disaster situation, complete with smoke, fire, and other dangers. Depending on the trainee's job description (i.e., foreman, shift boss, beltman, etc.), certain tasks need to be performed in addition to navigating primary and/or secondary escape routes. Each scenario allows for individual or team-based training and provides a means to educate mine workers in hazard recognition and hazard avoidance.

Using this program, mine workers can practice evacuating various mine layouts without the danger and expense associated with escapeway training in an actual underground mine. Each scenario can be changed to test the trainee's reaction in a variety of circumstances and run many times so the trainee can practice concepts. This training experience will help reinforce the knowledge acquired during more conventional classroom instruction, and the inherent flexibility of the program allows training materials to be tailored to meet the specific requirements of individual mines.

INTRODUCTION

First-person action games are among the most popular type of computer game produced today. Computer-generated worlds of preoptimized polygon models, animated texture maps, and three-dimensional sound are combined to create a compelling virtual experience. The addition of low-cost, increasingly powerful video accelerator hardware has added realism to games by allowing developers to enhance them with dynamic lighting, atmospheric effects such as smoke and fog, and additional polygon complexity.

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Bureau of Labor statistics for 1999 indicate that of the 5,461 occupational fatalities suffered in private industry that year, 1,190 occurred in the construction industry, 121 occurred in the agricultural industry, and 121 occurred in the mining industry. Of these occupations, mining had the highest fatality rate, with 22.6 fatalities per 100,000 workers (Bureau of Labor, 2001). Inadequate or insufficient training is often cited as a root cause for many mining, construction, and agriculture industrial accidents and fatalities.

Because of this, training is becoming a pressing issue for these industries. For example, in July of 1999, the Mine Safety and Health Administration (MSHA) initiated a new educational program, the Educational Field Service (EFS). This program aims at preventing mining accidents through educational assistance. At the kick-off for the new program, Mr. McAteer, 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" (McAteer 1998). In addition, MSHA has recently published 30 CFR Parts 46 and 48, which establishes safety training requirements for shell dredging, sand, gravel, surface stone, surface clay, colloidal phosphate, and surface limestone mines. This new regulation effectively prescribes training for over 120,000 previously unregulated miners (MSHA 1999).

The use of virtual reality- (VR) based training tools may help reduce these injury and fatality numbers by allowing mine workers to practice skills and recognize hazardous conditions from the safety of a computer. The goal of the research being undertaken by the National Institute for Occupational Safety and Health (NIOSH) at its Spokane Research Laboratory (SRL) is to use this technology to develop cost-effective, flexible, virtual mine environments to train surface and underground mine workers and rescue personnel in evacuation procedures and hazard recognition.

For evacuation training, the trainee would be able to practice escape routes in a three-dimensional, immersive computer model of the mine in a simulated disaster situation, complete with smoke, fire, and other dangers. The model would be based on maps derived from the mine's existing computer-aided design (CAD) files, typically drawing exchange files (DXF). Networking capabilities would allow several trainees to participate in the same simulation, so that teamwork could be evaluated. The simulation could be practiced numerous times, allowing the trainee to become familiar with procedures and evacuation routes specific to that mine.

These virtual mines could also be used to train mine workers in hazard recognition and hazard avoidance. A virtual mine might include such hazards as unsupported roof, uncovered holes in the floor, or electrical cables. The trainee could then be taught to recognize and avoid these hazards without actually being exposed to a real danger.

METHODS

An initial proof-of-concept for the hazard recognition and evacuation training software was developed using the first-person action computer game *Quake II* by Id software,[2] as the graphics engine for the simulations. Because of the widespread availability of editing software for this game, this method of creating custom VR simulations proved relatively simple.

The primary advantage to using existing software as the basic graphics engine is that a limited amount of programming is required to customize VR applications. Using existing game software

[2]Mention of specific products and manufacturers does not imply endorsement by the National Institute for Occupational Safety and Health.

provides the developer access to current state-of-the-art graphics features, such as atmospheric effects, which are updated regularly with each new release of the software. Cooperative play through a computer network is almost always supported in these games.

However, the goals of this project required a more flexible, customizable graphics engine. Numerous graphics engines were evaluated. A new action game was released during this evaluation phase–Epic Games' *Unreal*. Although similar to *Quake II*'s first-person game, *Unreal* was developed as an open-architecture gaming system. An editor is bundle with the game, giving end users the ability to create their own levels. A scripting language allows users with limited programming skill to create custom content for use in the game (Figure 1). Another advantage that *Unreal* has over *Quake* is that while *Quake* views the world as an infinite void that must be filled with level geometry, *Unreal* views the virtual universe as an infinite solid from which level geometry is initially subtracted, which yields great compatibility with existing three-dimensional mine modeling software.

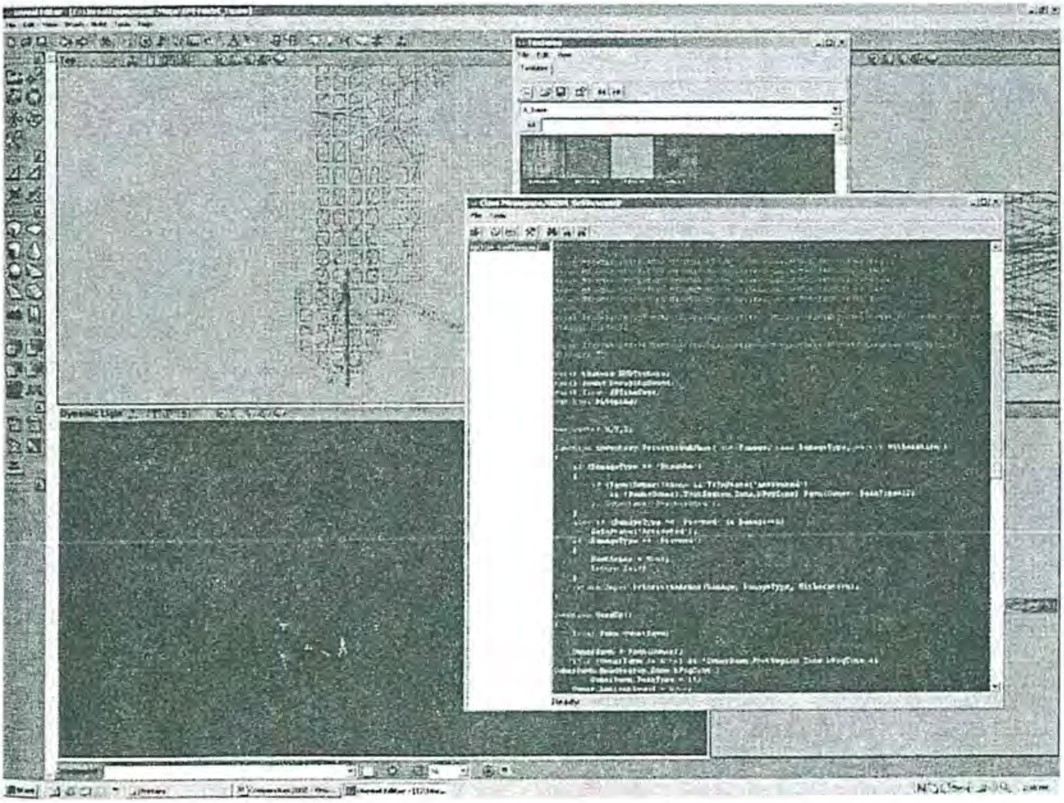

Figure 1. Screen of *UnrealEd* showing mine map imported for use in a simulation and the script-editing window.

With a strong game engine in place, the project team turned to the task of developing the custom content needed to recreate the virtual environment of an underground mine: mine maps, interactive objects, and miner characters. Each element has specific requirements for development, but maps, objects, and characters all start with a textured, three-dimensional polygon mesh.

To maintain the smooth feeling of immersion in the virtual environments, the computer should maintain an approximate frame rate of 30 frames per second, which is the frame rate achieved by standard video equipment. The factors that influence rendering time for each frame are the number of polygons and the number of lights in the virtual world. An increased number of polygons leads to an increased level of detail in the virtual environment, but a decrease in the frame rate. Thus, each element within the environment must be created with an overall polygon "budget" in mind.

The first step in creating a custom scenario is developing the basic map for the virtual environment. Mine map data can be imported via three-dimensional DXF data directly into *UnrealEd* (Figure 2). It is sometimes necessary to clean up these files to achieve better results within the simulation. Polygon "holes" must be patched to avoid unwanted visual artifacts within the simulation. Because DXF data do not contain texture information, textures are applied within *UnrealEd*. Numerous textures within the game are suitable for underground mine simulations, including various rock, stonework, and industrial texture sets. Custom textures can be obtained from digital photos of rock faces to depict a particular geology.

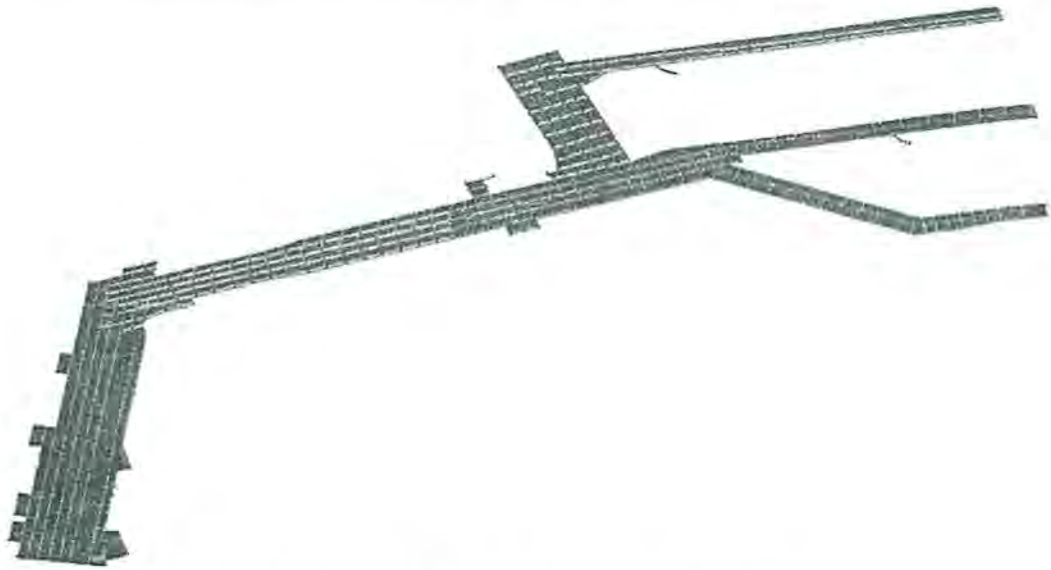

Figure 2. Solid model of Foidel Creek Mine ready for import into *Unreal*.

A mine map alone can create an excellent virtual environment for training purposes. Falling hazards are automatically included in any imported map because of the software's simulated gravity. Falling a short distance will damage the trainee's health. Larger drops may fatally injure the trainee and require that he or she start the training scenario over. Other hazards, such rock falls, require more effort within *UnrealEd*. The level designer can include triggers that activate rock falls in a section of the mine. The level designer includes some visual cues, such as broken rock on the floor, that should alert the trainee to avoid that area of the mine.

Because an underground mine is more than just tunnels in rock, the virtual environments must be populated with equipment, tools, etc. Some of these items are merely props to add to the visual reality; others are interactive and can be picked up and pushed, or will explode if mishandled (Figure 3). These objects are created using typical three-dimensional modeling software, such as Discreet's 3D Studio MAX. The textured models are imported into the *UnrealEd* software and added to the library of objects that can be placed into any scenario. The import process requires a script file for each object using *UnrealScript*, a custom scripting language that has been described as having characteristics of the JAVA and C++ computer languages. For static objects, the script is trivial, requiring only a few lines to describe the location of three-dimensional data, textures, etc. More interactive objects, such as fire extinguishers, require more programming.

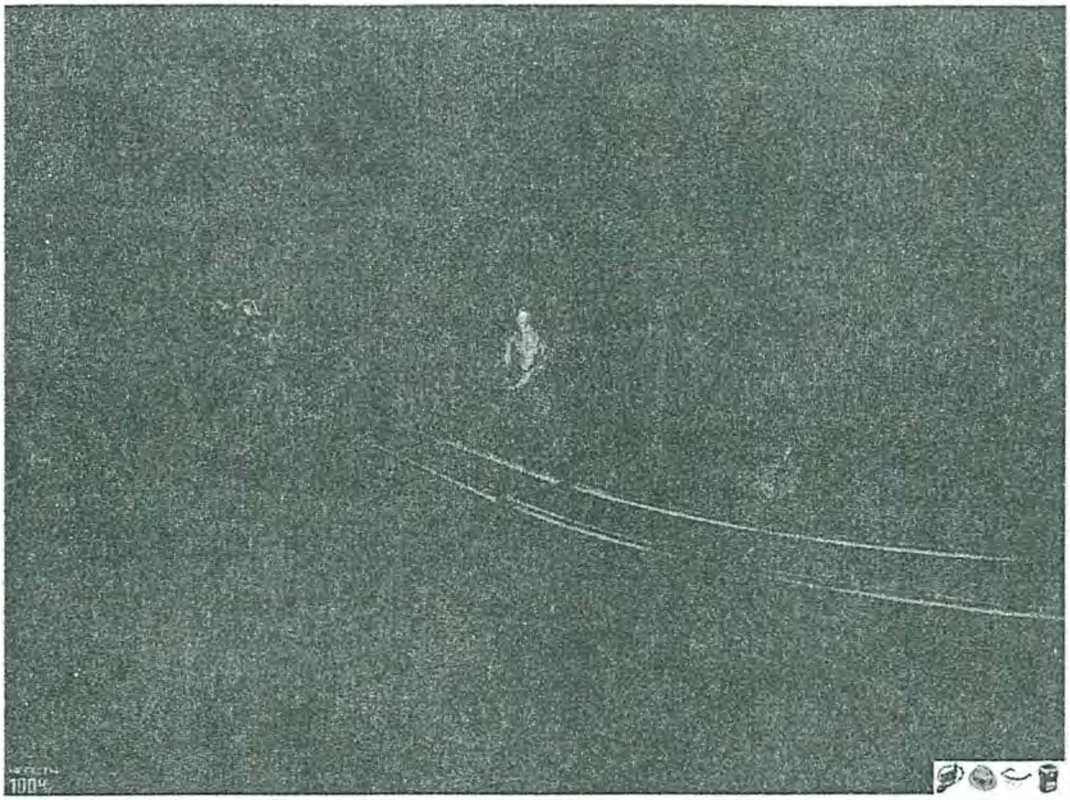

Figure 3. Simulated underground mine using custom content in the *Unreal* game engine.

Unreal is a first person game. The trainees using this software rarely see their own character or avatar in the virtual environment. However, *Unreal* is also designed for multiuser network games: therefore, trainees can explore the same virtual environments together. The character representations used for the game (generally burly space marines), while entertaining, are not suited for the serious task of mine safety training. Custom miner characters were created using photogrammetric software. This process allows for the development of photographically realistic computer generated characters using a minimum number of polygons (Figure 4).

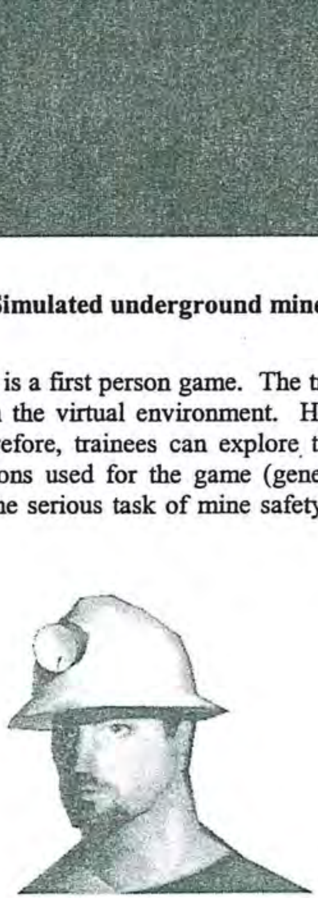

Figure 4. Miner character based on a photogrammetric model of the author.

The photogrammetric software allows the user to build an accurate three-dimensional polygon mesh of an object from a collection of photographs taken from numerous angles. The software also uses the digital imagery to create texture maps that are exported with the geometry data to create photograhically realistic computer graphics models. This automatic texturing is a significant advantage over traditional modeling methods.

SRL'S VIRTUAL REALITY MINE SAFETY TRAINING SOFTWARE

The trainee begins the simulation from the safety supply room. By manipulating the mouse and keyboard, the trainee can collect the appropriate safety equipment, which is located on the supply room shelves, thus adding these items to his or her personal inventory. As each item (hard hat, cap lamp, etc.) is selected, an icon appears at the bottom of the screen to indicate that these items are in use. Failure to select the necessary equipment may result in a reduction in the trainee's health as he or she continues through the simulation. Health is indicated as a percentage by the icon in the lower left corner of the display (Figure 5). Once the trainee has obtained the appropriate safety gear and has become familiar with the user interface, he or she is ready to go to work in the simulation.

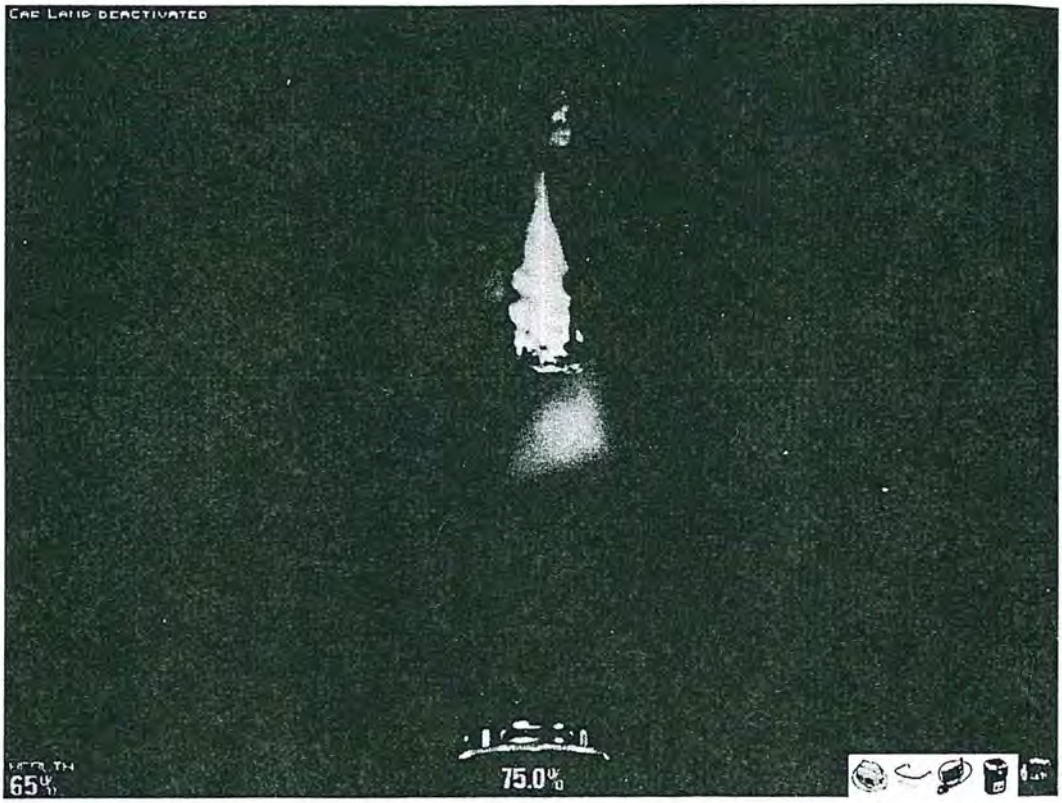

Figure 5. A screenshot from within the simulation.

The trainee proceeds underground via the mine portal. Several hazards are presented, such as uncovered holes in the floor, unsupported roof, and moving equipment. The trainee can receive warning messages regarding these hazards, depending on level of skill. The trainee can also be given specific instructions relating to an individual mine's safety procedures. Failure to follow these warnings results in a reduction of health points, possibly ending the simulation with a fatal mistake.

Hazard recognition and avoidance are seldom the primary task of a miner during an actual work shift. To accommodate this within the virtual environment, the trainee is tasked with collecting first-aid packs located throughout the simulated mine. Most packs are placed so that retrieval does not pose a safety risk to the trainee. However, several packs are placed in dangerous locations and cannot be retrieved without injury or death. The goal is to test the trainee's skill in identifying hazards.

The VRMST software can be implemented on a 500-MHz Pentium PC with a 16-Mbyte graphics accelerator. Because the graphics engine is developed for PC games, the software supports many of the popular operating systems and processors. Newer versions of the game are being deployed on game consoles such as Sony's Playstation 2 and Microsoft's Xbox. These systems retail for about $300 and could be used for future releases of the VRMST software.

In an effort to develop a more immersive experience, researchers at SRL have constructed a low-cost VR training room. A 100-in rear-projection screen gives the trainee a panoramic view of the virtual mine. A surround-sound speaker system allows the trainee to locate sounds in three dimensions. Force-feedback motion controls and a tactile sound transducer provide a physical connection to the simulated space. All these sensations combine to give the trainee a sense of presence within the virtual environment. The learning becomes experiential rather than didactic.

FUTURE WORK

The most pressing need for the future of this project is to obtain user feedback regarding the use of the software under actual training conditions. To achieve this goal, a mobile computer network with four stations has been constructed. The system is a self-contained, multimedia, computer-based training platform optimized for the VRMST software. Four Pentium 4 PC's with GeForce 3 graphics cards provide ample power for rendering the virtual environments. These are enclosed in a shock-mounted shipping case with detachable lids that become tables for the trainees. Other PC's at the training site can be connected to the mobile unit's network switch, thus enabling more participants to join in the VR training.

This technology has potential application to environments other than underground mine safety training. Surface mining, milling, agriculture, and construction are all occupations where VR training simulators could have a positive impact on safety. As the SRL training simulator matures, these areas can be addressed when funding becomes available.

CONCLUSIONS

Preliminary research indicates that low-cost VR simulators can provide effective safety training for mine workers. Experiential learning using this method provides a basis not just for gaining knowledge about job hazards, but also for changing unsafe behaviors in mine workers. These tools can be tailored to meet the needs of individual mines while remaining cost effective and relatively easy to use. The mining industry has supported this type of technology as a safety training tool. Further objective tests are required before the effectiveness of these tools can be fully assessed.

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Application of COMPUTERS *and* OPERATIONS RESEARCH *in the* MINERAL INDUSTRY

Proceedings of the 30th International Symposium

Edited by Sukumar Bandopadhyay

Published by the
Society for Mining, Metallurgy, and Exploration, Inc.

Society for Mining, Metallurgy, and Exploration, Inc. (SME)
8307 Shaffer Parkway
Littleton, Colorado USA 80127
(303) 973-9550 / (800) 763-3132
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ISBN 0-87335-219-X