HAZARD RECOGNITION—COMPUTER BASED SIMULATION

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ABSTRACT

A study by the National Institute for Occupational Safety and Health (NIOSH) on occupational deaths between 1980 and 1989 indicated that the mining industry had the highest average annual fatality rate (31.9 per 100,000 workers) of any industry in the United States. Mining also carries the highest risk for accidents in 23 states and accounts for the largest number of occupational deaths in three states. Researchers believe that the use of virtual reality- (VR-) based training tools will help to reduce these injury and fatality numbers. Accordingly, researchers at NIOSH's Spokane Research Laboratory are developing software that utilizes inexpensive computer hardware to deliver an immersive desktop VR experience to educate mine workers on the hazards of mining, as well as to train miners in evacuation routes and evacuation procedures. In addition, SRL researchers are developing computer animation techniques used to reconstruct mining accidents. These reconstructions will be used to train miners to recognize and avoid hazardous situations at the job site.

Computer-based training tools offer several distinct advantages over more conventional training tools. Computer-based tools provide a three-dimensional immersive environment that allows the trainee to experience mining hazards and view mine accidents without actually being exposed to such hazards. This "time-on-task" will help reinforce the learning acquired during more conventional classroom instruction. In addition, the inherent flexibility of this type of tool allows the training material to be tailored to meet the requirements of individual mines.

INTRODUCTION

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

A study [1] by the National Institute for Occupational Safety and Health (NIOSH) on occupational deaths between 1980 and 1989 indicated that mining industry has the highest average annual fatality rate (31.9 per 100,000 mine workers) of any industry in the United States. Mining also carries the highest risk for accidents in 23 states and accounts for the largest number of occupational deaths in three states. The use of virtual reality (VR) based training

[1] *Occupational Injury Deaths - United States, 1980-1989*, MMWR Vol. 43, No. 14 (1994).

tools may help to 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 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 CAD files, typically an AutoCAD-compatible format.[2] 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 trainees 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, or electrical cables. The trainee could then be taught to recognize and avoid these hazards without actually being exposed to a real danger.

Finally, researchers at SRL are also developing simple, cost-effective visualization tools that will be used to reconstruct accidents at mine sites. By viewing these computerized accident reconstructions, miners may learn to avoid such accidents in the future. The accident reconstructions are developed using many of the same computer programs used to develop the hazard recognition and evacuation training software. However, because the accident reconstruction animations are not rendered in real time, researchers can achieve much greater detail and fidelity, leading to more realistic and graphic depictions of the accidents.

METHODS

The initial proof-of-concept for the hazard recognition and evacuation training software was developed using first-person action computer games, such as Quake II by Id software, as the graphics engine for the simulations (Figure 1). Because of the widespread availability of editing software for these games, this method of creating custom VR simulations is relatively simple. There are several advantages to using existing software as the basic graphics engine, the main one being that a limited amount of programming is required to create customized VR applications. Using existing game software provides access to current state-of-the-art graphic techniques, 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. Twilight3D's 3D Graphics Engine (3DGE) was purchased to accommodate this need. Although 3DGE provides a feature list that is quite impressive, the engine requires a significant amount of programming to implement. Full details on the engine's capabilities are available on the company's web site at www.twilight3d.com. While many of these features have yet to be incorporated into the training simulator at SRL, a working version of the software has been developed. New features are being added on a regular basis.

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

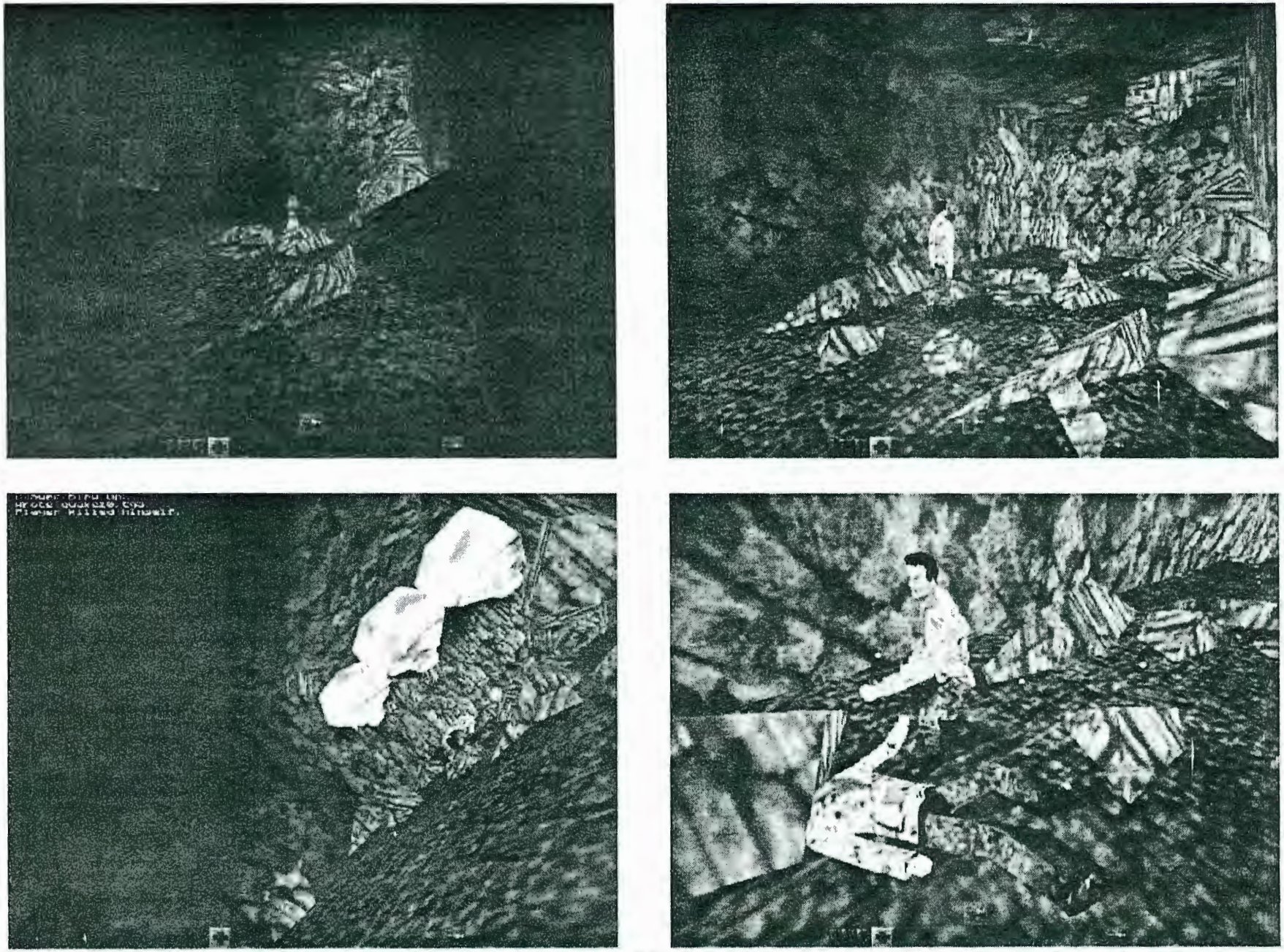

Figure 1: A series of screen shots shows a trainee being buried in a rock fall. The program is a modified version of the Quake II software.

The current version of SRL's simulator uses mouse or joystick controls to allow a trainee to navigate through the virtual mine from a first-person perspective. A dynamic light is attached to the trainee's viewpoint to simulate the cap lamp worn on a miner's hard hat. The virtual mine model is initially generated in Kinetix's 3D Studio Max software. This allows the developer to import mine maps from AutoCAD or a similar format and add features, such as texture maps from digital photos, lights, and other objects, that will increase the realism of the simulation. Further realism is achieved through incorporating moving objects and spatially located sounds.

The initial proof-of-concept for the accident reconstruction software was also developed using Kinetix's 3D Studio MAX software. This software allows researchers to create accurate computerized environments populated with custom, or off-the-shelf digital models of mining equipment, vehicles and characters.

SPOKANE RESEARCH LABORATORY'S MINE SAFETY TRAINING SIMULATOR

The trainee begins the simulation from the safety supply room. By placing the cursor on the appropriate safety equipment on the supply room shelves, the trainee adds 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 right corner of the display (Figure 2).

The trainee proceeds underground via the mine shaft and enters the shaft station. Several hazards are presented, such as uncovered holes, unsupported roof, and moving equipment. The trainee can receive warning messages regarding these hazards depending on level of skill (Figure 3). 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 VR mine simulation, 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 to test the trainee's skill in identifying hazards.

The simulation can be implemented on a 200-MHz Pentium PC with a 12- to 16-Mbyte graphics accelerator. In an effort to develop a more immersive experience, researchers at SRL are constructing a low-cost VR training room. A 100-inch 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.

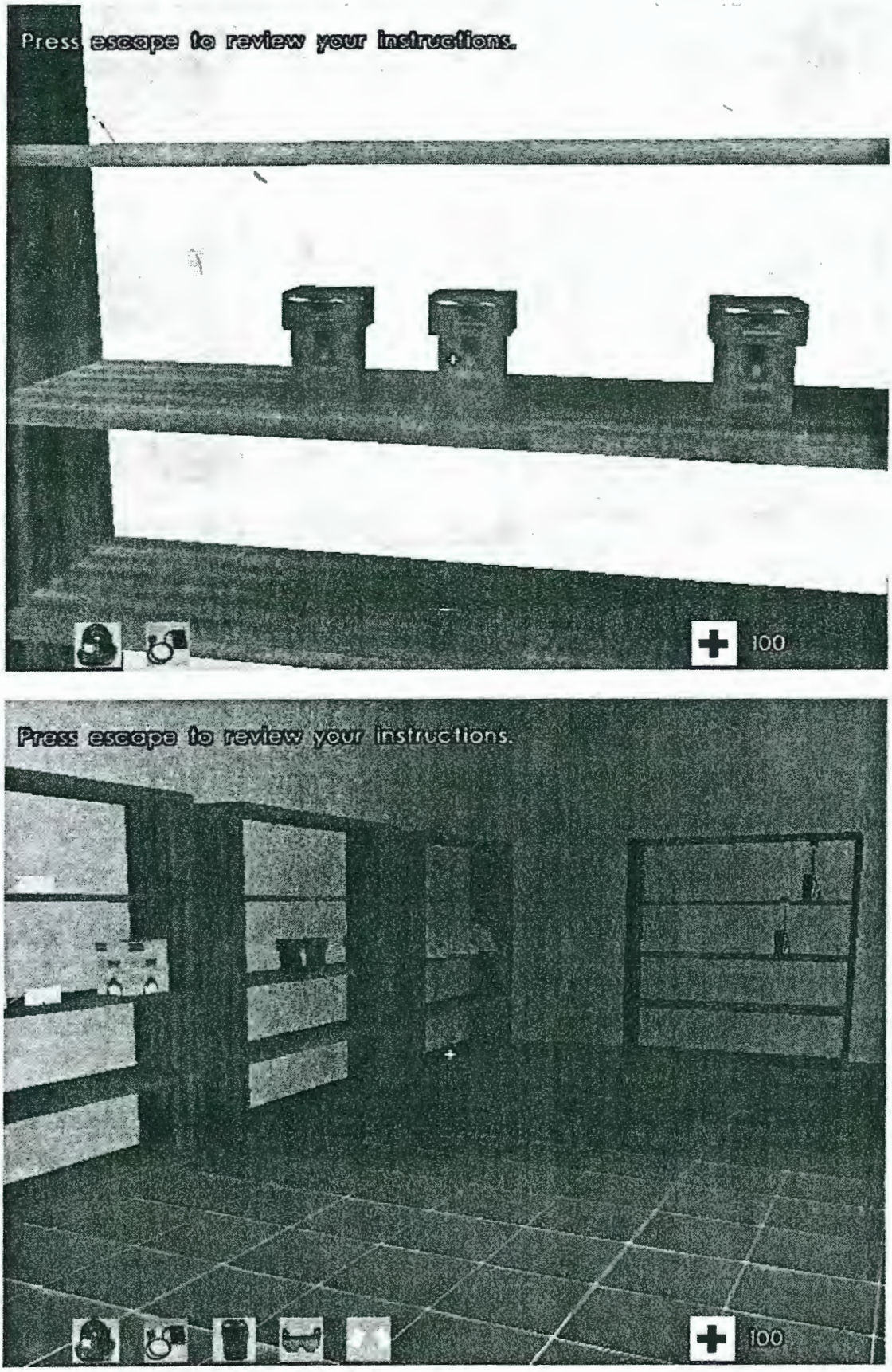

Figure 2: The trainee begins the simulation in the safety supply room.

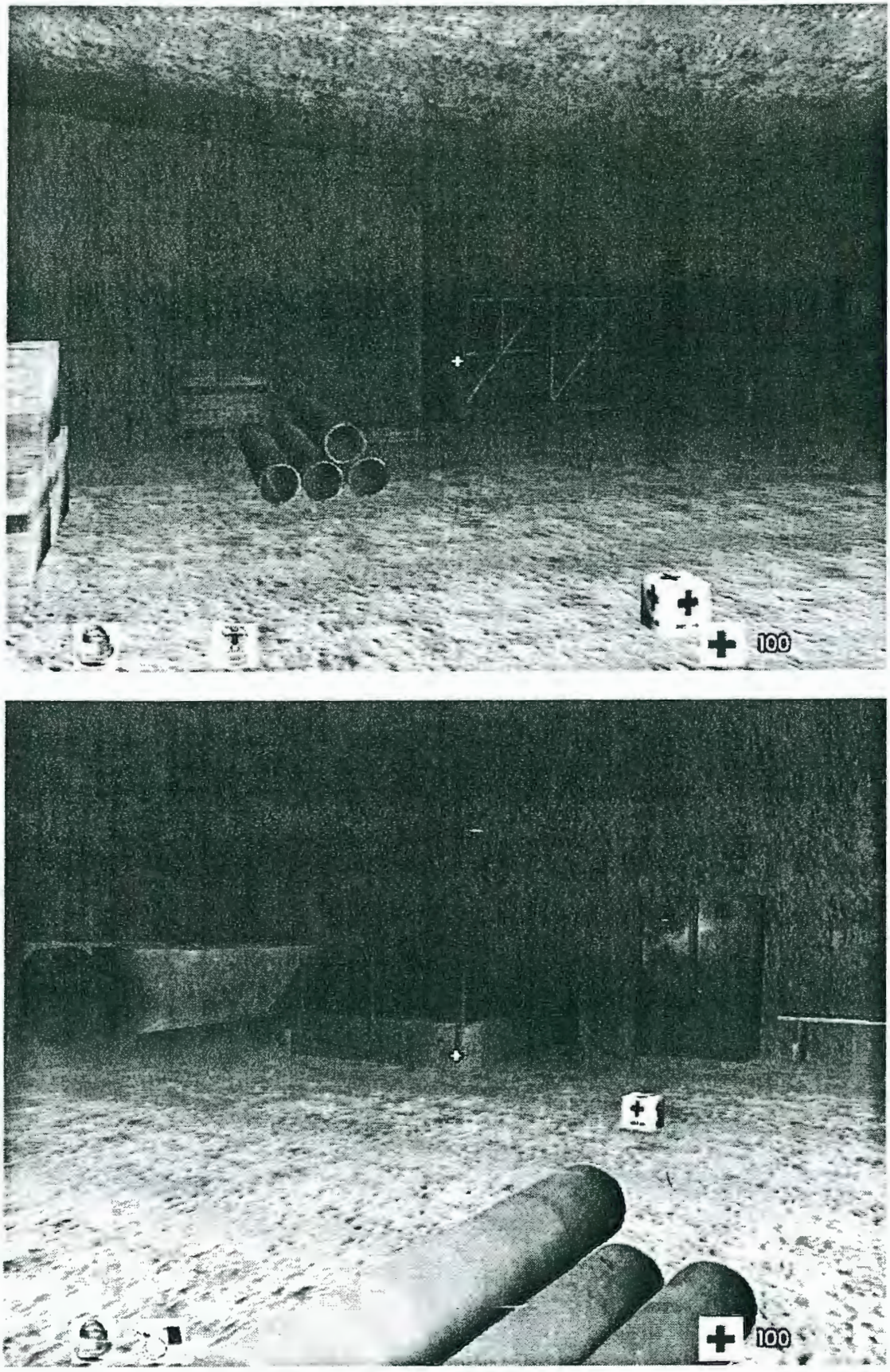

Figure 3: As the trainee enters the mine (top), he or she is presented with hazards ranging from moving equipment to open holes (bottom).

SPOKANE RESEARCH LABORATORY'S ACCIDENT RECONSTRUCTION

The goal of the accident reconstruction task is to develop simple, cost-effective computer visualization tools to be used to reconstruct accidents at mine sites. These reconstructions are generated using off-the-shelf computer software and three-dimensional computer models created at SRL, or obtained from third party model libraries. The reconstructions can then be used to train miners to recognize and avoid particular hazards associated with their jobs. For example, researchers have reconstructed a haulage accident that resulted in a fatality at a surface mine. The accident occurred when a worker stepped behind one dump truck in order to direct a second dump truck (Figure 4). The first truck then backed over the worker, killing him instantly. Researchers believe by viewing these types of reconstructions, mine workers will be more keenly aware of the hazards at their site and therefore likely to avoid such hazards.

One significant difference between the accident reconstruction software and the hazard recognition / evacuation training software is the level of detail achieved by these programs. In order to maintain the smooth, immersive virtual environments used in the hazard recognition and evacuation training programs, the computer should maintain an approximate frame rate of thirty frames per second, the frame rate achieved by standard video equipment. The factors that influence the 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. However, for a pre-rendered animation, such as those used for accident reconstructions, rendering times of two minutes per frame, or more, is acceptable. This allows for a much greater level of model detail through the use of more polygons, more elaborate lighting schemes, and more complex atmospheric effects.

Figure 4: A computer actor recreates the fatal mistake made by a worker at a surface dump. The truck at left backed over the worker as he directed other traffic at the site.

FUTURE WORK

While new features are added to the software on a regular basis, several major enhancements are currently under development. The most significant new feature for the hazard recognition and evacuation training software is a multi-user version that will allow several trainees to interact within the same virtual mine. This interaction is particularly important during mine evacuation procedures, but can also lend more realism to hazard recognition and avoidance training as the trainees perform regular work tasks. Enhancements to the mine model generating process are also planned and may include the development of custom software to assist in the conversion of mine maps to VR-ready models. Work continues on the development of more complex, more realistic equipment models and model behavior used in the accident reconstruction program.

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 at a low-cost, VR simulators and computerized accident reconstructions 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 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.

CONTACT INFORMATION

Demonstration software is available upon request. Please contact the authors at the address below.

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