Enhanced fire escape training for mine workers using virtual reality simulation

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Introduction

U.S. Mine Safety and Health Administration (MSHA) accident reports often cite poor training as a root cause for many fatalities and serious injuries, but traditional classroom safety training provides little practical experience for mine workers. Virtual reality (VR) training systems have been used successfully in many different settings including pilot training, military simulators and mining equipment operation. This type of training has the added benefit of providing simulated experience in dealing with a hazardous circumstance on the job without exposing the trainee to the hazard. Although this type of training has been successfully used in other fields, it has not been used much or tested for effectiveness in mining.

Therefore, this study answers the following research question — can a VR system be used in a mine safety training environment to teach evacuation procedures, provide simulated experience, and measure performance?

The study was an informal, preliminary test of the Virtual Reality Miner Safety Training (VRMST) software, developed at the National Institute for Occupational Safety and Health's (NIOSH) Spokane Research Laboratory (SRL). The VRMST software was designed for mine workers to practice evacuation routes and procedures. A preliminary test of this software was conducted during an eight-hour, MSHA-approved refresher training course. This training was led by an approved mine safety trainer and SRL research staff were the subjects of the preliminary testing of the VR training.

Based on these initial results, a new project was funded to further develop and enhance the VRMST software into a publicly available product and determine how the software could be distributed to safety trainers. The new simulation software uses the Unreal game engine from Epic Games (www.unrealtechnology.com). SRL researchers modified some of the high-level script code and included custom maps, models and animations.

By repurposing the computer game in this fashion, the end user does not see any elements of the original game on the screen. The software provides a first-person perspective on the virtual environment — meaning the computer display renders the virtual environment from the view of the person sitting at the keyboard as opposed to a top-down, or third-person perspective. Numerous researchers have used the power of this game engine for nongaming purposes such as teaching pedestrian safety (McComas, et al, 2002), creating architectural walkthroughs (Johns and Lowe, 2006) and military simulations (Ryan, et al, 2005; Wray, et al, 2004). In response to this, Epic Games decided to release a version of its game engine for nongaming, noncommercial purposes. The new NIOSH virtual reality training software is built on this game engine, which will allow the Institute to publish and distribute the resulting training products to the public. The first part of this paper describes an earlier software version that was never publicly released but led to the development of the current software package scheduled for release in late 2008. The simulation software currently under development is detailed at the end of this paper.

Abstract

Recent U.S. mine disasters identified a need for improved training of miners in escape from mine fires and explosions. Researchers at the National Institute for Occupational Safety and Health's (NIOSH) Spokane Research Laboratory (SRL) have designed fire-escape training software for use in a mine-safety training course. The software allows four trainees to work together in a virtual world via a computer network. Trainees responded favorably and showed a marked improvement in locating the proper evacuation routes on subsequent trials. In collaboration with the Pittsburgh Research Laboratory (PRL), a more elaborate fire evacuation scenario is being developed. Further study is needed to confirm that virtual training will translate to improved safety outcomes in the real world.

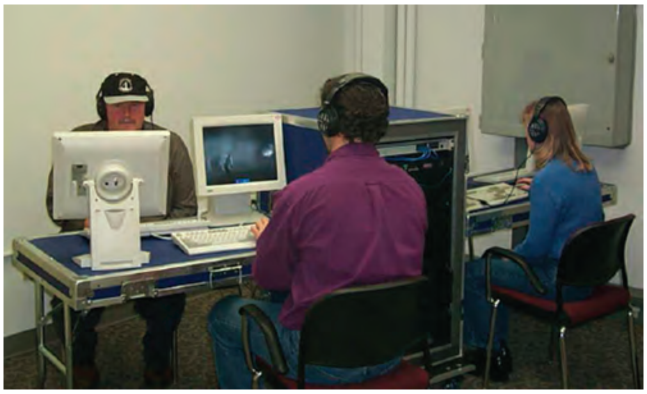
Design of VR software

The simulation software uses a computer network to place four trainees within the same simulated environment (Fig. 1). Each trainee is represented in the virtual mine by a computer-generated character called an avatar. Trainees have independent control over their avatar in the virtual mine using simple keyboard and mouse controls. The simulation style is first-person, meaning that each trainee can see the other trainees' avatars, but they do not see their own avatar on their computer screen (Fig. 2). First-person simulation attempts to provide a virtual "first-hand" perspective of the setting.

The virtual mine for this training simulated a common setup in underground longwall coal mining with a three-entry gate road development heading. A three-entry development consists of three parallel entries connected by crosscuts. Mine workers construct stoppings in these crosscuts as mining progresses to control ventilation air flow routed through the entries. Mandoors may be placed in some stoppings to allow travel from one entry to the next. In actual work settings, there are limited options for escape and miners, particularly new employees, can

FIGURE 1

The VR training computer network used for the test.



become easily confused about which escape route to take (Murray, et al, 2007).

The simulated evacuation scenario used in this training exercise was based on an actual incident involving a fire at a cooperating mine. The simulation included smoke that significantly obscures the trainees' VR vision in some areas. In addition, the virtual environment included falls of ground (as could be caused by the fire) that blocked the trainees' primary escape route and forced them to find an alternate path, just as they might experience in an actual evacuation. Trainees were also presented with VR obstacles that required them to consider various escape routes. This type of critical decision-making takes time and requires the trainees to analyze their virtual experience and talk with each other, via telephone if the computers are connected from remote locations.

Methods

Thirty-two trainees worked in groups of four to test the VR simulation program. Detailed demographic information was not collected from the trainees, but all participants were experienced mine safety professionals. None had significant experience playing first-person-type video games. Each group of four trainees was given 10 minutes to practice using the keyboard and mouse to control the movement of their avatar in the virtual mine. During this practice time, they were also instructed to take note of specific landmarks or other items in the virtual mine that would be helpful in finding their way out during the evacuation training sessions. Prior to starting the evacuation simulation the trainees were given the evacuation plan for their simulated mine, which included the preferred escape routes and a checklist of things to do as they evacuate.

To measure trainee performance, two escape scenarios were created by varying the location and number of blockages and obstacles. Escape scenario A was less complex compared to scenario B (Fig. 3). Scenario A consisted of a single fall of ground in the primary escapeway, forcing the trainees to double back and find the next inby mandoor allowing them to switch to the secondary escapeway. Scenario B required the trainees to alter their escape route more often, with blockages in both primary and secondary escapeways. This required them to eventually find their way to the belt entry as the only means of getting past the fire. The complexity of scenario B made it more likely for the trainees to become lost. Half of the four-person groups were asked to navigate through the more simple escape route first (scenario A), followed by the more complex one (scenario B). The remaining groups were first exposed to the more complex scenario, followed by the simpler one. Time to complete each scenario was recorded for each group and post training discussions were held to collect individual trainees' reaction to the VR training medium.

Results

The VR evacuation training was successfully integrated into the eight-hour annual safety training refresher course required by 30 CFR Part 48. The four groups that were given the simple escape route first were found to complete the more complex scenario 37 percent faster than the groups that were first exposed to scenario B, the more complex scenario. No difference in completion time was recorded for the groups to complete scenario A (the simpler evacuation route), whether it was administered first or second. The "solution time" for scenario A was about one-third of that recorded for each of the groups – meaning that someone who is proficient with the software controls and had advanced knowledge of the proper path around the blockages could complete the training task in less time. These factors indicate that the improved performance was a result of the VR experience and not from increased proficiency with the software.

Each of the eight groups successfully completed both evacuation scenarios. Trainees reported during post-training discussions that they felt the training was effective. Trainees also mentioned that they felt more prepared to follow a mine evacuation plan as a result of this VR training, although this would need to be compared to a control group with more traditional training to draw significant conclusions.

Discussion

The preliminary testing of the VR software indicated that trainees increased their ability to escape from a virtual mine fire. It is hoped that this would translate into an increased ability to escape from a similar situation in a real mine evacuation, but more elaborate testing would be needed to verify this assertion. There was also evidence that previous trainings that miners had received were applicable in the VR world. Six of the eight groups stayed

FIGURE 2

A screenshot showing a trainee's view of the simulated mine.

together in the virtual environment, as instructed, and waited for one another if they became separated. These groups also tended to follow the evacuation procedure checklist, as instructed at the beginning of the training sessions. However, in one instance, a group chose to follow a leader who clearly did not know how to navigate in an underground mine. That group circled the same pillar three times before realizing they were disoriented. The group chose a new leader and completed the training.

Because it is difficult to provide hands-on training for mine disaster situations, VR simulations can provide an opportunity for miners to be exposed to realistic situations without endangering their lives. Although VR simulations are relatively new to the mining world (other than equipment simulators), they have been used successfully in the military for some time. A rather interesting anecdote about military training simulation comes from education specialist, Don Johnson, who is a member of the Readiness and Training Unit of the Department of Defense (DOD) at the Pentagon (as cited in Prensky, 2001):

"During one particular battle known as 73 Easting – the flanking maneuver where our tanks sped around the Iraqi forces that were blinded and came at them from the West – a tank platoon led by an officer named McMaster encountered Iraqi tanks that were dug in. Military doctrine said that when you encounter forces that are dug in you need a three-to-one advantage in order to be successful. But McMasters' three or four tanks caught the Iraqis by surprise, rolling right over them and wiping out all 20 or 30 tanks that were dug in." (pp. 382-383).

McMaster explained that "We'd done it before – we did it in simulation," which supports the notion that their simulation training was effective. Prensky further cited Johnson, "In DOD, we probably have done more studies of learning technology than you will find anywhere. We've proven to ourselves that technology works. We've proven it academically, but more importantly, we've proven it operationally" (p. 382). Thus, the military has been able to successfully employ simulations to their employees, particularly in situations where hands-on-training is difficult to gain.

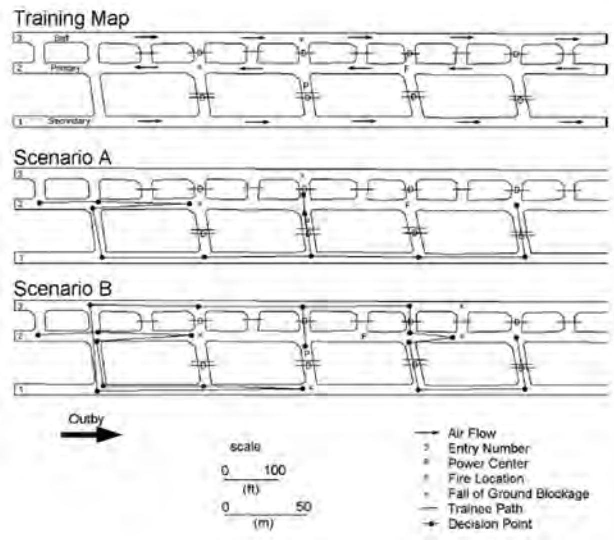
Researchers at the Rehabilitation Sciences Virtual Reality Lab at the University of Ottawa, Canada, tested the effectiveness of virtual reality for teaching pedestrian safety to children. Their results were mixed, but show promise and offer insights into how future efforts might improve the effectiveness of virtual reality training (McComas, et al, 2002). Specifically, they suggest;

1. Allow more time for each student with the VR program.
2. Create a VR program as similar to the real situation as possible.
3. Build social factors such as peer pressure into the virtual environment.
4. Introduce the VR intervention as part of a program using other instructional tools.

The new map reading and evacuation training modules attempt to address these suggestions, with the exception of item 1, as increasing the amount of time that safety trainers allot to any one topic is not always an option. Research staff worked closely with content experts and field-tested the software with test groups to ensure the realism of the simulations. The multi-user capability of the new evacuation module will help create the social factors suggested in item 3. The simulations include front-end training on the topics covered and also display post-training maps to show the trainees where they traveled in the environment to serve as a discussion point. These efforts offer promising support for future VR simulations in mining, but further research is needed to examine the use of computer simulation in training beyond these populations to see how well it translates to these other areas.

FIGURE 3

Scenarios A and B with critical decision points and obstacles.



Limitations

Limitations exist in the preliminary testing of the VR training created for the mining industry. First, it was conducted only in small groups and the demographics of the trainees were different from the anticipated characteristics of a typical miner. Second, it is possible that varying levels of computer literacy among trainees could present barriers to effective training for a broader mine worker population. The demographics of the test subjects does, however, match those of the management staff at a typical mine. Third, it is also possible that only one person from

FIGURE 4

Plan view of the room-and-pillar mine showing smoke in the belt and adjacent entries.

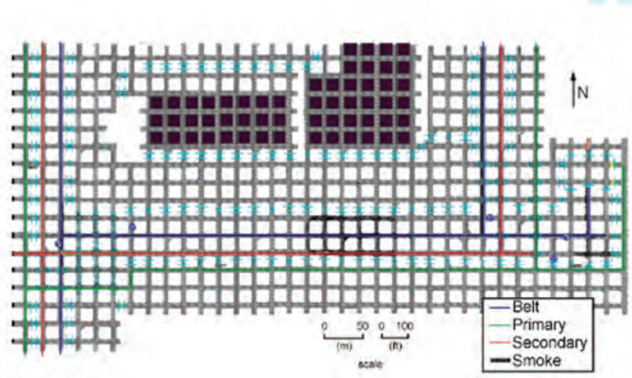


FIGURE 5

Trainees interact with computer characters to keep the training engaging and move the story along.

each group actually gained any skill and the others simply followed along. Additional research is needed to address these potential limitations, and identify and address others.

Future studies are needed to evaluate the effectiveness of the VR training with different sample populations. For example, testing of the software could be conducted with individuals, small groups, and in large classroom settings. The small group format was very useful in generating discussion after the VR training was complete. Similar discussion groups could be used among larger groups or even in larger classroom settings. Still, the final VR software product must be rigorously tested for effectiveness using standard educational assessment methods.

Current work

Toward this goal, the researchers from SRL are now collaborating with training and content experts from NIOSH's PRL to create the next generation miner training simulation software. The earlier effort lacked any lead-in training material to provide context for the trainees and guidance to the trainer for conducting the training sessions. The new project team developed a computer based training (CBT) front end for a new topic – basic map reading aimed at teaching new miners the knowledge and skills to read a paper map of an underground coal mine. The Web-based CBT can be self-administered or used as an interactive presentation to assist trainers with larger groups. Upon completion of the CBT, the trainees can practice their new underground navigation skills using a virtual reality simulation. The project team decided this topic would be easier to develop into a complete package, and would lend itself to future modification for evacuation training. The Map Reading Basics training package has been field-tested and reviewed and is awaiting final NIOSH management approval prior to publication, as of this writing.

A virtual reality evacuation training package is being built upon the same virtual mine environment used for the Map Reading Basics program. The purpose of this module is to aid miners in developing the knowledge and skills needed to evacuate during a mine fire. The simulation allows multiple users to participate, which helps draw trainees into the simulation as they interact with each other in the virtual environment to solve the problem of how to evacuate together. The room-and-pillar mine layout is far more complex than the earlier evacuation module and uses a realistic mine ventilation model to move smoke and mine gases through the mine (Fig. 4). Numerous enhancements to the realism of the simulation are also included; turning off the belt, on-screen communication between trainees, use of self-rescuers and lifelines, and a functional gas meter. Additionally, computer-controlled miner workers can interact with the trainees to enhance the realism of the simulation by providing background context and help move the storyline along (Fig. 5).

As with the map reading module, the evacuation module uses the newer Unreal Engine2 runtime software from Epic Games that has been customized by the research team for this purpose. Also as before, the module will undergo field testing and refinement in collaboration with several industry partners to ensure that the final product has broad applicability within the mining industry. Once published, these Unreal engine-based simulations could be further customized by NIOSH or third parties; mine companies, universities or consultants to enhance their capabilities and create new training modules.

Conclusions

Preliminary testing of the virtual reality mine evacuation training indicated that this type of training medium has the potential to enhance traditional training techniques. However, more rigorous testing and refinement is required. Supplementary training materials are needed to assist safety trainers in administering the simulation training program and analyzing the feedback regarding the trainees' performance and perceptions about the VR training medium. Additional studies will be conducted as the development of the VR software continues, and supplementary training materials are created to assist in the training and testing efforts concerning the effectiveness of VR in safety training for miners. The open architecture of the NIOSH virtual reality safety training software will also lend itself to further development and enhancement that may pave the way for additional training options in the future.

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