SME Annual Meeting
Feb. 25-Feb. 28, 2007, Denver, CO

Preprint 07-008

VIRTUAL REALITY SIMULATOR FOR TRAINING MINERS TO INSTALL ROCK BOLTS USING JACKLEG DRILL

D. Nutakor, Univ. of Missouri-Rolla, Rolla, MO
D. Apel, Univ. of Missouri-Rolla, Rolla, MO
L. Grayson, Univ. of Missouri-Rolla, Rolla, MO
M. Hilgers, Univ. of Missouri-Rolla, Rolla, MO
R. Hall, Univ. of Missouri-Rolla, Rolla, MO
J. Warmbrodt, Univ. of Missouri-Rolla, Rolla, MO

Abstract

MinerSIM is an augmented reality system with integrated hypermedia that is suitable for training underground miners in the basics of using a jackleg drill to install rock bolts. While statistical evidence shows that rock bolting with such a drill has an inherent level of risk, it is conjectured that this can be mediated with adequate safety training outside of the actual mine environment using a variety of educational media including interactive three-dimensional images, games, animations, and videos to describe the mechanics of rock bolting and its principles. Ultimately, trainees will install rock bolts in an immersive environment mixed with real and virtual images generated via a gaming graphics engine. This paper will discuss considerations, implementation issues, and evaluation methodologies of the MinerSIM system.

Introduction

Virtual reality (VR) training has a number of advantages over existing traditional methods including a larger amount of data collection during training, comprehensive review of a participant's performance, and systematic development of a trainee's skills. VR simulators are commonly used to train for hazardous environments in a manner that minimizes the exposure of a trainee to real risk. Underground rock bolting is one of the most dangerous mining jobs because rock bolters normally work under newly exposed roof area; consequently, there is a greater risk from the unsupported and sometimes unknown conditions. A survey conducted by MSHA from 2000 to 2004 revealed that the fall or slide of rock was the second cause of fatalities in underground coal mines, and the fourth cause in the metal and non-metal mines (www.msha.gov).

Labor statistics show that many experienced miners will be retiring soon, and this means there will be very little interface time between the new miners and the experienced miners, which could have been used for training the new inexperienced miners. The West Virginia coal industry predicts that it will need 5,000 to 7,000 more miners during the next 10 years to keep up with retirements. The estimated percentage of the retiring mining workforce in Canada during the next five years ranges between 14 and 17 percent, with a gap of 2,700 to 7,000 predicted. In Australia there will probably be 7,400 fewer employees in the mining industry during the next five years (Muir, 2006). It is therefore important to find means to capture the retiring miner's knowledge before an individual leaves; and the VR approach is ideal for training the expected influx of new and less-experienced underground rock bolters in order to reduce injuries caused by inexperience in handling drilling and bolting equipment.

Most of the VR simulators developed for the mining industry were designed to train operators of heavy equipment, and no system addresses underground rock bolters using a manual drill. Examples of companies and research centers which developed or work on VR simulators for the mining industry include:

1. The University of Nottingham AIMS Research Unit, which developed VR training simulators that are interactive, graphically programmed through drag-and-drop modeling software, and provide hazard spotting. Some of their designs include dynamic simulation of backhoe equipment and simulators for operators of hydraulic excavators (www.aims-solutions.co.uk).
2. 5DT (Fifth Dimension Technologies) is a high-technology company specializing in virtual reality. 5DT develops, produces and distributes VR hardware and software to the mining industry. They developed simulators for training truck operators as well as continuous-miner operators and operators of mechanical roof bolters (www.5dt.com).
3. Immersive Technologies developed dump truck simulators for Caterpillar which are interactive, immersive, and make use of real machine controls. The simulators are able to achieve an advanced level of realism and fidelity through the use of proprietary data and machine technical information (www.immersivetechnologies.com).

MinerSIM – The Miner Simulation System

The University of Missouri – Rolla (UMR) is contributing to mine safety training with a system known as the "Miner Simulation System" or MinerSIM, for short. It is an augmented reality system with integrated hypermedia that is suitable for training underground miners in the basics of using a jackleg drill to install rock bolts. MinerSIM is an integrated system that has two main pedagogical approaches. During the early stages of training, the educational media is comprised of learning objects that utilize progressive scaffolding allowing the trainee to choose between text, three-dimensional images, animations,and videos to learn the basic principles of ground control and rock bolting using a jackleg drill.

When a more immersive approach is appropriate, augmented reality is used. MinerSIM simulates underground rock bolting using a jackleg drill in a hard rock mining environment with fractured rock mass. The simulator allows trainees to inspect ground conditions in the virtual mine, scale down loose rock, set-up the jackleg, drill holes for the rock bolt installation, choose suitable rock bolts (friction, rebar, or mechanical), and install the rock bolts. This training is performed in a safe and secure environment under the watchful eye of a trainer.

MinerSIM has several potential advantages beyond safety. Total training time will be shorter than conventional approaches since training can run asynchronously on demand. UMR's VR simulator when completed can be used in any mining environment, meaning that the set-up will allow switching between environments typical for an underground coal mine and a hard rock mine with different ground conditions. Evaluation and validation of the resulting product will be carried out at the UMR Experimental Mine involving students and mine supervisors. Recommended changes will be made before distributing the final product leading to cost savings through reusability.

Project Design and Simulation

Multimedia System

The first part of the proposed training is in multimedia format, and it closely follows an underground rock bolter's typical work sequence, which includes general preparation of the work face, positioning and setting-up of the drill, drilling a hole, and installing a bolt. General preparation of the face is a miscellaneous category that includes washing the face, scaling, handling ventilation material, performing a gas check if necessary, handling supplies, and examining the workplace. Drilling bolt holes involves inserting the drill steel in the chuck, adding extension steels if necessary, changing the bits, drilling the hole, and removing the steel. Bolt installation involves making up bolt assemblies, inserting resins in the hole if required, inserting bolts into the hole, aligning the bolts, and spinning to mix resin or torque the installed bolt.

Several strategies were used to elicit learner interest, such as:

- Clear performance objectives stated at the beginning of each section, with links established between these objectives, and their pertinence to the rock-bolting tasks.
- A logical and easy-to-use structure including a simple and straightforward navigation tool, which minimizes efforts required by the trainee to achieve the performance objectives.
- The use of a variety of stimuli (symbols, images, animation, sound, and videos), representative of the professional interests of the targeted audience.
- The use of a representation of an underground mine to create a user-friendly environment. This is done through inclusion of videos and photographs taken on rock bolting at the UMR Experimental Mine.
- The content is organized in a modular format with quizzes and review exercises at the end of each section to enable trainees to discuss with their instructor any information they do not understand.

The primary development software used for this part of the training module is Macromedia Flash (Flash Professional version 8). Flash allows incorporation of 3D models and animations (generated using Macromedia Fireworks version 8 and Swift 3D version 4.5) into its authoring environment. A programming language in Flash (Action Script 2.0) was used for creating audio and video, and also to add interactivity to the system. Figure 1 shows a screen view from the first part of the proposed training module.

Virtual Reality Computer Simulation

MinerSIM is an augmented reality system. Formal definitions say that any system that allows a person to interact with three dimensional graphical objects is *virtual reality.* The system is considered to be *augmented reality* if the 3D graphical images are mixed in some way with the physical world. How this mixture is done is left to broad interpretation. MinerSIM performs the mixture in the following way. The virtual environment is essentially a so-called mod of the HalfLife® game. This means that MinerSIM uses the game engine as the driver for the virtual environment. The underground world is produced by using a modeling tool called Valve® to develop maps that are imported into HalfLife®. This approach allows the designation of interior rooms and corridors representing stopes and drives of an underground mine. To achieve the mixture, MinerSIM uses hardware and software technologies. Figure 2 shows a schematic diagram of major components of MinerSIM with the function of each component shown in Table 1.

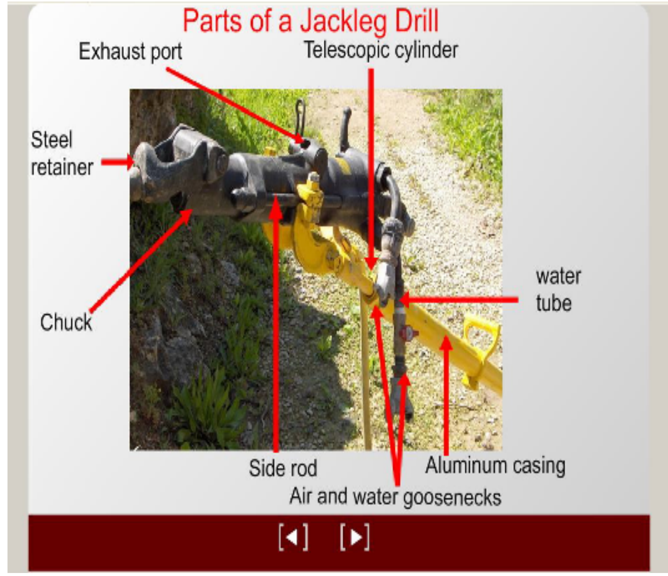

Figure 1. A Screen View Showing Major Parts of a Jackleg Drill.

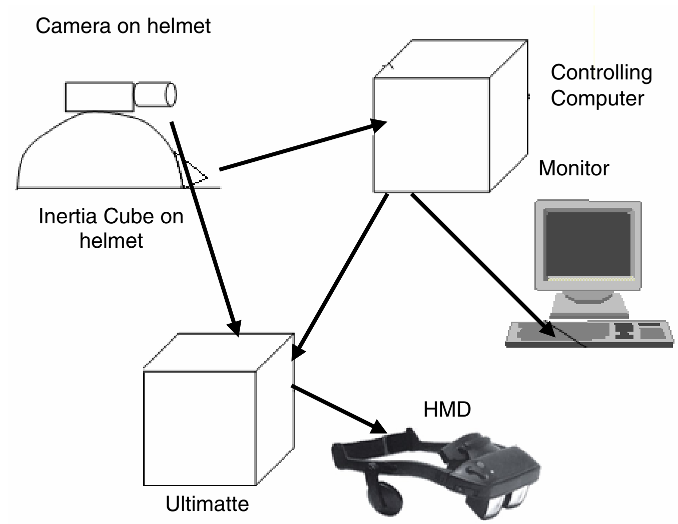

Figure 2. Major Components of MinerSIM

Table 1. Functions of Components of MinerSIM

Component	Function
Inertia Cube	Tracks the location of the trainee's head and sends data to the controlling computer
Controlling Computer	Produces the virtual environment and sends video to the Ultimatte
Camera	Captures details of the blue-room environment (hands, tools, blue walls) and sends video to the Ultimatte
Ultimatte	Takes the camera video and replaces anything blue with the video from the computer (the virtual environment)
Head-Mounted Display (HMD)	Takes combined video from Ultimatte which enables the trainee to see the virtual environment

The entire system is set up in a "blue-room" (Figure 3) which is replaced by the virtual environment (Figure 4) after a trainee puts on the head-mounted display (HMD).

Figure 3. Trainee (without the HMD) in the Blue-Room.

Figure 4. Trainee (with HMD) in the Virtual Mine Environment.

MinerSIM Assessment and Evaluation

Laboratory for Information Technology Evaluation (LITE)

The project assessment and evaluation will be carried out under the auspices of the UMR Laboratory for Information Technology Evaluation (LITE). The primary purpose of LITE is to examine and evaluate the impact of information technologies on people with a particular focus on learning technologies. The laboratory has carried out a number of such evaluations, including large-scale projects sponsored by the National Science Foundation, the United States Department of Education, the Department of Defense, the National Institute for Occupational Health and Safety, and others. Results of these projects are being disseminated widely in the literature (Philpot and Hall, 2006; Philpot et al., 2005; Sullivan et al., 2005; Wilfred et al., 2004). A general framework is used for the evaluation (Hall et al., 2002; Hall et al, 2004), and modified for each project. The model is based on two principles: a) Evaluation should be iterative, carried out throughout the development process, aiding development with constant feedback; and b) The evaluation should consist of multiple methodological measurement approaches and conclusions should be based on the triangulation of these findings.

Initial Evaluation

The evaluation will initially focus on the virtual reality simulation system, with a series of two to three usability tests using small sample sizes, in order to address some fundamental usability issues that often arise complex augmented reality interfaces, such as this. The LITE lab has implemented such a strategy effective with complex VR training systems in the past (Hilgers et al., 2004). The focus is on logistical implementation and task realism. System modifications will follow each of these iterations. This stage will be followed by a final small-sample pilot study, which includes the entire training system, including both the multimedia and virtual reality components, as they would be used when the system is deployed. This would again be followed by modifications in both of the system's components as implied by the results of this evaluation.

Applied Evaluation

Following this initial evaluation, and system modifications, a series of one or more applied-comparative experiments will be conducted using University of Missouri-Rolla students who have some experience in mining based on their coursework and experience in UMR's experimental mine. These will consist of between-subject, experimental/control experiments with control students learning via traditional lecture/text formats.

The applied evaluation will culminate with the evaluation of the system as a tool for working minors in collaboration with industry professionals. The nature of the methodology in this applied research will be partly dependent on the number of participants available, since a minimum of approximately forty participants would be required to conduct a traditional comparative study utilizing inferential statistics in assessing outcome differences. However, previous research conducted by the LITE lab on a similar system, has found that a small sample study, focusing on qualitative outcomes, can also yield much practical information about system efficacy with participants who represent the target population (Hall et al., 2004).

Consistent with the basic LITE evaluation model discussed above, a number of quantitative and qualitative outcome measures will be implemented across all studies focusing on both foundational and applied knowledge. Further, individual differences and processing variables will be examined in an effort to identify the mediational effect of learner and learning factors.

Conclusions

Fatalities and injuries in underground mines cannot be prevented by addressing events that caused them retrospectively. It is time to prevent accidents from happening by providing miners with effective high-fidelity training to make new miners aware of hazards they will face prior to entering the real mining environment. The flexibility of MinerSIM will allow it to be configured quickly and produced relatively cheaply. In addition, the proposed training program will run on standard, currently available desktop personal computers; therefore, there is no need to buy any special equipment apart from providing a blue room to run the system. The ability of computers to create synthetic representations of the real world in virtual reality offers a number of opportunities to enhance current rock-bolting training. The proposed training module will allow users to learn within computer-generated environments, giving them an opportunity to make mistakes and suffer the consequences without putting themselves at risk. It is, however, important to note that MinerSIM is not intended to replace reality-based training, but only to supplement and enhance it.

References

1. Fifth Dimension Technologies, "Training Simulators for the Mining Industry", available at www.5dt.com, accessed July 28, 2006.

2. Hall, R.H., Flori, R., Hubing, N., Oglesby, D., Philpot, T., Watkins, S., and Yellamraju, V. (2002), "A Model for the Evaluation of Innovative Engineering Courseware: Engineering an Assessment Program", *Proceedings of the American Society of Engineering Education Conference*, Montreal, Canada, *http://www.asee.org/acPapers/2002-1697_Final.pdf*.

3. Hall, R. H., Philpot, T.A., Hubing, N., Flori, R.E., and Yellamraju, V. (2004), "A Model-Driven Multi-Year Assessment of a Software Development Project for Engineering Instruction", *Proceedings of the American Society of Engineering Education*, http://www.asee.org/acPapers/2004-1651_Final.pdf.

4. Hilgers, M.G., Leu, M.C., Hall, R.H., Agarwal, S., Lambert, T., Albright, R., Nebel, K. (2004), "Virtual Environments for Training First Responders", *Proceedings of the Interservice/Industry Training, Simulation and Education Conference (I/ITSEC),* Paper No. 1766.

5. Immersive Technologies, "Virtual Domination with Training Simulators", available on-line at www.immersivetechnologies.com, accessed September 22, 2006.

6. Macromedia Studio 8 "Applications Program for Content Authoring", Macromedia, Inc., San Francisco, California.

7. Mine Safety and Health Administration, "Fatality Statistics and Accident/Injury Information", available on-line at www.msha.gov, accessed July 24, 2006.

8. Muir, E. (2006), "Mining Boom is Sustainable", SME Mining Engineering Publication, Vol. 58, No. 7, pp 33-41.

9. Philpot, T.A., Hall, R.H., Hubing, N., Flori, R.E., and Yellamraju, V. (2005), "Using Games to Teach Statics Calculation Procedures: Application and Assessment", *Computer Applications in Engineering Education*, Vol.13, No.3, pp. 222 – 232.

10. Philpot, T.A., and Hall, R.H. (2006), "Animated Instructional Software for Mechanics of Materials: Implementation and Assessment", *Computer Applications in Engineering Education*, Vol. 14, No. 1, pp. 31-43.

11. Sullivan, J., Hall, R., Hilgers, M., Luna, R., Buechler, M., and Lawrence, W. (2005), "Iterative Usability Evaluation Methods Applied to Learning Technology Development", *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications*, pp. 1188-1193.

12. Swift 3D Version 4.5, "3D Vector and Raster Animations Program for Macromedia Flash", Electric Rain, Inc., Boulder, Colorado.

13. University of Nottingham AIMS Research Unit "Excavator Simulator", available on-line at www.aims-solutions.co.uk, accessed September 13, 2006.

14. Wilfred, L., Hall, R., Hilgers, M., Leu, M., Hortenstine, J., Walker, C., and Reddy, M. (2004), "Training in Affectively Intense Virtual Environments", *Proceedings of World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education*, pp. 2233-2240.