Improving Health and Safety Through Conveyor System Training in a Virtual Environment

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ABSTRACT

Preventing injuries and fatalities related to conveyor system use in the mining industry is important and increases uptime while decreasing lost time. The research presented here is funded by the National Institute for Occupational Safety and Health (NIOSH), and intended to accomplish this prevention by the use virtual environments (VEs) to improve training and help miners better understand the hazards of working around conveyor systems.

Two conveyor system VEs designed to teach miners about hazards and to safely complete tasks around conveyor systems were developed for this project. The first conveyor system VE, called the instructional tour, gives the miner a semi-automated tour of a conveyor system and teaches the miner about possible hazards (eg, missing guarding) and how to safely fix conveyor problems (eg, a stuck idler) using lock-out, tag-out procedures. The second, called the virtual shift, allows the miner to freely navigate around a conveyor system to detect and avoid hazards. The miner is presented with equipment failures that need to be safely repaired during the virtual shift. If the miner fails to identify and avoid a hazard or fix a failure in a safe manner, an animation of the consequences is shown to the miner, who must start the virtual shift over.

The models for the conveyor system VEs were created using 3DS Max. Desktop versions of the VEs were then created using Deep Creator™, an authoring application for creating interactive 3D environments. Later, more realistic versions of the VEs were created for CAVE™, a room-sized visualisation system, using DIVERSE, an application programming interface.

In initial evaluations of the conveyor system VEs, mining colleagues have indicated great interest in such training tools. According to their feedback, these and similar VEs would provide excellent alternatives to normal classroom training and serve as positive precursors to hands-on experience. These VEs provide new miners a chance to experience hazards associated with working around conveyor systems without being in possible danger.

INTRODUCTION

Safety is extremely important in any industry and the mining industry is no different. New and innovative methods of training are being explored in order to reduce accidents and fatality rates. The industry places safety at the forefront of their working culture with the realisation that each accident and fatality costs the industry lives, lost time and money, and has long-term psychological effects on co-workers and families. Considering these factors, current training methods are being examined and improvements in training are being researched.

In order to improve current training methods, new training requirements need to be identified. Traditional training methods involve classroom training accompanied by the use of videotapes and PowerPoint presentations. These methods are often not engaging and, therefore, may not maximise knowledge acquisition and retention (Burke *et al*, 2006). Adult learners have been identified as 'problem-centred' and 'solution-driven' (Kowalski and Vaught, 2002). Hence, training methods that are engaging and task-centred are likely to be more effective.

A VE is a synthetic, 3D world seen from a first-person point of view that is under the real-time control of the user (Bowman *et al*, 2005). Immersive Technologies and Fifth Dimension Technologies (5DT) are two companies that sell training solutions to the mining industry in the form of simulators. These types of VEs allow miners to train in operating pieces of equipment, such as shovels and draglines, using a cockpit with real controls and interacting with a screen displaying a virtual world. These training solutions are task-centred and more engaging than traditional classroom training, and hence should aid learning and retention of material.

Conveyor systems are common pieces of equipment found at almost any mining operation. Working around these systems can be hazardous; accidents occur each year involving conveyor systems. Given the natural complexity of these systems, several factors contribute to accidents involving conveyors, including improper maintenance and incorrect operational procedures. Developing a new training solution that addresses these contributing factors while being engaging and task-centred will improve current training methods.

This paper discusses research funded by the National Institute for Occupational Safety and Health (NIOSH) and conducted at Virginia Tech. The research intends to prevent injuries and fatalities linked to conveyor systems by using two VEs to improve training and to help miners better understand the hazards of working around these types of systems. The first VE, called the instructional tour, teaches the miner about possible hazards and how to safely fix conveyor problems. The second VE, called the virtual shift, gives the miner a chance to practice proper techniques for repairing conveyor problems while avoiding potential hazards. The design and development of the two training VEs are discussed in later sections, including a discussion on preliminary evaluation findings and industry response.

BACKGROUND

Conveyor accident analysis

Conveyor safety training is important to the mining industry in order to prevent injury and decrease costs from down time and medical expenses. Goldbeck (2003) reports 459 injuries associated with conveyor accidents, both fatal and non-fatal, between 1996 and 2000. Of these accidents, 13 were fatal and 22 involved permanent disability injuries, the remainder were reported as lost

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time accidents. According to fatal investigation reports of the Mine Safety and Health Administration (MSHA), there have been 36 conveyor accidents resulting in fatality since 2000 (MSHA, 2008). Based on figures originally published in 1986, and adjusted for the inflation rates of 2008, each fatality in a mine costs an estimated US$1.99 million (Goldbeck, 2003; US BLS, 2008). This cost includes medical expenses, worker's compensation, accident investigation, loss of family income, and lost production value. Likewise, each permanent disability accident costs an estimated US$462 000, and each lost time accident costs an estimated US$9700. Identifying the contributing factors of conveyor system accidents is important in order to reduce worker injuries and the economic impact of these accidents.

Based on analysis of fatal investigation reports from MSHA involving conveyor systems, between 1995 and 2007, improper maintenance, improper operational procedures, and unsafe work conditions were the most common types of cited violations in conveyor accidents. Figure 1 shows the percentages of each type of violation cited based on 112 violations cited in 75 fatal conveyor accidents. Improper maintenance citations include violations of the Code of Federal Regulations (CFR, 2008), Title 30, Sections 56.141XX, 75.512, 77.502, and others. Improper operational procedure citations include violations of Sections 56.12071, 56.142XX, 77.1607, and more. Citations for unsafe work conditions include violations of Sections 56.110XX, 75.2XX, and 75.36X. Violations related to training and retraining, communication, and other miscellaneous misconducts are included in the miscellaneous category.

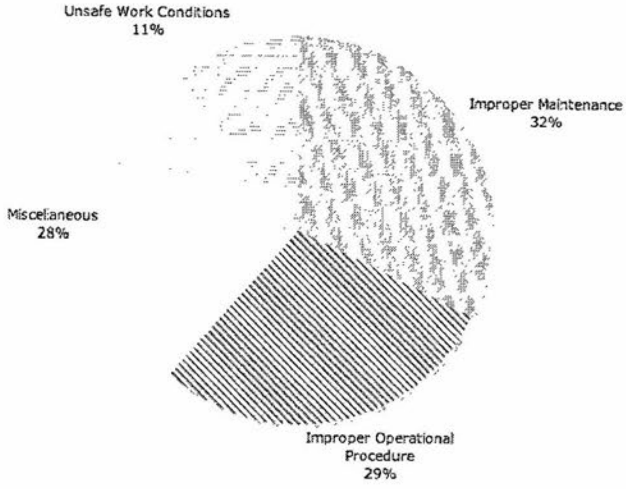

FIG 1 - Categories of cited violations in conveyor system accidents.

Considering the complex nature of conveyor systems, it is not surprising that multiple factors contribute to accidents involving these systems. Focusing training on safety procedures and regulations should reduce violations associated with improper maintenance and improper operational procedures. Increasing hazard awareness through training can lessen the number of violations involving unsafe work conditions. Most of the contributing factors of conveyor accidents can be addressed with improved training solutions that focus on hazard avoidance, safety procedures and regulations.

Current industry training methods

Title 30 of the Code of Federal Regulations requires 24 hours of training for all new miners in surface mining operations. Four of these hours are required before the miner starts any work, while the remaining 20 hours are required within 60 days of starting work. Title 30 also requires 40 hours of training for all new miners in underground mining operations. Most of these hours consist of training in conditions closely duplicating actual underground conditions, while the remaining eight hours are given at the mine site. MSHA also requires task specific training when a miner is assigned a different job and eight hours of refreshment training annually (Code of Federal Regulations, 2008).

Typically the MSHA requirements are met through classroom training, with the information being presented through video tapes and PowerPoint presentations. In this situation, a training professional lectures a group of employees. Oral, written and practical tests are used to demonstrate training completion. These training methods are passive in nature and the trainees observe more than participate. According to Burke *et al*, engaging training methods are the most effective for knowledge acquisition and retention of material (Burke *et al*, 2006). Kowalski and Vaught have identified adult learners, such as miners, as 'task-centred and problem-centred' and 'solution-driven' (Kowalski and Vaught, 2002). Hence, these typical training methods may not be the most effective.

Some mining facilities go beyond the requirements of the CFR with weekly safety talks or meetings to update miners of near misses at their facility or to discuss accidents reported in the industry during the past week. Safety professionals take these opportunities to remind their employees of proper safety procedures. Other mining facilities have developed incentive programs to make miners responsible for their own actions and those of their co-workers. Some of these programs are based on monetary bonuses, while others are based on social rewards (such as baseball games and picnics).

Training with virtual environments

Since each accident has lasting effects, financially and psychologically, on the mining industry and the victims' families, it is important that adequate safety training programs be developed. One approach to improving training is to use virtual environments that are engaging and task-centred.

VEs have been used throughout other industries as successful training tools. VEs have been used to train phobia patients to deal with their fears (Rothbaum *et al*, 1995), to train military infantries in combat tactics (Durlach and Mayor, 1995), and to train medical students (Gutierrez *et al*, 2007) in new procedures. Using VEs for training provides a level of realism not possible in classrooms, as well as more flexibility and reduced costs compared to real-world exercises (Bowman and McMahan, 2007).

In the mining industry, VEs in the form of simulators have been used to successfully train miners in the operation of various pieces of powered equipment. Immersive Technologies offers simulators called advanced equipment (AE) simulators for training miners how to operate haul trucks, dozers, shovels, excavators, wheeled loaders, and draglines (Immersive Technologies, 2008). Figure 2 shows an AE simulator used for haul truck training. Similarly,

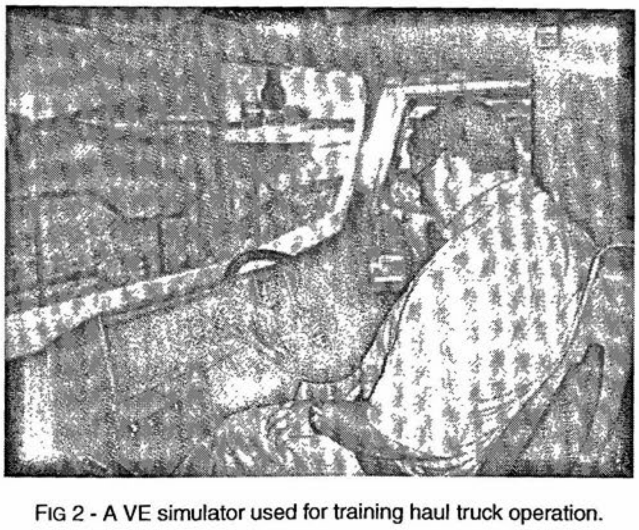

FIG 2 - A VE simulator used for training haul truck operation.

5DT offers several simulators for training workers to operate haul trucks, dozers, shovels, excavators, wheeled loaders, draglines, continuous miners, longwalls and roof bolters (5DT, 2008).

In addition to commercial simulators, other forms of VEs have been researched for training miners. Dellabio *et al* (2007) used VEs to improve safety and design through information visualisation and accident simulation. VEs have also been used with underground mine safety training for procedural training and identifying hazards (Ruff, 2001; Orr, 2003). Dezelic *et al* (2005) and Kizil and Joy (2001) conducted separate research using VEs for equipment operation in mining facilities. Stothard, Galvin, and Fowler (2004) used VEs for health and safety activity simulation. VEs have been used with great success because of their ability to safely simulate real life events in a digital environment that might otherwise be too dangerous or expensive to create (Haller *et al*, 1999). VEs offer valuable interactive training environments that allow trainees to take charge of their environment and learn at their own pace.

TRAINING APPROACH

Considering the number of accidents involving conveyor systems and the success of other VE training applications in the industry, new VE training applications were developed for surface conveyor belts.

Analysis of current training practices, materials and accident reports shows that most accidents occur because of lack of knowledge of safety procedures and hazardous conditions. Considering these factors, the VE training applications developed here focus on identifying hazards, on proper safety procedures and on regulations. Specifics about performing maintenance tasks are not included, since these types of tasks are often system specific, but common maintenance tasks such as the proper steps to follow before conducting parts replacement are included.

In addition to deciding which accident-contributing factors to include, other factors in this training approach include effective presentation of information to the trainee, assessment of the trainee's retention of information, and reinforcement of the importance of proper safety procedures and regulations. In order to accomplish these goals, two VE training applications were developed. The first application, an instructional tour, trains the user on safety regulations, hazard recognition, and procedures for working around a conveyor belt system and creating a safe working environment. The other training application, the virtual shift, tests the user's ability to complete designated tasks while tracking the user's performance, and stresses the importance of avoiding hazards and following safety procedures with the use of animations.

The instructional tour takes the user around a conveyor system along an automated path, with designated stops or stations. This allows the user to become familiar with different areas of the conveyor system without needing to navigate from place to place manually. This type of automatic navigation also ensures that the trainee reviews all of the information presented.

Each station in the instructional tour contains a series of flashing coloured spheres, or hot-points, that correlate to information about maintenance procedures, safety procedures, hazard awareness and conveyor components and assemblies. These hot-points are grouped into stations by proximity in order to minimise the number of stations and are not grouped by type (hazard, safety, etc). When the user selects a hot-point, animations and informational windows containing images and text are presented to them. When the user has selected all of the hot-points at a station, the instructional tour continues by guiding them to the next station. The instructional tour contains six stations. The training topics or points for these stations are outlined in Table 1 and were identified by the research team after conducting literature review and interviews with industry professionals.

Once the user completes the instructional tour, the virtual shift is used to assess the trainee's retention of information and to reinforce the importance of proper safety procedures. During the virtual shift, the user is allowed to navigate freely around a conveyor system while completing an objective. Upon starting the training application, the user is presented with the objective to complete a pre-operational check of the conveyor system to ensure the work area is clear of hazards and that the conveyor runs properly before operation. After the presentation of the objective, the VE represents the beginning of a work shift with the conveyors turned off and de-energised. There are working breakers and controls within the environment for the user to energise and turn on three separate conveyor belts.

The first task of the pre-operational check is to ensure that the environment is free of hazards. There are three hazards presented in the VE and the user is expected to indicate and answer a series of questions pertaining to each hazard as the hazards are encountered. The hazards presented include a material accumulation, a missing return idler guarding, and a broken railing.

Once all three hazards are identified, the second task of the pre-operational check is to properly start-up the three conveyor belts. This process includes turning on the breakers, sounding the alarm, and turning the lever on to start each conveyor belt. After the belts are turned on, the user needs to ensure the belts are running properly. A damaged idler on one of the conveyor belts produces smoke and the user is required to follow the proper lock-out, tag-out procedures in order to fix the idler. Every action the user takes in completing the virtual shift is evaluated in order to assess the user's retention of safety training.

Suggestions from professionals and examples in literature were used in the development of the virtual shift scenarios. Industry professionals were also asked to review the information presented to ensure accuracy and completeness. Comments and suggestions from these professionals were accounted for during the development of the two VE training applications.

TRAINING IMPLEMENTATION

Modelling development

In order to develop the VE training applications, a conveyor system model was necessary. Since the training involved focuses on specific components and procedures, the conveyor system model needed to have detailed components to support all of the training information. Autodesk's 3D Studio MAX (Autodesk, 2008) was used to create the conveyor system model. Images collected from the literature review and conveyor operation manuals were used to aid in the development of this model. The final model consisting of three conveyor belts offers the capability of simulating hazards common in an actual working environment. In addition to the conveyor model, a working environment similar to a processing operation was modelled to enclose the new conveyor model.

Desktop application development

Upon completing the conveyor system and environment models, 3D Studio MAX was used to export a .3DS file containing the developed models. This file was then imported into Right Hemisphere's Deep Creator application (Right Hemisphere, 2008) to create desktop versions of the two training applications. Deep Creator software is designed for rapid application development, with modelling capabilities, basic animation features and a built-in LISP editor for advanced programming. Deep Creator also allows for production of Windows executable files.

In order to make the two VEs appear more natural and realistic, sounds and animations were added. Each cylinder in the model representing an idler was given a property to rotate around its central access to simulate the idlers turning. The actual conveyor

TABLE 1

Identified training points and purposes, sorted by station.

Station	Training point	Training type	Purpose
1	Entanglement	Hazard	Discusses entanglement and pinch points
1	Falling material	Hazard	Explains hazard of falling material and what actions to take in cleaning material and fixing source of spillage
1	Handrails	Safety	Discusses handrail requirements
1	Safety gear	Safety	Discusses safety information about gear
1	Belt damage	Safety	Discusses types of belt damage
1	Return idler	Component	Explains component and possible defects
1	Return idler guarding	Safety	Discusses proper guarding requirements
2	Drive motor	Component	Explains component and possible defects
2	Falling from heights	Safety	Discusses issues of working from heights and using harnesses if necessary
2	Head pulley	Component	Explains component and possible defects
2	Missing guarding	Safety	Explains that guarding is required at drive motors
3	Emergency stop cord	Safety	Describes purpose of stop cord and procedures if it is pulled
3	Feed chute	Component	Explains component and possible defects
3	Impact idler	Component	Explains component and possible defects
3	Tail pulley	Component	Explains component and possible defects
3	Troughed idler	Component	Explains component and possible defects
4	Bend pulley	Component	Explains component and possible defects
4	Crossover	Component	Explains component and possible defects
4	Inspect structure	Safety	Explains importance to check integrity of structure including failed welds, etc
4	Spillage sources	Hazard	Explains importance of identifying the cause of spilled material to prevent a recurring hazard
4	Take-up pulley	Component	Explains purpose of component
5	Lock-out, tag-out	Safety	Discusses proper procedures for lock-out, tag-out before performing maintenance
6	Start-up procedures	Safety	Discusses proper procedures for sounding alarm and starting conveyor

belt surfaces were given a property to have the textures move along the surfaces to make the belts appear to be moving. Noise and ripple alterations were programmed to allow for more natural movement of the belts. All of these animations were set to a trigger so the conveyor system could appear to be turned on and off.

Informational windows for the instructional tour and necessary text captions were developed by creating objects within the environment that appear at the face of the camera and are controlled through trigger events connected to hot-points and other key interaction points. Animations are controlled in a similar manner by trigger events. An example of this style of interaction can be seen in Figure 3, which is an illustration of the hot-point correlating to information about proper lock-out, tag-out procedures. An informational window appears and explains the animated process that occurs. In this case, the lever on the breaker is placed in the off position, a lock is added and shut, the key is removed, and a tag is placed to represent the proper steps for the procedure. Knowledge of this information, as well as other information presented within the instructional tour, is required for the user to complete the tasks involved with the virtual shift.

The automated navigation of the instructional tour was created with animations and also controlled with the use of triggers. Counters as system variables are added within the LISP editor to make sure that all hot-points are reviewed at each station. Once the counter for a particular station registers that all the hot-points and information has been reviewed, the user is presented with a 'continue' button to proceed to the next station using the automated navigation. This process continues until all six stations have been completed. For the virtual shift training application, Deep Creator's default navigation is used to allow the user to freely navigate around the VE using the keyboard and mouse.

In order to handle the hazard recognition task of the virtual shift, three hazards were programmed into the environment so that the user can click on the area of the hazard and then answer a series of questions pertaining to that hazard. LISP code clusters were programmed for presentation of the questions to the user. For each possible answer, a line of code is connected to it. This allows the system to record the user's answers into a standard text file. If the user answers a question incorrectly or fails to identify a hazard, an animation of the consequences of taking the incorrect action is presented. For example, with the missing railing hazard, an animation is shown simulating the user walking too close to the broken rail and falling. A text caption is also presented to the user to further explain the animation and why the selected answer is wrong.

The virtual shift must also ensure that the user does not perform an action out of sequence. System variables were included within the LISP coding for this purpose. For example, the system is designed to ensure that, when the user attempts to start-up the conveyor belts, the breaker is on and the alarm is sounded before the belt can be turned on. If the user tries to turn on the belt without sounding the alarm, a warning about the missed action is given and the missed action is recorded to the text file for later assessment of the user's training. Also, if the user tries to fix the damaged idler before following the proper safety procedures, for example before turning off the belt, shutting off the breaker, placing a lock, taking the key, and tagging it out, the user is given a warning and the error is recorded to the text file.

When the virtual shift training application is complete, an evaluation and analysis of the user's actions, based on the records of the standard text file, is presented to the user. This evaluation informs the trainee and the trainer of the trainee's retention of the

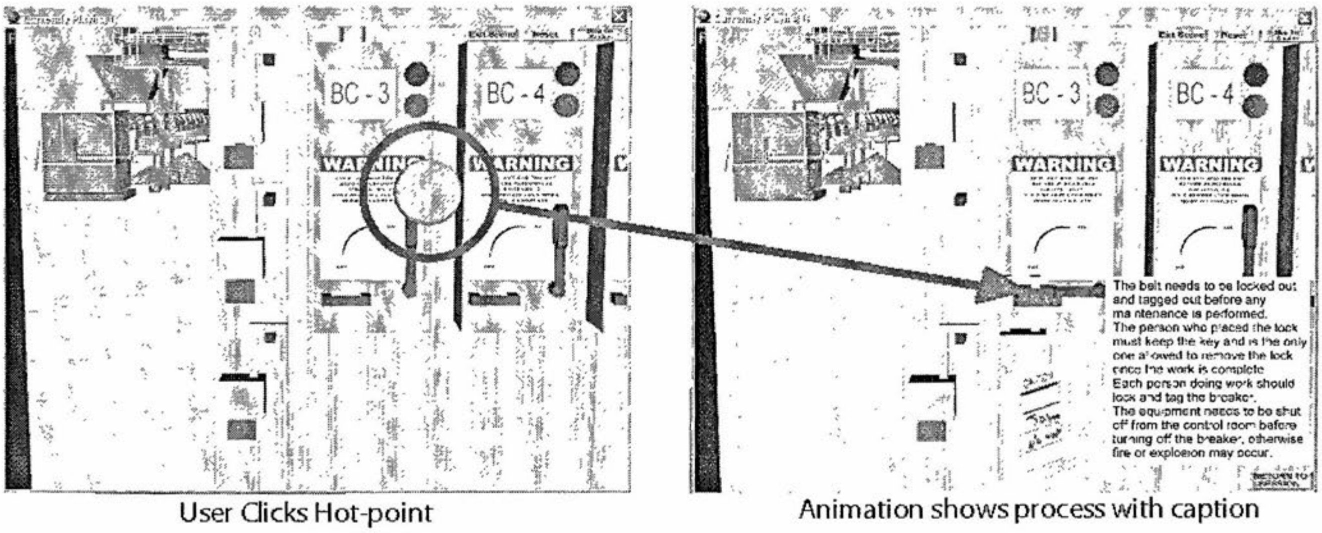

FIG 3 - Hot-point example: lock-out and tag-out.

information covered in the instructional tour and if further training is necessary. The evaluation also stresses the importance of proper safety procedures and regulations.

Immersive application development

In addition to creating a desktop version of the two training VEs, the research team decided to create an immersive version of the VEs to provide a different training experience. In order to facilitate such an immersive experience, the team decided to use a four-sided CAVE™. A CAVE is a room-size visualisation system (Cruz-Neira, Sandin and DeFanti, 1993). The CAVE used for this research has three sides (10' × 9') and a floor (10' × 10') and uses projection technology, stereoscopic displays, and head tracking to create an immersive experience. The CAVE also uses an Intersense IS-900 tracking system with a six-degree-of-freedom (DOF) head track and a 6-DOF wand device with four buttons and a 2-DOF joystick.

DIVERSE, an application programming interface, was used to recreate the two VE training applications developed with Deep Creator in order to provide immersive versions of the applications in the CAVE. DIVERSE provides user interfaces for interactive graphics and for hardware specific to the CAVE, such as trackers, wands, and motion bases (Kelso *et al*, 2002). In order to recreate the two VE training applications, the models developed in 3D Studio MAX were exported and loaded into immersive versions using DIVERSE and a custom 3DS importer. The task of recreating the animations and triggers used in Deep Creator was more complicated. Each animation and trigger was programmed into the immersive versions of the two training applications using DIVERSE and basic C++ programming. In order to interact with triggers involving mouse clicks, ray-casting, a type of 3D interaction technique (Bowman *et al*, 2005), was used with the 6-DOF wand device. Pointing, another 3D interaction technique (Bowman *et al*, 2005), was used for navigation in immersive version of the virtual shift.

A major benefit of creating CAVE versions of the training VE is the immersive and realistic experience that is engendered by use of a CAVE. Increased levels of immersion within the CAVE versions contribute to increased spatial understanding and more depth cues for users (Bowman and McMahan, 2007). Unfortunately, immersive versions of the VE training applications cannot be shared as easily with trainers as the desktop versions because the CAVE versions are designed for a specific CAVE installation. Figure 4 illustrates what the CAVE version of the instructional tour looks like.

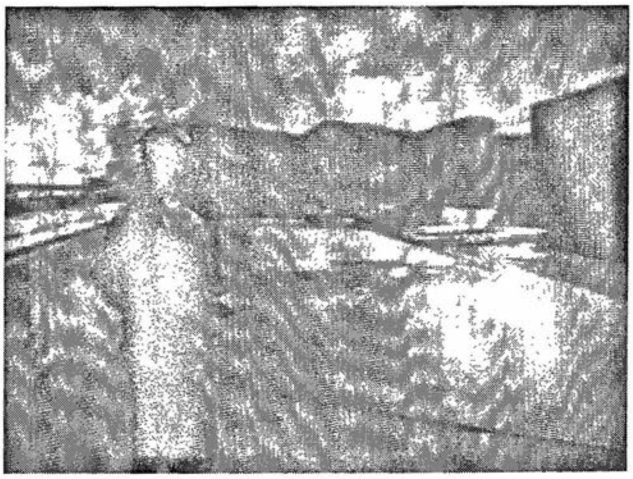

FIG 4 - The CAVE version of the instruction tour training application.

EVALUATION

Expert inspection

To initially evaluate the VE training applications, an expert inspection was conducted. During this inspection, experts and professionals from the mining industry examined and worked with the training systems in an effort to detect potential training problems and to give feedback on their impressions of the applications.

The expert inspection indicated that minor improvements could be made to both the desktop and CAVE versions of the VE training applications. For the desktop version of the virtual shift, experts indicated that navigating the environment was difficult and not user-friendly for people who do not play video games. They did not find the same problem in the CAVE version because of the pointing travel technique used. The experts also pointed out that some of the informational windows and text captions were difficult to read in the CAVE versions of the training applications. This difficulty is a result of active stereoscopic glasses creating a dimmer view of the VEs. The experts did find the ray-casting technique easier to use in the CAVE versions than the desktop versions.

The expert inspection also resulted in positive feedback. All of the mining experts thought the VE training applications could improve current classroom training methods by providing more engaging methods to train miners. The experts also noted the applications presented safety information in a more task-centred and effective manner than traditional videotapes and PowerPoint presentations. In addition, all of the experts preferred the CAVE version of the training applications to the desktop version.

Additional planned evaluation

In addition to the expert inspection, the research team plans to run experiments to empirically evaluate the effectiveness of the VE training applications. Since the purpose of the VEs is to provide effective training, the retention of information after using them will be evaluated. A similar experiment was conducted for a medical training VE (Gutierrez *et al*, 2007). In that experiment, a learning evaluation method was used to evaluate the VE effectiveness by administering a knowledge assessment test before and after using the VE. The knowledge assessment test involved rating the relatedness of pairs of concepts critical to the training. A Pathfinder scaling algorithm and knowledge structures were then used to quantify how much trainees learned using the medical training VE. The same process will be used to evaluate the effectiveness of the VE training applications. Additionally, the process will be used to compare the effectiveness of the desktop version to the CAVE version.

From the empirical evaluation, significant learning increases are expected from using the VE training applications. These increases will demonstrate the effectiveness of the applications as training tools and provide insight in improving mine safety training.

DISCUSSION

Many trainers in the mining industry believe that VEs will be an invaluable training method that will provide effective training for working in naturally harsh environments without risking the safety of the trainees. Industry professionals consulted for this research confirmed that a VE training application can be extremely beneficial as a training tool and offers valuable training experiences to new miners outside of a classroom environment without exposing them to hazards that exist in real mining environments.

This research has investigated using such beneficial VEs for training miners to work around conveyor systems. Two VE training applications, the instructional tour and the virtual shift, were developed to effectively convey safety information and procedures to users, to assess the retention of information and training, and to reinforce the importance of safety around conveyors. Two versions of the VE training applications were developed to provide a dispersible training solution in the form of the desktop versions and to provide an immersive and realistic experience with the CAVE versions.

Feedback from mining experts indicates that the VE training applications are engaging and more effective than traditional classroom training. The consulted experts believe that these applications are an improvement over current training methods and invaluable training tools. An empirical evaluation is planned in order to verify the positive feedback from experts and will verify the effectiveness of the VE training applications developed for this research.

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