

The Umbra Simulation And Integration Framework Applied To Emergency Response Training

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Abstract. The Mine Emergency Response Interactive Training Simulation (MERITS) is intended to prepare personnel to manage an emergency in an underground coal mine. The creation of an effective training environment required realistic emergent behavior in response to simulation events and trainee interventions, exploratory modification of miner behavior rules, realistic physics, and incorporation of legacy code. It also required the ability to add rich media to the simulation without conflicting with normal desktop security settings. Our Umbra Simulation and Integration Framework facilitated agent-based modeling of miners and rescuers and made it possible to work with subject matter experts to quickly adjust behavior through script editing, rather than through lengthy programming and recompilation. Integration of Umbra code with the WebKit browser engine allowed the use of JavaScript-enabled local web pages for media support. This project greatly extended the capabilities of Umbra in support of training simulations and has implications for simulations that combine human behavior, physics, and rich media.

1.0 INTRODUCTION

1.1 Problem and Significance

On January 2, 2006, there was an explosion at the Sago mine in Upshur County, West Virginia. Twelve miners were trapped. Eleven miners died. According to one mine rescue expert, in theory, they could have all walked out. The national outcry was overwhelming as the Sago story dominated all media for over a week. The Sago mine disaster demonstrated that mine accidents today have a potential for political and economic consequences far beyond their direct cost in money and lives.

Furthermore, although the US has the lowest fatality rate per ton produced of any major coal-producing nation, there are several factors that have the potential to make mining less safe in the future. The first is that much of the underground coal mining workforce is approaching retirement. [1] As they retire, the training and work habits that helped build this safety record will retire with them. The second is that underground miners must work under more challenging conditions as production expands. Closed mines have been reopened, like Sago, as the demand for coal has increased.

Coming after a half-year of dramatic increases in petroleum prices and rising concerns about energy and national security, the Sago disaster focused the nation's attention upon coal mining issues. Within weeks, the West Virginia Legislature passed sweeping new regulations affecting all underground coal mines in West Virginia and mandating a

number of new technologies for messaging and miner tracking. Dr. R. Larry Grayson, chair of the recently formed National Mining Association (NMA) Committee on Mine Safety, points out the limitations of this approach. "What miners really need", he says, "is a comprehensive system with scenario-based training and multiple options for survival"[2]

2.0 METHODS

2.1 Current Methods

"Table top" exercises are a common way to meet this need. People who could be in the command center role play the events of an emergency, often while sitting around a table. These exercises do a good job of helping participants visualize some of the implications of emergency procedures. However, they also miss much of the complexity inherent in mine emergencies and lack the impact that builds learning. Because only managers are involved in these exercises, they do not help miners understand how their actions must harmonize with those of mine management in order to mitigate the consequences of an emergency. "Mocks" provide more realistic training situations that do not have these shortcomings. Mocks are large-scale drills carried out at the mine itself or at a training and research facility. Not only does everyone involved with the mine participate, but in some cases, organizations from the nearby town even play roles in the simulation. Police, fire, and emergency

medical personnel all benefit from the opportunity to work with mine personnel. The mocks are realistic and inclusive, but they interfere with production and may not be practical at smaller mines.

2.2 Computer Simulation

Computer simulation has the potential to expand the realism of a “table top” exercise. Just as simulation has come to play a significant role in enhancing aviation safety, one would expect similar benefits in the field of mine safety. The Mine Emergency Response Interactive Training Simulation (MERITS), developed by the National Institute for Occupational Safety and Health (NIOSH) is a notable development [3]. In testimony before the U.S. Senate Appropriations Subcommittee on Labor, Health and Human Services, and Education, David E. Hess, Secretary of the Pennsylvania Department of Environmental Protection, stated that training, including MERITS, was a key factor in the successful rescue after a major accident at Quecreek, Pennsylvania. Hess testified that “the rescued miners have said the safety training they received helped them in several ways, first to warn the other miners to leave the rapidly flooding mine, how to share resources and protect themselves underground and to understand what rescuers above ground would be doing to rescue them.”

MERITS communicates events stemming from a simulated mine accident to a class through voice synthesis. The class may give instructions to miners and rescuers and order needed supplies. The class must piece together the nature of the emergency from the voices and execute a successful rescue of two trapped miners during a mine fire. The class can draw upon a multimedia library of information about the mine, including a personnel roster, emergency plan, and a detailed map of the mine and its contents. Although designed for supervisors who would direct a rescue operation, MERITS clearly gave these miners a useful understanding of the role their individual actions had to play in the rescue process.

Unfortunately, MERITS was designed to run on the computer systems of 10 years ago and is no longer compatible with current standard desktop security settings. It is a single scenario exercise that would require rewriting and recompiling portions of the code in order to change the scenario or reflect changes in Federal regulations. Furthermore, much of the code is written in MODSIM [4], a simulation language that is no longer widely used. We proposed to create a modernized, improved MERITS 2 to rectify these limitations.

2.3 Umbra Integration and Simulation Framework

The Umbra Simulation and Integration Framework, was a promising tool for a number of reasons. It allows program function to be easily changed, even during system execution. This is because, in an Umbra simulation, C++ modules call one another through easily edited Tcl scripts [4]; [5]. In Umbra, it is possible to “fine tune” behaviors without having to pause to recompile code. Standard interfaces facilitate the rapid construction of complex simulations. Scalability is enhanced through the use of the Worlds concept, by which each subprogram in the simulation is “aware” only of the information that the real entity would have access to.

Umbra was originally conceived at Sandia National Laboratories for the development of swarming and other cooperative behaviors and tactics for robots, including Unmanned Aerial Systems (UAS). Consequently, it lends itself to agent-based simulation and has a large library of routines that can be used for either embodied or non-embodied agents. However, it has not previously been applied to a training situation for a number of reasons. One is that there was no provision for integration with rich media, such as audio, video, and html documents. Another is that the lack of dockable windows made it impossible to cleanly page between simulation output and web pages. Finally, in the proposed mine rescue simulation, the computer would have to play the role of the mine telephone, communicating with the class through voice synthesis, a capability that had not been previously incorporated into Umbra.

2.4 Extending Umbra

The first requirement was to integrate the multiplatform Graphical User Interface toolkit, Qt 4.5 [8], into Umbra. By doing so, we would be able to not only quickly build effective user interfaces, but also to add the WebKit open source browser engine, the same code that powers Apple’s Safari browser. WebKit, unlike Explorer, provides a secure way to communicate between local and remote web content and local SQL databases using HTML5 database support. This would make it possible to replicate the media functionality of the original MERITS while complying with current security standards for networked desktops, thus solving one of the most important problems associated with the older version of MERITS. In order to use Qt 4.5, it was first necessary to recompile Umbra using VisualStudio 2008. The C-Space Toolkit [9], which provides detection of

geometric intersection of objects and plays a key role in path planning and the OpenSceneGraph output graphical libraries also had to be recompiled.

The existing libraries that were implemented into MERITS were the graphics interface for the visual elements, path planning, route placement interpolators and related generic utilities, collision detection, time-event generation, and event handling. New libraries generated were the Qt interface; GUI design, layout, and implementation; GUI event generation and handling; miner object behaviors; the voice interfaces; the wrapper for the existing NIOSH fire effects algorithm (GFire); and code to query GFire data based on position and object type.

2.5 Voice Synthesis

Because the current Umbra libraries had no provision for voice synthesis, it was necessary to add this capability. However, one of our constraints was that the resulting training application had to be distributable to noncommercial users without royalty payments. Consequently, we chose to use the open source code eSpeak [6]. However, the quality of the voices generated by this application was sufficiently low as to limit intelligibility. Consequently, we used phonemes generated by Mbrola [7], developed by the TCTS Lab of the Faculté Polytechnique de Mons (Belgium). Mbrola performs concatenation of diphones. Starting with a file of phonemes, durations, and a piecewise linear description of pitch, it uses a phoneme database to produce synthetic speech. We configured eSpeak to create appropriate phoneme files for Mbrola to convert to .wav output.

2.6 Agent-Based Simulation

Miners and rescuers were represented by autonomous agents based on preexisting robot simulation codes. We programmed these agents to carry out the following commands:

- Check (smoke, gasses, status)
- Close (door, regulator, etc.)
- Open (door, regulator, etc.)
- Evacuate (section or mine)
- Monitor (phone, fan, etc.)
- Stop monitoring (phone, fan, etc.)
- Move object(s)
- Move people (includes self)
- Pick up phone
- Turn on (belts, etc.)
- Shut off/turn off (belts, etc.)

Figure 1 shows how the menu selects telling a miner to pass on a command to make a gas check at a specified location and send the results back by mine phone.

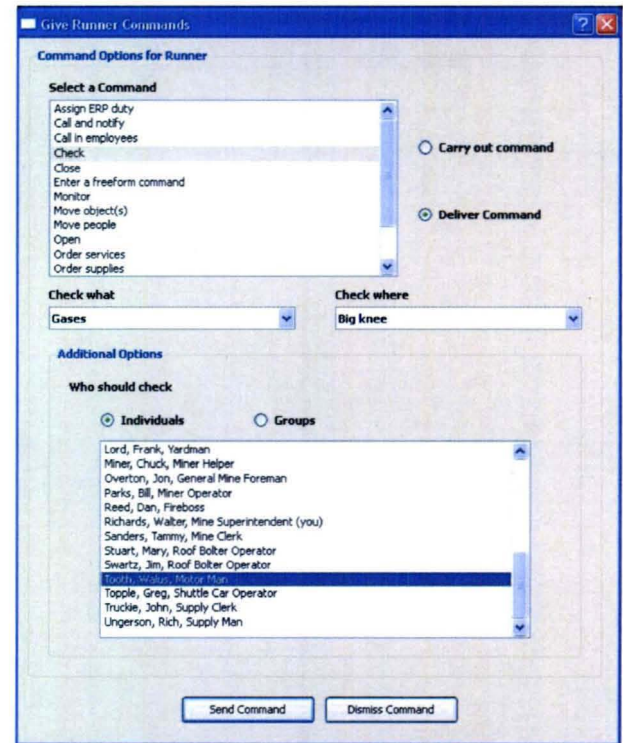


Figure 1: Command Menu

Rescuer agents are miner agents that are scripted to establish a Fresh Air Base for communications and enter the mine to find stranded miners using approved procedures. A third class of agents is the mantrip. These are trolley-like vehicles that travel in and out of the mine on command, carrying miners and supplies.

2.7 Path Planner

We used Umbra's existing RoadPathPlanner class, which implements the GBS, or graph-based search, algorithm. This algorithm was created to plan a path using city streets on irregular terrain. However, we found that appropriate reformatting of the files describing mine geometry allowed the code to simultaneously plan paths using both the underground tunnels and surface road. Also, the ability to randomize the speed taken on a given route is very useful for naturally separating miners on the same route – otherwise they would all be on top of each other and it would be impossible to determine who was there. It also prevents multiple "arrival" events from occurring simultaneously. In the event of a group evacuating the mine, the miner

agents can be instructed to travel together at the speed of the slowest member of the group.

3.0 RESULTS

3.1 Extending Umbra

The combination of Qt and WebKit worked well, allowing the full integration of local and remote web media into the Umbra environment. JavaScript code not only made dynamic web pages possible, but also allowed the incorporation of persistent data storage. Simulation variables could be easily transferred to and from web pages, enhancing realism. One is having each miner tag in and out of the mine on a simulated tag board visible to the trainees. The persistent data storage capability allowed users to insert, edit, and delete notes labeled with the simulation time into the record of the session.

Figure 2 shows a JavaScript-enabled graphic that simulates a fan pressure chart. It is refreshed every minute from the simulation. As the simulation progresses, there is a roof collapse that is accompanied with a sudden pressure spike at the intake fan. The trainees can quickly page between a map of the mine and the fan pressure chart as they try to interpret the available data to determine what has happened.

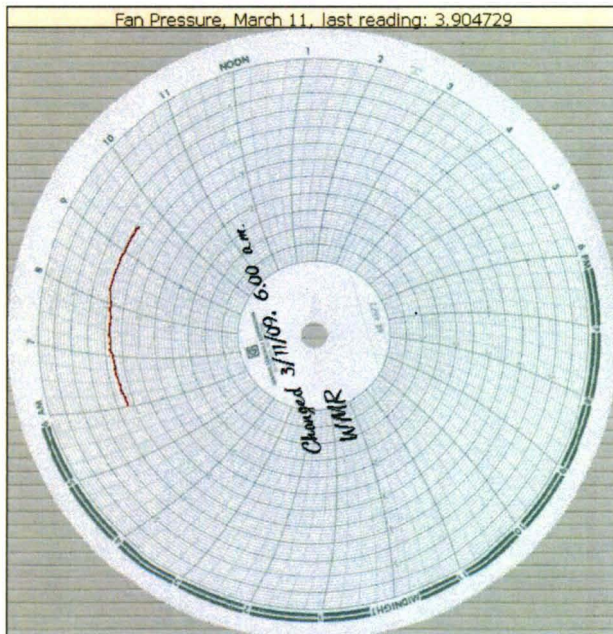


Figure 2: Web Image of Fan Chart

3.2 Voice Synthesis

The combination of eSpeak and Mbrola produced voices that were highly intelligible. Depending upon the text supplied to the synthesis code, the resulting

voices vary in naturalness, primarily because there is no way to code syllable stress. Nevertheless, the voices were judged suitable for this application. For commercial applications, proprietary products such as AT&T Natural Voices could greatly enhance realism as they overcome the limitations of diaphone concatenation [11].

One problem we encountered was that the voices had to run in the same thread as the simulation. This led to the voices breaking up under some circumstances. The MERITS 2 system employs a stream of background "chatter" to simulate the effect of typical conversations over the mine phone system. When an event-driven simulation response produced speech during the playing of "chatter", the result was two voices speaking at the same time. In most circumstances, the voices simply played together. However, there were times when one of the voices was blocked and replayed, causing an unnatural "echo" effect. Both of these problems were mitigated by allowing the Umbra process to use more of the CPU. They might well persist in a more graphics-intensive environment than MERITS 2, however, and it would be important to investigate ways of multithreading such simulations.

3.3 Agent-based Training

We demonstrated that by equipping miner, mantrip, and rescuer agents with a relatively small number of scripted behaviors that could be elicited by either simulation events or user commands, we could build a flexible simulation in which scenarios could be easily modified by editing Tcl scripts. We plan to extend the behavior by adding some more rules such as detection and reporting of smoke and fire, mortality if unprotected in a toxic atmosphere, and incorporation of fire, smoke, and gas concentrations into the path planner. We anticipate that these additions will further increase the training value of MERITS scenarios by fostering more complex emergent behavior for the trainees to deal with.

In Figure 3, three miner agents have noticed smoke in the passageways. The routine for the calculation of smoke density and gas concentrations is an adaptation of one developed by NIOSH. This example is from a developmental run and shows how a legacy program can be incorporated into an Umbra simulation. During a MERITS 2 exercise, the trainees are not able to see this view of the miners and smoke except when the instructor replays the exercise with "god mode" turned on. However, the trainees can call the miners on the nearest mine phone and ask them to report back airflow, smoke, and gas data.

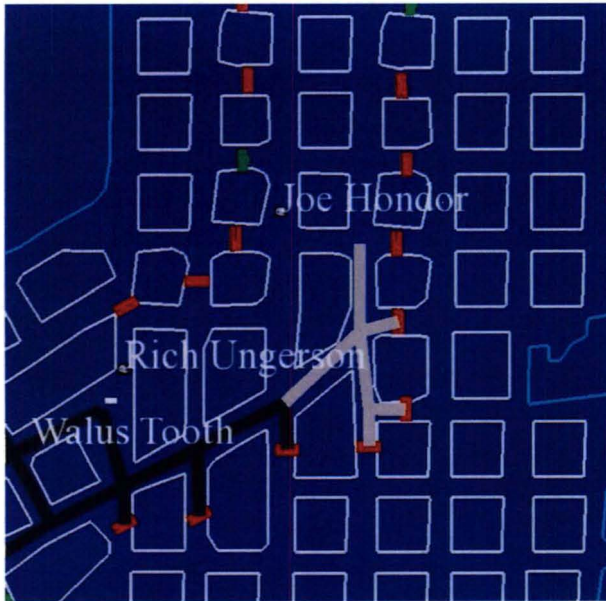


Figure 3: Miners Discover Smoke and Fire

3.4 Path planner

Once the C-Space Toolkit was incorporated into MERITS 2, it was found to work well. The original MERITS had scripted miners who followed a specified path regardless of whether or not a real miner could use it. With MERITS 2, miner and rescuer agents were able to discover a route between locations either on the surface or inside the mine whenever such a path existed. In fact, it was discovered that one of the work locations specified in the original MERITS was inappropriate when the path planner determined that there was no exit from it.

4.0 DISCUSSION AND CONCLUSIONS

As a result of this work, Umbra became much more useful in a scenario-based training environment. The ability to modify agent actions through the use of Tcl scripts turned out to be useful in the refinement of miner and rescuer behavior. The integration of dynamic web pages and audio into the Umbra simulation made for a more immersive training experience while also allowing users to research topics relevant to a better understanding of the simulated mine emergency. The potential uses of the Qt 4.5 integration include the incorporation of event-triggered video into Umbra simulations and the triggering of simulation actions from HTML links.

In a broader sense, our work with MERITS 2 shows how the benefits of simulator training, long recognized in aviation, can be extended into a variety of industrial environments to address the

more general problem of workplace and other civil accidents and emergencies. These situations include firefighting, ship damage control, and response to acts of terrorism. Such training simulations must incorporate accurate physics to work at all yet also deal with fragmentary knowledge of the situation, a potential for complex emergent behavior leading to unexpected consequences, and even a lack of definition as to what the objective should be (for example, should one try a risky plan to rescue all or a safer one that will only rescue some). These problems fall on a continuum stretching from linear "tame" problems to ill-defined "wicked" ones. Umbra, with its flexibility and low computational overhead, has been effective even at the "wicked" end of this continuum, and is now suitable in a training context.

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