METS VR: Mining Evacuation Training Simulator in Virtual Reality for Underground Mines

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***Abstract*—The mining industry is one of America's most important suppliers of raw materials such as metals for the manufacturing, construction and high-tech industry. It is very profitable, but requires the mine to be fully active. Mining is also a comparably dangerous line of work and lives can be lost on the work site due to an emergency. As of right now, mines will generally conduct quarterly training to go over evacuation drills and how to handle emergency situations. However, the mine needs to halt production during drills, which is a major disadvantage of this training method. This in turn becomes a loss of profit for the mine. With the Mining Evacuation Training Simulator (METS), the mining industry will have a virtual training scenario for their workers. A more immersive experience is critical to the quality of training as the teaching content actualizes the real world experience. METS is a cost efficient training and safe alternative to the current model of evacuation training. With METS the mine will still be able to remain in production while a few employees at a time perform evacuation and emergency training.**

***Index Terms*—Locomotion, Immersion, Emergency Training, Unity, Mine Safety**

I. Introduction

Mining is one of the oldest industries across the world. It supplies the demand of natural resources needed to sustain and develop modern life. One of the biggest difficulties that underground mines face is preparing workers for emergency situations. In underground coal mines evacuation training is done every quarter out of the year, since it is a necessity for all workers to know the proper emergency procedures. However, the training is extremely disruptive to the operation of the mine. In order to train workers on proper evacuation steps, the mine has to halt operations and proceed with training. When a mine is not in operation, money is essentially lost as equipment's value further depreciates and infrastructure has to be kept running to full extent. To combat this we are presenting an immersive and portable mining evacuation training simulator (METS).

This simulation can be seen as a "serious game" and is constructed on the Unity Game Engine using the SteamVR API. METS will place one user in the center of a mine while the other user is inside of a control room on the surface. An emergency will occur within the mine, such as a fire, that requires the underground personnel to evacuate. The user in the control room will be able to communicate through a radio transmitter to the users in the mine, in order to notify them where the dangers are located. Additionally, he will have a map of the mine and will instruct the user inside on how to escape. The user inside of the mine will have a radio transmitter and a headlamp, and must evacuate from the mine from the instructions given to them by the user in the control room.

METS will give an immersive training experience by placing the users into the scenario using the HTC Vive head worn virtual reality device. This simulation will be beneficial to the mining industry as it teaches proper evacuation procedure and supports communication in a realistic mine environment. METS will provide benefits to the production at the mine as well, because the production won't need to be shut down in order to train employees. A foreman and some of the employees will be able to conduct the training in an office on the surface where the virtual reality sets are prepared, all the while the mine is still running. Another benefit of METS, is that the foreman can evaluate and improve evacuation route signs within the mine based on how employees navigate the simulation. Another feature of the METS system is a multiplayer mode, which puts emphasis on teamwork and results in an even more realistic simulation. This will improve the mine workers' communication, especially the response and reporting procedures to the mine clerk, who supervises the mine from the control room.

II. Background

VR has been around for decades, but due to high investing costs, slow frame rates and low resolution HMD's were mostly overlooked by many industries in the past. However, due to the introduction of cheaper HMD goggles and vast improvements in computing performance, several industries have employed VR for training and simulations [11]. At the same time, research about mine accidents has revealed that there is room for improvement of training mine workers [16]. The mining industry is slowly picking up, however most VR applications in mining have only been developed for research at Universities and have not been commercialized. Existing VR systems in mining are few and mostly refer to virtual applications on computer screens. The resulting level of immersion is lower than on HMD's [21]. The University of Queensland, Australia has developed and built a 360-degree cylinder, which one can step in and is surrounded by displays [11]. Different models for safety training, mine modelling etc. can be experienced within the displayed VR environment. Other VR applications refer to simulated virtual worlds that one can interact with on a 2D computer display [15]. HMD applications are constricted to an underground mine drilling training, developed by [24] and an underground mine pilot training from [7] for new miners.

The test results of using immersive technology for training workforce showed that the vast majority of test participants preferred the HMD over other training methods (videos, pictures, lectures). Additionally, most felt, that they will memorize the taught material better when learning it in an VR environment [3], [7], [24]. The purpose of simulated mine fire evacuations is evaluating the emergency response plan of the mine, optimizing evacuation routes and training personnel on proper evacuation procedures. Current mine evacuation simulations are confined to drills executed at the mine site or training sites and digital simulations on 2D computer displays [15]. Evacuation drills in underground coal mines have to be executed at least every 90 days [13]. In nonmetal/metal mines these have to be conducted every 180 days [12]. Mine workers can't pursue their work for several hours and parts of the mine have to be shut down [4]. A portable evacuation simulator such as the proposed METS, can be used to train workers without having to halt the operation, spending much time to commute to training sites or can fill in theoretical evacuation instructions. Data from individual mines can be fed into the system, so mine workers can train in their mine and learn the emergency response plan unique to the mine site.

III. Functionality

METS is created for use on the HTC Vive [9]. The HTC Vive will help provide an immersive feeling to both players within the simulation as it transports them to the virtual space with a display that will take up most of their field of view. The HTC Vive allows the user to move the screens closer or further away from their face, as well as being able to adjust the interpupillary distance. This allows for the user to have the most comfortable fit with their head and eyes for the screen.

A. Overview

In order to make the evacuation simulation as realistic as possible, we will employ a multi-player mode. Players from all around the world can simply join the simulation in Unity. The players will be able to communicate in the simulation itself. This functionality of recording sound is activated by mimicking a motion of pulling a radio transmitter from the player's belt. To deactivate the function the radio transmitter will be motioned to the belt line again, which snaps it virtually to the hip area of the player.

One player will have a 'masterview' and will therefore be able to oversee everything that happens in the mine. He will be sitting in a virtual control room, which has several virtual TV-screens, that shows camera footage from different locations in the mine. One of those cameras will show a birds-eye-view of the mine, where the control room operator will also be able to see the current location of the miners. Based on this information he can make decisions and give advice on which route is the most efficient to safely evacuate the other players.

The player in the mine will be able to travel using two different methods of locomotion. The two methods used will be a version of walking in place and a touchpad based movement style. The walking in place method will be based off of the player's foot movement. They will need to stay in place and syncopate their legs as if they were actually walking in place. The touchpad based movement will require the player to press on the touchpad on their hand remote in order to move themselves through the mine.

A fire will be initiated upon start of the simulation and spread over time, taking up more room and in some cases might even block the evacuees' initial route. Also, a clock will start running upon initialization and will end the simulation after 15 minutes. The timing is chosen to simulate the limited time that the SCSR (self-contained self-rescuers), which is a portable oxygen source that provide miners in evacuation situations with breathable air, can be worn. Smaller sized SCSRs provide breathable air for 14 minutes, bigger ones for maximum 99.5 minutes [23]. The preferred exit in an underground mine evacuation is the mine shaft. However, the evacuees are given an alternative option: a refuge chamber. Few of these chambers are placed in underground mines and give a last resort to evacuees, in case they can't make it to the shaft in time or their evacuation route is blocked. Refuge chambers however place high physical and mental discomfort on the evacuees and can provide people with necessities for only 1-4 days [18].

B. Immersion

Immersion can be described as having the feeling of being physically present in a non-virtual environment. To create an immersive virtual reality environment, the system must generate imagery that occupies the user's entire field of vision [10], [17]. Two current methods for immersive VR are caves or head mounted displays. Caves are constructed by multiple walls that surround the user and function as big projection surfaces, while a head mounted display places screens directly in front of each of the users eyes [10].

For METS, with the use of the HTC Vive, we are able to fill the user's field of vision with the displays within the headset. The HTC Vive eliminates outside light and other factors from interfering with the user's vision. Visual realism is another aspect that contributes to immersion. Two components of visual realism, that need to be accounted for, are: geometric realism (the virtual object's geometry matches the real object's geometry) and illumination realism (the lighting model resembles lighting in the real world) [17]. The light sources within the METS application are rather dim in order to replicate the lighting conditions in a mine.

On top of geometric and illumination realism, we have to ensure that any moving objects behave according to the law of physics. Immersion can be broken if an object starts moving in a way that isn't behaviorally realistic [17]. The particle systems that handle our fire have colliders attached to them. This helps to capture the smoke within the tunnel that the fire is occurring in. If fire and smoke were to just disappear through the ceiling, the realism of the fire would be compromised, which would result in a loss of immersion of the participant.

C. Networking

To allow for a multi-user experience we included a networking framework that takes advantage of the Fizzy Steamy Mirror API [6], [14]. We used the Mirror API because the current version of Unity that we utilized had deprecated their networking capabilities. The mirror API and the multiplayer framework that we implemented recreate Unity's old networking capabilities. We did not use the updated version of Unity's networking, because the current networking capabilities were in a beta version at the conception of this application.

As of right now the networking capabilities allow for two users to connect and be placed into the same environment. They are able to communicate through voice functions and the user in the control room can track where the other player is at in real time. There is no direct player to player interaction aside from the voice communication, but there is possibility in the future to include multiple miners trying to escape together.

D. Locomotion

Locomotion is described as the ability to move oneself from one place to another. This is especially important in a virtual environment because it allows the user to change their perspective within the environment. If they were not able to move around, then they would not be able to experience the entirety of the environment and the overall immersion and user's experience would be degraded [2]. Usually, locomotion is not the main goal of an application, but it is crucial to the navigation of the users through the environment [2]. With METS, locomotion is absolutely necessary because it enables the user in the mine to actively navigate the mine and follow the escape route that is being described to them.

There are many methods of locomotion that can be used to propel a user through a virtual environment. Some methods of locomotion are by use of the touchpad on the hand remote, using additional sensors to create a walking in place method, using weight sensors to create a human joystick, point and teleport methods, omnidirectional treadmills, and more [1], [2], [19]. Within METS we take advantage of touchpad movement, walking in place, and a passive omni-directional treadmill. The treadmill used in METS is the Virtuix Omni which can be seen in Figure 1.

Figure 1. The Virtuix Omni, a passive omni-directional treadmill, allows a user to run/walk in place, and allows the user to steer based off of the direction of their hips [22]

As of right now the touchpad movement is a temporary method of movement as it reduces user immersion. This degradation in immersion comes from the user not performing some sort of relatable motion of movement that translates to movement in the virtual environment [19]. We want to keep METS as realistic as possible to create the most immersive experience possible. Without an immersive experience the user will not get as much out of the training as they possibly could. The walking in place method of movement allows for minimal space to conduct the training but still allows for an immersive experience by recreating what walking feels like.

E. Communication

For communication in METS, we used a method of voice communication. Each user is able to press a button to start transmitting voice. There is a very minor delay from when the person begins talking to when it actually transmits, this is due to network latency. Originally the way voice would transmit is that each user emits from their location in a logarithmic manner for the volume based on distance. To make it sound more like a radio transmission, we adjusted the volume to stay max at an unlimited distance. This eliminated volume issues by de-coupling the distance of the users to each other from the volume of recorded and transmitted sound. The initial problem that arose was echoing for the person speaking, as the volume was up at zero meters from the speaker. To fix this we defined a short range around the transmitting player, where the volume equals zero. The way the application is set up, is both players will never be within the short vicinity that is the muted area, which will allow for transmissions to always be heard. In the future, instead of transmitting from player location, we would like the sound to be broadcasted from the radio attached to the players.

IV. Implementation

METS is designed using the Unity game engine. The Unity version that is being used for the project is 2018.3.7f1. The advantage of Unity is the SteamVR asset which easily allows virtual reality implementation to any project. Unity allows for inclusion of many other assets which allowed us to focus more on the application itself rather than the design of the environment.

A. Assets Used

SteamVR is a simple download and use asset on the Unity Asset Store [20]. It is free of charge and gives the programmer a plethora of virtual reality tools. The most important tool is the creation of action poses. What this allows the programmer to do is assign names to different button presses on the HTC Vive remotes. Having different poses also allows the programmer to have multiple mappings for the remotes. For instance, our player in the control room can have a unique button scheme that differs to the button schemes of the player in the mine. This is especially helpful for implementing multiple methods of locomotion. It allows us to create the most streamlined control scheme for each method of movement.

The multi-player mode is enabled by implementing the Mirror Networking API in Unity, which is available on GitHub. By using the Mirror API the Server and Client are one entity, which simplifies networking [6]. Additionally, the FizzySteamMirror API will be embedded in the Unity game, which is a Steam P2P transport that communicates with the Steamworks API and enables connecting to other Steam players. For running the VR game in Unity, the Steam platform is required and has to be running in the background. The game can be made accessible through the 'Collaborate' feature of Unity, where developers can save, share and sync their games with others. The other option is to publish the game on Steam, which is a platform by Valve Corporation, where video games can be published and purchased. The METS simulation, which can be seen as a "serious game", will be accessible through the collaborate feature of Unity. However, the player will have to hold a Steam-Account in order to join the simulation. Also, he will have to download and open the METS simulation in Unity. Once the simulation is running, the hosting client can invite him by using their steam64id.

The Mirror API also allows the players to chat via their headset. Sound recordings via the microphone will be activated by pushing and holding the 'Home'- button on the Vive controller. The sound recordings will be sent as a package through the Mirror API and be broadcasted via the player. Unity's Audiolisteners, which will be placed on each player's virtual head, transmit the sound to the player's earphones.

In order to move within the VR mine an omnidirectional treadmill (in this case the Virtuix Omni from Virtuix Inc.) was connected, as it imitates a more natural and hands-free form of locomotion than e.g. teleportation. Enabling locomotion via the Virtuix Omni in the VR world is as simple as running the corresponding application. As the player moves his feet on the treadmill, the HTC lighthouse sensors will register the movement of the tracking pods on the player's feet, which will then be translated to movement in the VR world.

B. Features

The control room will be equipped with several monitors that show camera footage from the mine. These monitors are realized by creating a 'render texture' and assigning it to the target texture of the desired camera. The render texture can then be applied to a plane, which will as a result show the camera footage in real-time. As of right now there are six fixed monitors that are strategically placed in high traffic areas of the mine. At a later point, more cameras will be added in this mine, and the control room player will be able to cycle views on the screens within the control room.

When looking at the monitor with the birds-eye-view, the location of the players within the mine will be indicated by a white disc object. The birds-eye-view from the players perspective in the control room can be seen in Figure 2. These discs will float high enough above the individual's head so that it is located above the mine tunnel and therefore be visible for the control room operator. The player in the control room will also be able to see where fires are located allowing them to better navigate the player within the mine.

Figure 2. The player in the control has an overall view of the map. They can see where the miners are at in the mine by the white disc(as seen in the top right).

C. Player Characteristics

In order to navigate the mine, the 'miners' will be assigned one of three methods of movement. The three methods of movement will be using the touchpad on the HTC Vive hand remote, the omni-directional treadmill or a walking in place method of movement using two additional trackers for the HTC Vive. The additional trackers can be seen in Figure 3. These trackers are each attached to a velcro band that the player can wrap around their ankles. The data from each foots position of the player will be sent to Unity in order to propel the player forward. What the code looks for, is syncopation in the user's legs. The player will move in the direction they are looking. The walking in place method is similar to the use of the treadmill, however, with the treadmill the orientation of the hip determines the direction of moving. For the touchpad movement style, they will press on the HTC vive touchpad. They will be propelled in the direction they press on the touchpad. This method will be based off of the direction of the hand remote. If the player is pointing straight ahead of them with the remote, then press forwards on the touchpad; they will move in the direction the remote is pointing. The player will not be able to move through walls because the entire mine as well as the player have a collider. This will cause the two colliders to hit, and prevent movement through one another.

The player in the role of the miner will also be equipped with a headlamp to illuminate what is near them as the majority of the mine is in darkness. The player will also be

Figure 3. Additional trackers for the HTC Vive that allows for more tracked parts of the body or additional objects. [8]

equipped with voice communications and be able to contact the player within the control room. Throughout the mine, the player will come across many things that could possibly be within a mine such as: mining vehicles, mining equipment, light fixtures, and tools. The players perspective can be seen in Figure 4.

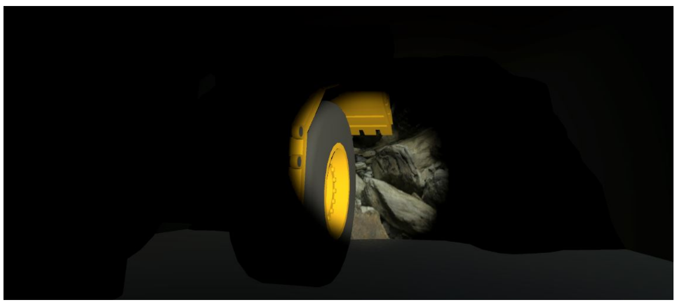

Figure 4. A player in the role of a miner looking at a mining vehicle that is digging out a new drift.

Fire and smoke are created by using Unity's particle systems, which enable the programmer to customize fluid entities. The particles color, emission rate, shape and lifetime were adjusted in such a away that they resemble fire or smoke. The smoke particles are generated as sub-emitters of the fire particles. Additionally, each smoke particle has a collider, to prevent that the smoke disappears through the drift's roof. The fire and smoke effect can be seen in Figure 5. Smoke particles dissipate after five seconds. This prevents frame rate loss within the simulation as less particles need to be computed. The location of the fire is randomly assigned to one of the predefined coordinates as soon as the simulation is started.

Upon start a timer will be running and count down from 15 minutes and be displayed in the field of view of each player by creating a windshield canvas. If all evacuees reach the mine exit in the given time, the training will be considered successful.

V. Conclusion and Future Work

A. Conclusion

The first users of METS were students at the University of Nevada, Reno. They gave positive feedback about the diversity of locomotion techniques and the overall concept. Some of the positive feedback we received was that the movement methods seemed ”intuitive” and that ”steering with gaze was simple and understandable.”

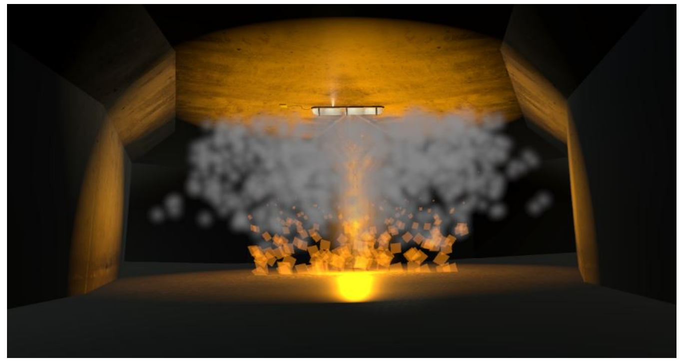

Figure 5. Players perspective within the mine of a fire that can block the player's path.

Initially, users experienced echoing when using the implemented voice communication feature. This problem was solved by creating a small dead zone around the person talking so they wouldn't hear what was being broadcasted by themselves. Another issue that was raised was that the frame rate seemed to drop at times, which made some feel uncomfortable while moving through the VE. The cause of this frame rate drop was found to be the multiple fires being active at the same time. In order to maintain the frame rate the fires were only rendered if the user was within approximately 30 meters of the fire. Additionally, the amount of particles that was emitted by each fire particle system was reduced. This resulted in less calculations occurring for collision as well as keeping the same visual aesthetic.

The feedback was overall positive and through the preliminary testing it became evident that once the METS application is further refined, it can be a useful tool to train and practice emergency communication during underground mine evacuations.

B. Future Work

The developed METS simulation is an ideal framework to add more functionalities and complexity.

In order to enhance the feel of immersion the layout of the mine will be refined by adding more irregularity to the drift walls as well as drift designs including different gradients of the pathways. This could be realized by reading in LIDAR data and generate a 3D object based off the data. A sample of LIDAR data recorded from a drone being displayed as a 3D pointmap can be seen in Figure 6. This would allow site specific training rather than generic training. To increase immersion and add a better aesthetic to the overall application, character models should be included so the users can see and locate each other.

Due to the rare nature of evacuations and elevated stress-levels, accidents are more likely to happen. The training goals of METS can be further expanded to where users learn how to medicate a wounded co-worker or how to properly use a fire extinguisher. The fire itself could spread over time and eventually limiting the evacuation options even further.

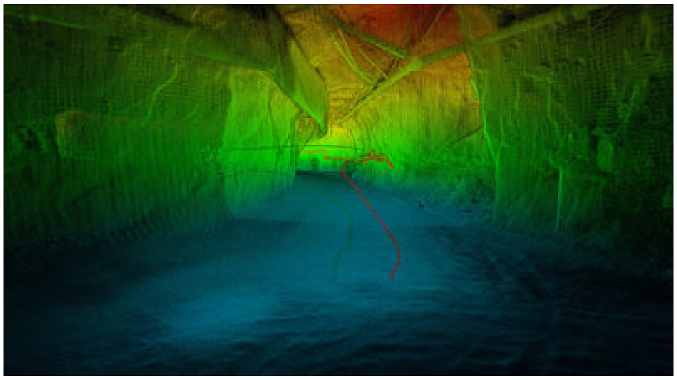

Figure 6. A 3D point cloud map recorded by flying a drone through a mine affixed with LIDAR. [5]

Since communication in emergencies is very critical, a speech recognition module will ensure that only standardized commands and instruction will be passed on to the co-players. This ensures the efficiency of communication.

In order to quantify the effectiveness of METS, relevant measures such as knowledge gain and memorization have to be defined and investigated through user studies. Furthermore, it would be beneficial to have actual miners participate in the studies and have their opinions and suggestions collected through surveys.

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