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Virtual Reality Fire Drill for Campus Evacuation

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Abstract Evacuation drills are needed for campus safety. There is a need to prepare for fire drills on campus as emergencies cannot be predicted. Virtual reality (VR) offers an experimental set-up to conduct fire evacuation drills in a collaborative VR environment. This paper presents a VR simulation of a campus fire evacuation scenario to educate and train individuals on proper evacuation procedures. The simulation includes a realistic virtual environment of the campus building and surrounding areas, interactive elements to guide users through the evacuation process, and AI-controlled characters to simulate various behaviors and responses. The simulation provides feedback and evaluation mechanisms to assess users' performance and understanding of evacuation procedures. The implementation of the VR campus fire evacuation environment was done using Unity 3D gaming engine. The VR environment incorporates detailed modeling, sound effects, animations, interactivity, and AI functionality.

Keywords XR · VR · Simulation · Training · Evacuation Drill · Educational Training · 3D Modeling · GUI design · Unity · Interaction

1 Introduction

College institutions have a need to prepare for various emergency scenarios in an effective manner. One of the significant emergency situations universities should prepare and train for is for evacuations when there are fire hazards that the campus occupants must escape. However, training people with just the campus buildings and general escape protocol does not give a realistic sense of the fire hazard. It is also very difficult to include realistic fires without actually having fires, which would risk the safeties of the participants of training exercises. Another limitation in implementing evacuation training exercises is that there are large amounts of involved parties of various roles that should be trained to handle the evacuation scenario, not just emergency responders. However, even just basic training for all the people involved would be difficult to implement on a large scale. One possible way to handle training to account for all of these existing limitations is by leveraging Virtual Reality (VR) to make a realistic simulation for college campus fire evacuation training.

Using VR for campus fire evacuation training can provide many advantages. Firstly, VR can provide a safe mechanism to simulate various aspects of the hazards of fires without risking the safeties of participants. Effective representation of the fire hazards will allow for people to be familiar with how fires would be seen and experienced along with the actual risks of fire hazards rather than just the evacuation procedure. However, the VR application can still provide the evacuation protocol in an effective manner as well. To increase the realism of the evacuation, a realistic and accurate model of the campus environment should be developed and used for the VR simulation. With realistic, immersive and high quality simulation of a fire evacuation scenario, VR can be used to effectively familiarize and train users on how to not only evacuate but to also handle the fire. In the case that a user does get virtually harmed, they could also be trained on what actions to take when some they or anyone else in the evacuation need medical attention.

Another advantage of using VR for campus fire evacuation training is that development and deployment of the application would be of much lower cost than organizing in person training drills, especially over several years. An application could also much more easily be modified and adapted than a training drill. In addition to saving users from having

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to wait for scheduled, formal training, using an application — especially a mobile application — would enable users to train whenever they would like to. Due to the application-based nature of the training, the college would still have the option to offer both the application for use at any time and official, planned instruction. Another advantage of application-based training is that the VR application can integrate user feedback forms and tools so that the institution may also more quickly assess the training's efficacy and experience and obtain feedback.

Another advantage of using a VR application for fire evacuation is that it makes training on a greater scale possible. Training a large number of people using a downloadable application is far simpler than training them all in person. VR also has a greater capacity to accommodate various types of participant roles and their responsibilities. For fire evacuations, the primary roles that should be accounted for are evacuees and emergency responders. Within those roles, there are many audiences that could be targeted by a VR campus fire evacuation training application. Firstly, because they are often present on campuses and for extended periods of time, students, staff, and faculty at educational institutions should receive training on handling fire evacuations. They should be equipped to face the scenario of having to evacuate the establishments they frequently visit for their own safety and well-being. Even visitors and university guests should also have the opportunity to get familiar with evacuation protocol in the unlikely scenario that an evacuation is necessary. Secondly, university security personnel in particular should be trained on how to oversee the evacuation of all building occupants and ensure that they are all safe and receive medical attention if they are injured. Lastly, the emergency responders who work with colleges should also be trained in managing the evacuation's aftermath as well as how to put out fires and deal with any damage or emergencies they may have caused. Emergency responders that have received training should work more effectively.

In this paper, we present a VR application we developed for fire evacuation training for our campus environment specifically. For this work, we have developed a high-quality simulation of a fire and its risks and hazards, modeled our campus building and its interior furnishings and surroundings accurately and realistically, developed an evacuation protocol with guiding Graphical User Interface (GUI) elements, and used Artificial Intelligence (AI) controlled agents to simulate a user guiding evacuees to safety and providing them with medical attention.

The rest of the paper is organized as follows. Section 2 for evacuation simulations. Section 3 discusses and demonstrates how we implemented the realistic campus modeling and VR simulation application, including the evacuation protocol and the design of the GUI. Lastly, section 4 presents our conclusion.

2 Related Work

This section presents recent studies and advancements in the area of VR fire evacuation simulations, emphasizing the contributions, approaches, and results of these studies. This section offers insights into the development of VR-based fire evacuation training and highlights significant trends and advances by using a wide range of research. Using an evolutionary virtual reality platform, Lorusso et al. demonstrated a revolutionary method to fire emergency evacuation, demonstrating how evolutionary algorithms may optimize evacuation techniques inside a virtual setting [5]. Their work aids in the creation of cutting-edge virtual reality instruments that enhance safety precautions and evacuation procedures. With the use of an online serious game, Yang et al. investigated virtual fire evacuation exercises and provided a novel viewpoint on the use of web-based platforms for fire safety instruction [10]. Their research highlights the adaptability of VR technology in providing educational material by using gamification aspects that improve user engagement and learning results. A mixed reality-based fire evacuation practice system was presented by Sakaguchi et al., combining components of augmented and virtual reality to improve training [6]. Their hybrid method offers a complete disaster preparation training solution by fusing the immersive experiences of VR with the contextual information of Augmented Reality (AR).

The efficacy of evacuation procedures was the main focus of simulation-based evaluations of fire emergency preparation and response carried out in virtual reality by Kwegyir-Afful et al. [2]. Through its ability to improve safety precautions, their research highlights the value of using VR simulations to evaluate and improve emergency response plans. To emphasize the need of cooperation and coordination in emergency response situations, Sharma et al. suggested a collaborative virtual reality environment for building evacuation training [7]. The research improves communication and cooperation during evacuation exercises, resulting in more efficient emergency responses, by enabling user participation inside a shared virtual reality environment. Virtual reality was first used in fire evacuation research by Kinateder et al., who emphasized the technology's ability to produce lifelike simulations that may be used to examine how people behave in emergency situations [4].The virtual reality system for fire evacuation training was presented by Sookhanaphibarn et al. It allows users immersive training experiences to improve their grasp of emergency response methods and evacuation processes in a 3D virtual environment[9].The value of realistic training scenarios and collaborative learning experiences were pointed out by Sharma et al. when they built an immersive collaborative virtual environment of a university campus for conducting virtual campus evacuation drills and tours for campus safety[8].A fire evacuation and management model based on virtual reality and building information model-

ing was introduced by Gao et al. It integrates cutting-edge simulation methods to simulate fire incidents and optimize evacuation routes in intricate building environments[3].Cal et al. studied AR's application in evacuation training games. They explored how AR optimized evacuation training participant engagement and learning. The researchers added AR strengths to the training game to make it more immersive and engaging, help users realize evacuation and emergency response processes[1]. Their research established the foundation for further investigations by proving that virtual reality can accurately simulate evacuation situations and evaluate evacuation plans. From modeling evacuation situations to improving evacuation techniques and increasing user engagement, these studies together show the many uses of virtual reality in fire evacuation training. Researchers are making communities safer and more resilient by using VR technology to further their innovative work in the area of preparing for emergencies.

3 Implementation

In this work, we specifically integrated a model of our campus building to provide a sense of realism and familiarity to the users. Using realistic modeling for the virtual environment will better prepare the users we train to handle evacuations as they will be practicing evacuating with a model similar to the building they frequently occupy. The implementation of an extensive protocol for handling the evacuation also helps increase the realism of the VR training simulation by emulating essential elements the experience of evacuating involves. Lastly, we developed a robust GUI for the user to be well engaged when in the simulation. Each of these aspects will be covered in detail in the following subsections.

3.1 Modeling

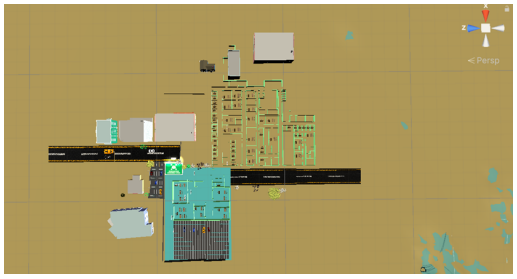
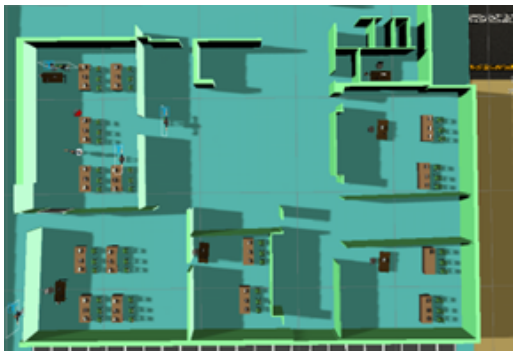
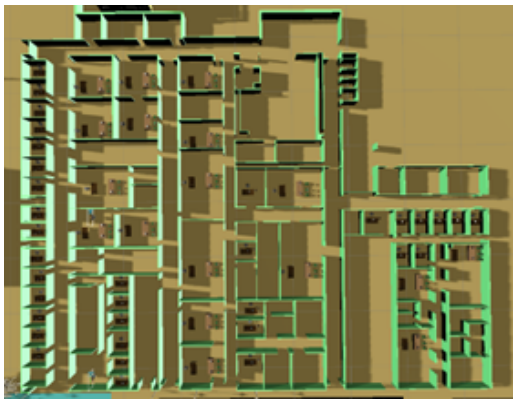


Fig. 1: Full scene model.

The virtual environment of our simulation, shown in Fig. 1, includes realistic, textured models of the engineering campus layout with customized, furnished building interiors, terrain and trees, surrounding areas, evacuation routes and fire hazards.



(a) Virtual Campus Building 1.



(b) Virtual Campus Building 2.

We converted a 2D Drawing (DWG) model of our university's engineering campus, which is named Discovery Park, that included classrooms, offices, walkways and more. Using Sketchup, we extruded the faces in order to create a 3D model of the campus layout for our virtual environment. The model was then imported into Unity for use in our VR application. Within Unity, to increase the sense of realism and immersion, we furnished the campus layout environment. We imported and placed assets of a variety of models for different types of items typically found in a college campus such as desks, chairs, computers, briefcases and more. By including furniture, obstructions, and moving parts, the simulated setting becomes more complicated and replicates the difficulties of a real-world evacuation. In addition to the modeling of the campus buildings, our virtual environment modeling also includes surrounding areas such as parking lots, other buildings and transportation roads. The target evacuation area is also within the surrounding area.

3.2 Evacuation Protocol

The objective of the evacuation is to get to the evacuation area goal without either the player or AI agents losing all health, which virtually would represent dying. The AI agents in the simulation represent other people in evacuation scenarios as evacuations are rarely done in isolation or with only one person. The AI agents specifically follow the user, so the user

is serving as an evacuation guide in the implemented protocol. This trains the user to get familiar with guiding others in fire evacuation emergencies rather than just escaping by themselves, giving motivation to users to learn how to lead and take consideration to other people and their safety.

(a) Initial VR simulation environment state.

(b) VR simulation environment in the middle of the evacuation drill.

(c) VR simulation environment when the user and AI agent have reached the evacuation target area.

Fig. 3: VR simulation environment at different evacuation drill states.

The evacuation protocol and the fires do not immediately begin once the user starts the application. Rather, the user has the option of either pressing a keyboard key or a GUI button specifically for starting the drill. However, the user can still move around the environment with either the joysticks or the keyboard movement keys (W, A, S, D) both before the drill and during the drill. Once the user triggers the drill to start, several things occur to indicate the drill is active. Firstly and most noticeably, a fire alarm sound plays and continues as long as the drill is active. Secondly, fires become "active" in that they are not only visible but also cause damage to the user and AI agents when entered. Lastly, GUI elements specific to the evacuation procedure are displayed, one of which is a stopwatch that only starts after the evacuation is triggered. Additionally, though not analogous to real life evacuations but necessary for simulation user experience, the evacuation can be paused. The evacuation continues until the user reaches the evacuation area goal.

Once the user reaches the evacuation goal area, the health statuses of both the users and the AI agents are checked. Firstly, they are checked to see if anyone lost all health as that represents dying and is an unacceptable result as that would be analogous to letting someone die in evacuations in real life. The user gets informed of failing the training through both a failure sound as well as a displayed message. In the other case that everyone still has some health left after completing the evacuation, the amount of health all parties have is checked. If anyone at all lost any health, medical help must be called for. In that situation, a GUI button to call emergency services becomes visible and the user is informed to call emergency services. After the user presses the button or an assigned keyboard key, then a call sound plays and an ambulance near the evacuation goal area becomes visible. This is analogous to how in real evacuations, medical first responders need to actively be called in order for them to come; they are not just immediately present after evacuating.

3.3 Graphical User Interface and Interactions

In order to allow effective user agency in the training, a GUI must be designed to display everything the user needs to know as well include sufficient interfacing to interact with the simulation components. Thus, we created a robust GUI to properly be able to simulate fire evacuation training. The GUI should also be dynamic and reflect the current state of the simulation and the user's status rather than just include a fixed set of interface elements. However, there are some GUI elements that are necessary to keep throughout all evacuation stages, though their contents and values might change. In our GUI design, the GUI elements that are present throughout include a status panel, a status display message, an exit button, and some joysticks for movement and looking around. Especially for a high-emotion and stress environment of a fire emergency, the GUI should include guidance for the user as the danger could cloud their judgement and lead them to panic instead of acting. The status panel should be present throughout the simulation in order to help users know what actions to take, not only for the simulation but also to be trained on how to handle actual fire evacuations at various points in the process. Though not analogous to actual fire evacuations, having a way to exit the simulation at any instance is essential, so the exit button is available for the entire duration of the simulation. Lastly, the user should be able to move and look around at any point in the simulation just like they would be able to in real life, so the joysticks are also available throughout the simulation. The joysticks also allow for movement and looking otherwise not possible on mobile applications, which can be more widely distributed than personal computer (PC) applications for training purposes. Consideration for both PC and mobile application roll-out has been done throughout our GUI design by assigning actions for multiple different possible input devices such as PC keyboards and computer mouses as well as mobile touchscreens.

(a) Default closed state of the door.

(b) The door being open after the user moved into close proximity to it.

Fig. 4: Door interaction.

In addition to the GUI buttons, there are 2 other main types of objects that can be interacted with: the doors and the fires. As shown in Fig. 4, when the user's avatar gets close enough to any of the doors in the VR environment, the door plays an opening animation and plays a door opening sound when the user enters. This is analagous to how users will need to open doors when there is a fire evacuation as it cannot be assumed there is a completely empty path towards the area to evacuate to in the case of actual emergency situations.

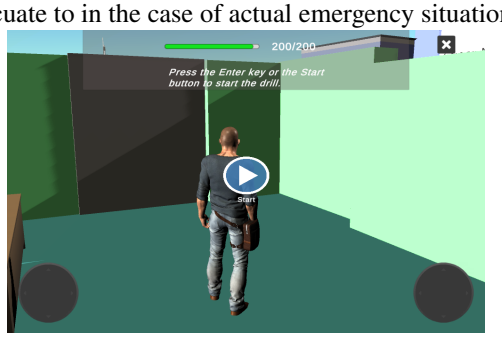


Fig. 5: The GUI elements before the drill is started.

Fig. 5 shows the GUI in the state before the drill starts. Though there is no fire or anything to cause damage before the drill starts, the health status within a GUI panel is still displayed to the user to show that they start off with full health. Instructions are displayed in the status panel on what inputs should be used to start the drill either through keyboard input or GUI buttons, and to start the drill there is a dynamic GUI button dedicated to starting the drill.

Fig. 6: The GUI during the drill.

During the drill itself, there are several changes to the GUI. Some of the contents are changed for the constant GUI elements, such as displaying a different instruction message. The user is no longer waiting for the drill to start, so the message was changed to indicate that the evacuation has started and that the user needs to go to the evacuation area. Another change is that previous GUI elements that were available before become unavailable as they are no longer needed, such as the start button as the drill is already happening and the user no longer needs to be able to start the drill. Lastly, new GUI elements become available. Firstly, as there is time-sensitive environment activity and procedure happening, a pause button becomes available as a user should be able to pause in the case that something briefly needs their attention and they need to be able to get back to their current level of progress in the evacuation after addressing it. Additionally, a stopwatch icon and a stopwatch time display are added in order for the user to know how long they are taking to complete the evacuation.

Including a stopwatch display for the user specifically is beneficial for evacuation training for several reasons. Firstly, the fires themselves, and thus their hazard, could grow as time moves forward. Growth of fire could also cause more damage to both the area and its occupants. If the user gets harmed through fire, they could also lose their ability to move, especially their ability to move quickly, which thus impairs their ability to evacuate as well as lead others to evacuate. It is thus very important for the users to feel the urgency of the fire emergency and try to escape as quickly as possible. However, a user should not be pressured to rush as it would risk not only their safety, but also the safeties of those following them, represented in simulation through the health of the AI agents following them. Including a stopwatch display that shows how much time has passed keeps users aware of how long they are taking which should help them balance the need to evacuate quickly while also proceeding with caution to not unnecessarily risk their own safety or the safeties of those being guided to evacuate.

Fig. 7: Fire damage interaction.

Regarding the fires, as long as the user or an AI agent is in any of the fires, the user takes damage and a fire sound is also played. The behavior continues until the user is sufficiently away from the fire. This is similar to how people can hear and feel fire in real life when close to it. The combination of the visuals, sound, and damage of the fire in the VR simulation makes the hazard of fire more tangible to the user to take it more seriously and gives a more immersive experience.

Whenever the user is harmed, not only does the health bar visual decrease, the value decreases. Whenever a user gets harmed from actual fire, due to the nature of fire damage, the user will require medical assistance and treatment. Actual harm from fire cannot be left untreated. In order to emphasize the urgent need for medical attention, as soon as the user gets damaged from fire, a representative health icon starts flashing to indicate the need for medical attention and motivate the user to move towards the evacuation goal area to be able to call for help to get medical treatment.

Fig. 8: GUI when drill is complete.

In the case that evacuation was done successfully in that both the user and the AI agents received no damage to their health, the a message display as well as a sound indicating success will be shown, as seen in Fig. 8. As no one needed medical attention due to no loss in health, the GUI button to call for help would not be available.

(a) GUI after the drill in the case that someone needs medical assistance.

(b) Drill complete, ambulance.

In the case that either the user, the AI agents or both were harmed once everyone reached the evacuation goal area, an emergency phone call button becomes available. The icon indicating medical assistance is needed still flashes until the ambulance "arrives," i.e. until the ambulance model becomes visible.

In both the case of successful evacuation and evacuation requiring medical assistance at the end, the final values of the stopwatch and user health are left for the user to see and evaluate their simulated evacuation performance.

4 Conclusion

In conclusion, using VR to simulate fire evacuations can be more effective than physical, in person training. VR allows for risk-free immersion that is not possible with in person training and also can help people become more familiar with the fire evacuation experience how to handle university campus fire evacuations. In this work, we successfully implemented a VR application for campus fire evacuation with realistic modeling and immersive, high-quality user experience that has an extensive protocol and robust interactions.

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