Improving Emergency Response Training and Decision Making Using a Collaborative Virtual Reality Environment for Building Evacuation

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Abstract. Emergency response training is needed to remember and implement emergency operation plans (EOP) and procedures over long periods until an emergency occurs. There is also a need to develop an effective mechanism of teamwork under emergency conditions such as bomb blasts and active shooter events inside a building. One way to address these needs is to create a collaborative training module to study these emergencies and perform virtual evacuation drills. This paper presents a collaborative virtual reality (VR) environment for performing emergency response training for fire and smoke as well as for active shooter training scenarios. The collaborative environment is implemented in Unity 3D and is based on run, hide, and fight mode of emergency response. Our proposed collaborative virtual environment (CVE) is set up on the cloud and the participants can enter the VR environment as a policeman or as a civilian. We have used game creation as a metaphor for developing a CVE platform for conducting training exercises for different what-if scenarios in a safe and cost-effective manner. The novelty of our work lies in modeling behaviors of two kinds of agents in the environment: user-controlled agents and computer-controlled agents. The computer controlled agents are defined with preexisting rules of behaviors whereas the user controlled agents are autonomous agents that provide controls to the user to navigate in the CVE at their own pace. Our contribution lies in our approach to combine these two approaches of behavior to perform emergency response training for building evacuation.

Keywords: Virtual reality · Immersive VR · Building evacuation · Collaborative virtual environment

1 Introduction

During emergencies and disasters, there is a need to minimize the potential impact on life and property. As a result, emergency response teams are organized to serve as pre-emergency preparedness function such as planning, training, and exercising. Training is needed for all emergency response tasks because of the uncertainties involved in it and a need for urgency in response [1]. Thus emergency response training is needed to prepare

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an emergency response team and first aid responders to promptly detect the onset of an emergency, assess the situation, and respond effectively to the situation. Emergency response training is a learning process that can lead to the development of individual and team expertise. Expertise can be outlined as the achievement of consistently superior performance through experience and training. Expertise can be built through guidance programs which include formal training programs, on-job activities, and other learning experiences. Expertise can be classified as the breadth of expertise and depth of expertise. The breadth of expertise focuses on the diversity of training and learning gain as part of a career within an organization. On the other hand, the depth of expertise focuses on skill-building that is needed to build expertise. For emergency response training and decision making there is a need to understand the depth of learning as well as the content or breadth of learning activities. Depth of expertise consists of three components: (a) knowledge that is highly procedural zed and principled, (b) mental models that are well organized and structured, (c) self-regulatory systems that are well developed [2].

Training exercises are needed to explore possible responses to emergency events and explore different what-if scenarios. Thus, training exercises are planned to address the cognitive skills of the user to respond to unexpected events and scenarios. The purpose and scope of these training scenarios for unexpected events include training of emergency response teams, evaluation of new evacuation guidelines, building trust on trainees, and testing the emergency operation plans (EOP). One of the possible ways to accomplish this type of training is to create a collaborative virtual reality environment (CVE) where the training concepts are attractive to the users and allow them to be fully immersed in the environment without being exposed to any dangers. The CVE can help in improving the planning of security tasks and procedures as well as for performing virtual evacuation drills. The development of such CVE is very critical for the training of different types of scenarios in emergency events to enhance the security agent's skills (Fig. 1).

Fig. 1. View of security personnel training module for active shooter events

With the recent advances in technology, CVE based training incorporates real-world scenarios and creates a “sense of presence” in the environment. The collaborative virtual environment offers a considerable advantage for performing real-time evacuation drills for different what-if scenarios. The use of CVE allows us to run virtual evacuation drills, eliminates the risks of injury to participants, and allows for the testing of scenarios that could not be tested in real life due to possible legal issues and health risks to participants. This paper presents a CVE platform for improving emergency response training and decision making for building evacuations. The CVE will aid in developing an experimental setup to train emergency response personnel as well as first aid responders for decision-making strategies and what-if scenarios. The emergencies can be a result of fire and smoke as well as active shooter events. This work also verifies the feasibility of designing a CVE for training security personnel and occupants of the building in active shooter events. The proposed CVE is implemented in Unity 3D and is based on run, hide, and fight mode for emergency response. The user can enter the CVE as a policeman or as an occupant of the building. Our proposed CVE offers flexibility to run multiple scenarios for evacuation drills for emergency preparedness and response. The modeling of such an environment is very critical in today’s life because of the need to train for emergency events. This paper presents a CVE platform where experiments for disaster response can be performed in CVE by including 1) Artificial Intelligent (AI) agents: defined by pre-existing rules, 2) User-Controlled agents: to navigate as autonomous agents.

The rest of the paper is structured as follows. Section 2 briefly describes the related work for CVE, active shooter response, and disaster evacuation drills in CVE. Section 3 describes the collaborative virtual reality environment for building evacuation. Section 4, describes the implementation of the CVE in three phases. Section 5 presents the simulation and results. Finally, Sect. 6 discusses the conclusions.

2 Related Work

The need for evacuation training goes beyond training participants to evacuate a building. It is also useful in training airline pilots to conduct airplane evacuations [3]. An example of a successful evacuation training program can be seen in [4] where a pre-test and a post-test assessing the participant’s knowledge gain in regards to proper evacuation methods revealed a positive knowledge gain among participants. Wagner et al. [5] have argued that evacuees are more confident and less hostile while evacuating with an evacuation assistant than evacuating without an evacuation assistant. Alemeida et al. [6] have built a VR environment that studied user’s compliance with safety warnings regarding potential safety hazards in the environment. Sharma et al. [7, 8] have created a CVE for emergency response, training, and decision making in a megacity environment. They have also developed a CVE for a real-time emergency evacuation of a nightclub disaster [9] and an active shooter training environment [10]. Their CVE includes user-controlled agents as well as computer-controlled agents. computer-controlled agents include behaviors such as hostile agents, non-hostile agents, leader-following agents, goal-following agents, selfish agents, and fuzzy agents. On the other hand, user-controlled agents are autonomous agents and have specific roles such as police officer, medic, firefighter, and swat officials. Sharma et al. [11] have also used VR as a theme-based game tool for training and education tools. They have conducted virtual evacuation drills for an aircraft evacuation [12], a building evacuation [13], a subway evacuation [14], a university campus evacuation [15], and a virtual city [16].

Lindell, Prater and Wu [17] have argued that preparation and warning times during evacuation time analysis are very important to a successful evacuation. Lindell and Perry [18] have emphasized the importance of evacuation planning in emergency management. Similarly, Bowman et al. [19, 20] have also stressed on the use of VR gaming approach and VR evacuation drills. Musse [21, 22] has provided a real-time communication between users and virtual agents by defining three levels of autonomy: 1) Autonomous crowd 2) Guided crowd 3) Programmed crowd. The above three levels of autonomy are represented in ViCrowd using two kinds of interfaces: scripted and guided interface. The scripted interface incorporates script language where action, motion, and behavioral rules are defined for crowd behaviors.

3 Collaborative Virtual Reality Environment for Building Evacuation

Our proposed collaborative VR environment for building evacuation includes: 1) immersive (use of Oculus Rift), and 2) non-immersive environments (Desktop Environment). The participant can enter the CVE setup on the cloud and participate in the emergency evacuation drill, which leads to considerable cost advantages over large-scale, real-life exercises. We hypothesize that the "sense of presence" provided by the CVE will allow running training simulations and conducting evacuation drills. Virtual evacuation drills are:

- More Cost Effective
- Take Less Setup Time
- Able to Simulate Real Dangers
- Improved Response Time.

3.1 Non-immersive Environment

The non-immersive environment or a desktop environment was developed to interact with the VR environment using mouse and keyboard. Photon Unity Networking (PUN) is a built-in networking asset in Unity 3D to create a multi-user environment on the cloud. The photon cloud has PCs running photon server on them. The cloud of servers offers the flexibility to host CVE or multiplayer games. Figure 2 shows that the movement of the avatar (client), can be described in 5 stages:

1. The user initiates the action to create a CVE on photon cloud network (PUN)
2. The action is submitted to the photon cloud of servers.
3. A server validates the action and assigns a room ID for the CVE.
4. Any Change done by one client in CVE is propagated to all the other client avatars.
5. All client avatars can see the motion and updated actions of the other ava avatars.

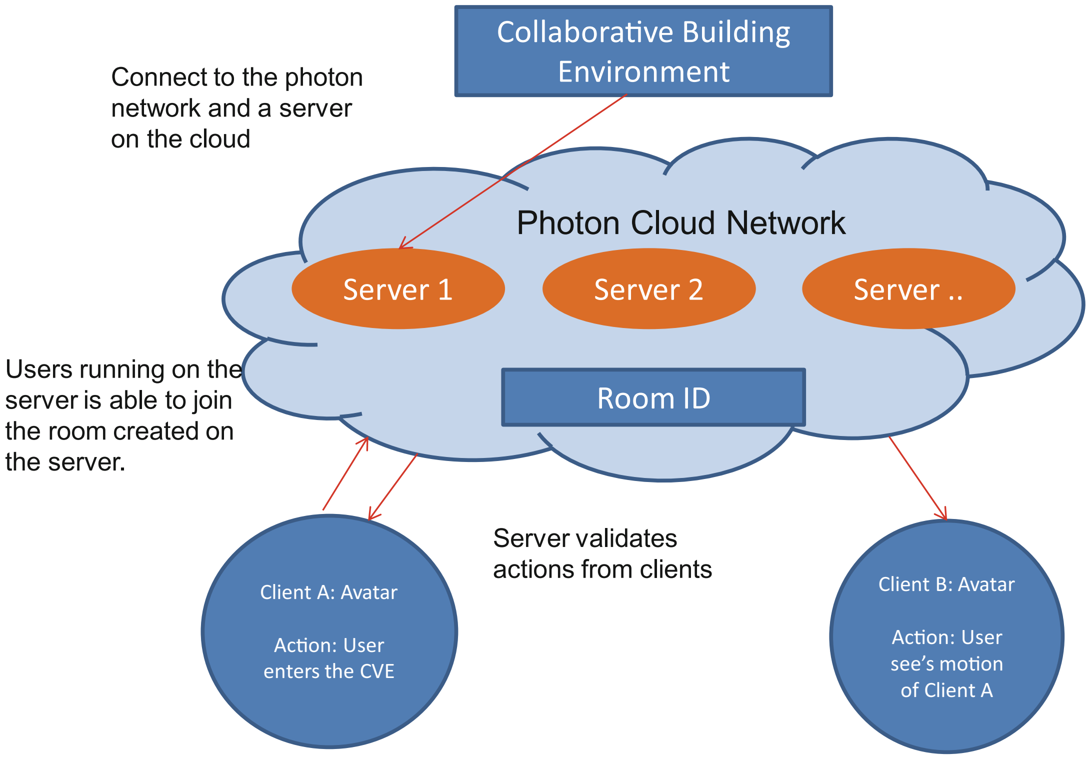

Fig. 2. System architecture diagram for CVE using photon networking asset tool in Unity 3D.

Figure 2 shows the proposed system architecture diagram for CVE on the photon cloud network. The photon cloud network has multiple servers on the cloud. The host player connects to the photon network to a server inside the cloud with a valid room ID. The created room on the server is available to all the client's avatars who would like to join the room. The clients also have the option to communicate via chat with the other client avatars who enter that room. When the connection is established the server validates actions from clients and calculates the new CVE environment according to the updated action.

3.2 Immersive Environment (Oculus Rift)

An oculus Rift head-mounted display was used to allow the user to be immersed in the CVE. The environment was designed in such a way that the user can enter the environment as policemen or as a building occupant. If the user entered as a building occupant the training module is based on run, hide, and fight mode of emergency response. It offers the flexibility to train building occupants for different what-if scenarios. During an emergency, the first option for the user is to run and escape from the building. This can be done by running away from the active shooter by leaving behind their belongings. During this option, it becomes important to help others to escape and warn other building occupants from entering the building. The second option during an emergency is hide. This can be done by getting out of the active shooter's view and staying quite. It becomes important to silence cell phones and lock doors and windows. Thus staying quite at a locked space until the law enforcement arrives. The third option during an emergency is to fight as an absolute last resort. This involves throwing items to distract and disarm the shooter.

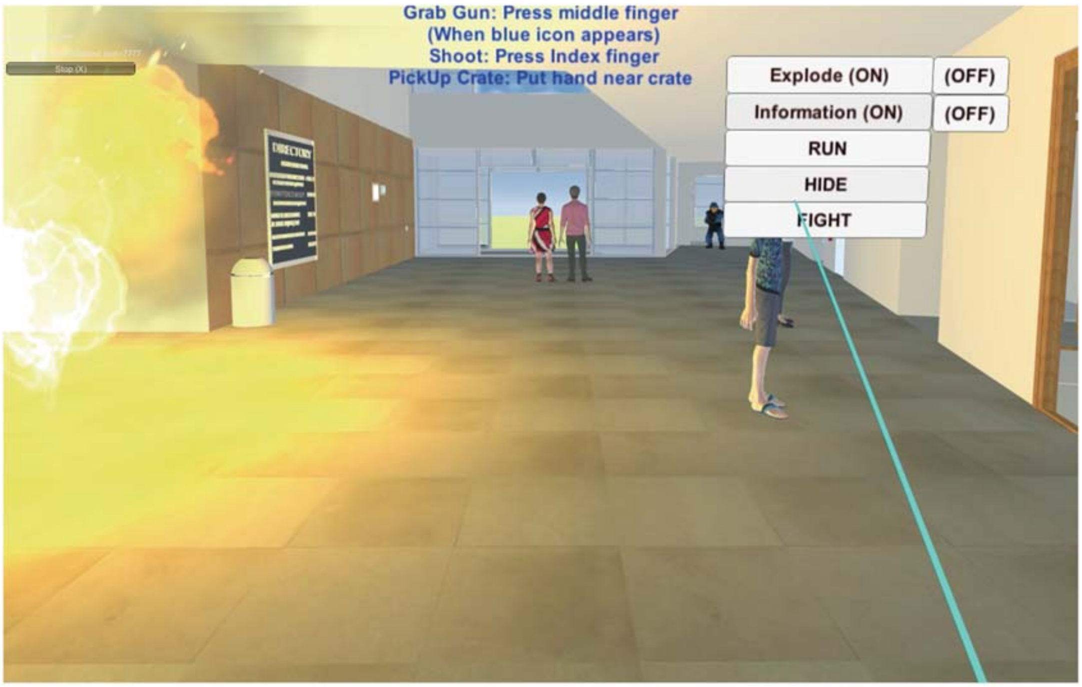

Fig. 3. Training module of run, hide, and fight for a fully immersed user-controlled player

Active shooter response for run, hide and fight is shown in Fig. 3. The user can use the laser pointer triggered through the oculus controllers to choose the correct option from the menu in the CVE. The menu is used to trigger the explosion as well as to navigate in the CVE. The user can grab the objects in the environment through an oculus touch controller and throw them at the active shooter.

4 Implementation of the CVE

The implementation of a collaborative virtual reality environment for building evacuation for improving emergency response training and decision making was done in four phases.

4.1 Phase 1: The Modeling Process

Phase 1 consists of modeling the building on campus using 3D Studio Max and Google Sketch Up. The building was modeled to scale and incorporated real-time textures. The environment also includes adding 3D models for furniture, table, chairs, computers, etc. in the room, lecture halls, and meeting places. Figure 4 shows the view of the first floor of the building in Google Sketch-Up.

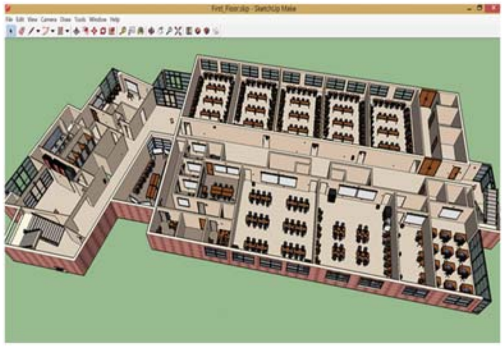

Fig. 4. Google Sketch Up 3D scene view of the model.

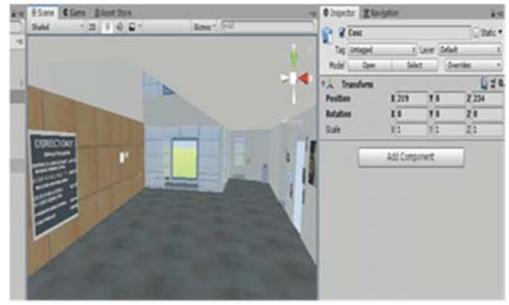

Fig. 5. Unity 3D scene view of the game.

4.2 Phase 2: Unity 3D and Photon Cloud Setup

Phase 2 consisted of exporting the environment from Google Sketch Up to the Unity 3D gaming engine as shown in Fig. 5. Unity 3D tools for animating avatars were incorporated to give each agent in the CVE the necessary behavior for navigation in the environment. There were two kinds of agents implemented in the CVE. User-controlled agents and computer-controlled AI agents. Both the agents were given functionalities for walking, running, and jumping. Besides, C# scripts were added to the user-controlled agents to give users the ability to communicate with the AI agents and grab the objects in the environment. Multiple C# scripts were added for triggering events in the environment. For example, user-controlled agents were given the ability to communicate with the menu using a laser pointer for selection as shown in Fig. 3. Similarly, C# scripts to implement the Photon server/client networking system were developed to allow collaboration and communication in the CVE.

4.3 Phase 3: Oculus Integration and Controller Hand Simulation

Phase 2 consisted of incorporating Oculus Rift and the Oculus Touch controllers in Unity 3D. The left and right controllers were used for integrating the menus and laser pointer for selecting the objects from the menu. The menu design includes options for triggering the explosion which resulted in fire and smoke. The menu also included options for triggering run, hide, and fight modes of interaction for active shooter events. Figure 4 shows the menu option to trigger smoke and fire in the modeled environment using the two oculus touch controllers. With the use of Oculus Rift and the Oculus Touch controllers, users can navigate the environment and interact with objects. The Oculus Touch headset allows users to experience full immersion in the CVE. Oculus Touch controllers also give haptic feedback to the user when using grab option. The trigger button situated on the right controller is used to grab and place the objects in their preferred locations by selecting, holding, dragging, and releasing the trigger as shown in Fig. 6.

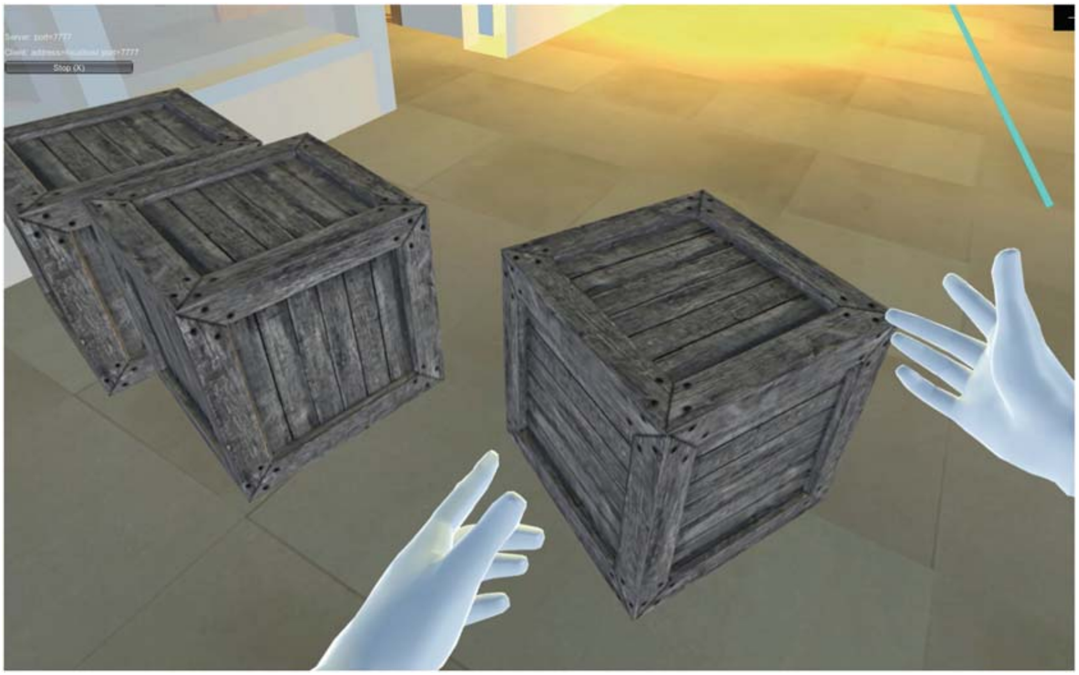

Fig. 6. Unity 3D scene showing the grab option with Oculus Rift S touch controllers.

5 Simulation and Results

One of the goals of this project is to demonstrate the feasibility of conducting emergency response training and virtual evacuation drills in a building using a CVE. We have tested our approach using 10 clients running at the same time on the photon cloud. The environment incorporates smoke and fire. The users can use Oculus Rift to immerse themselves in the CVE and are can turn around 360°.

We have modeled two kinds of threat scenarios such as bomb threat and an active shooter gunman threat in the CVE for a building. Figure 7 shows a scenario where a policeman (as a user-controlled agent) is responding to the active shooter threat. We have modeled behaviors based on pre-defined rules for computer-controlled agents. Through this experimental approach in CVE, emergency personnel and building occupants can be trained on how to respond to emergencies safely and securely by following proper procedures. The platform can also be used in building teamwork for decision-making strategies to follow in case of emergencies. User-controlled agents can enter the CVE to interact with the computer-controlled characters as well as the objects (grab) present in the environment. Multiple users can interact with one another and train on how to respond to active shooter events using the run, hide, and fight option for different what-if scenarios. The collaborative environment is implemented in Unity 3D and is based on run, hide, and fight mode of emergency response as shown in Fig. 8.

Fig. 7. Active shooter response for policeman training

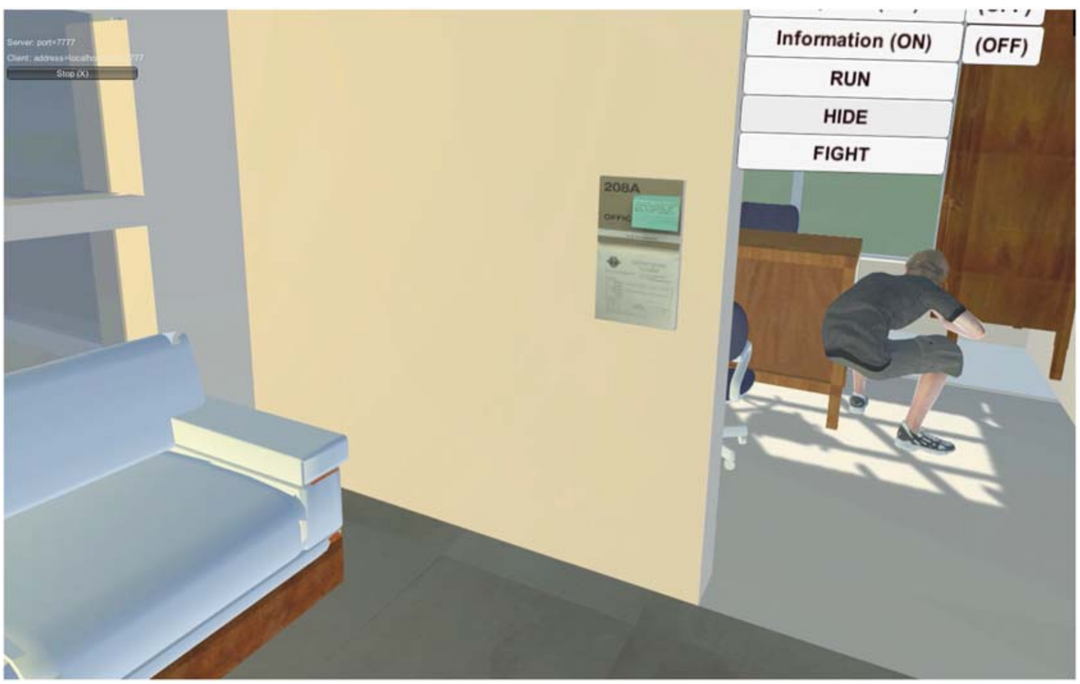

Fig. 8. Active shooter response for hide for building occupant's training module

6 Conclusions

In conclusion, this CVE system will act as a platform to allow emergency response training to police offices/security personnel and building occupants to follow protocol in an emergency situation. Unity 3D was used to develop the collaborative server/client-based virtual environment that runs on the photon cloud. Our proposed CVE incorporates artificial agents with simple and complex rules that emulate human behavior by using AI.

We have presented a hybrid (human-artificial) platform where experiments for disaster response and training can be conducted using computer-controlled (AI) agents and user-controlled agents. We hope our proposed CVE will aid in visualizing emergency evacuation time and training for different what-if scenarios that are difficult to model in real life. CVE can also act as a training and educational tool for strategizing emergency response and decision-making strategies. Future work will involve the implementation of more behaviors such as altruistic behavior and family behavior for AI agents in the environment. Figure 9 shows a bomb blast scenario where a policeman (as a user-controlled agent) is responding to the threat. An explosion is triggered at the building leading to fire and smoke.

Fig. 9. User triggers a bomb blasts resulting in fire and smoke.

The proposed CVE incorporates emulated behavior in emergencies by defining rules for computer-controlled agents, and giving controls to the user-controlled agents to navigate the environment in an immersive environment (head-mounted display) or non-immersive environment (desktop monitor, mouse, keyboard) in real-time. The analysis of these combination controls make it possible to better understand human behavior under such extreme conditions. Knowledge and data obtained by performing the evacuation drill and training exercises will facilitate a more efficient evacuation procedure. Emergency responders will benefit from education on time management during an emergency evacuation drill by better managing and reducing response time to save more lives and casualties. Our contribution in knowledge will complement and improve the skills of emergency responders to handle the traditional emergency response and evacuation drill in real life more efficiently.

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