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Megacity: A Collaborative Virtual Reality Environment for Emergency Response, Training, and Decision Making

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Abstract

The simulation of human behavior with avatars and agents in virtual reality (VR) has led to an explosion of training and educational research. The use of avatars (user-controlled characters) or agents (computer-controlled characters) may influence the engagements of the user experience for emergency response, and training in emergency scenarios. Our proposed collaborative VR megacity environment offers flexibility to run multiple scenarios and evacuation drills for disaster preparedness and response. Modeling such an environment is very important because in the real-time emergencies we experience in day-to-day life, there is a need for preparation to extreme events. These emergencies could be the result of fire, smoke, gunman threat, or a bomb blast in a city block. The collaborative virtual environment (CVE) can act as a platform for training and decision making for SWAT teams, fire responders, and traffic clearance personnel. The novelty of our work lies in modeling behaviors (hostile, non-hostile, selfish, leader-following) for computer-controlled agents so that they can interact with user-controlled agents in a CVE. We have used game creation as a metaphor for creating an experimental setup to study human behavior in a megacity for emergency response, decision-making strategies, and what-if scenarios. Our proposed collaborative VR environment includes both immersive and non-immersive environments. 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 present two ways for controlling crowd behavior. The first defines rules for agents, and the second provides controls to the users as avatars to navigate in the VR environment as autonomous agents. Our contribution lies in our approach to combine these two approaches of behavior to perform virtual drills for emergency response and decision making.

1. Introduction

During life-threatening situations such as building fires, building collapses, and terrorist attacks, lives are lost partly because people have not been properly trained on how to safely evacuate their setting. Evacuation drills reduce, if not eliminate, the possibility of injuries and fatalities occurring during emergencies. Research has proven that virtual reality (VR) is a powerful supplement to education and training as it provides an environment where users can engage in learning activities by interacting with the environment and fully immersing themselves in it. Immersive VR environments can give the user a realistic view of what an emergency would look like and how they should respond and evacuate, given a familiar setting. In this paper, an immersive collaborative virtual environment (CVE), along with evacuation scenarios, is built for a VR megacity environment. To assess the power of immersion, two versions of the environment were built: an immersive version and a non-immersive version. The user interacts with the immersive version using the Oculus Rift Head-Mounted Display (HMD) and with the non-immersive version using keyboard/joystick and mouse. The immersive CVE also offers a unique way for training in emergencies.

Evacuation training is essential to save human lives because it explains to participants how to conduct themselves during a real emergency and what improvements should be made to ensure the safest and most efficient evacuation possible. Evacuation drills give participants an idea of what route to take, where to assemble once evacuated, and procedures to follow before and after evacuating. Drills should be done periodically to guarantee that evacuation procedures are properly followed [1]. A live evacuation drill is an ideal method for evacuation training. However, an evacuation drill done in a virtual environment would better inform users on evacuation routes and expectations since VR is a tool proven to engage users mastering a concept. According to [2], VR is a particularly useful learning tool for those who find it easier to learn using shapes, colors, and symbols.

Fig. 1 Megacity in CVE shows an officer, a patient lying on the ground in need of care, emergency response vehicles, and police car for an emergency situation

A virtual world provides us the ability to perform various tasks seen in the real world. For example without VR, imagine how expensive and time consuming it would be to simulate an emergency evacuation in a plane. To simulate evacuation, our needs include paying for access to a real size plane, recruiting sample passengers, pilots, flight attendants, and crew members. Sharma et al. [3-10] explains the use of Agent-Based Modeling and Simulation (ABMS) for emergency evacuations. ABMS has been used to simulate human behavior in aircraft evacuation [9]. Using an accurate simulation model is very important especially in emergency evacuation scenarios [3]. The accuracy is even more important in a virtual world where results can change as various parameters are changed. For example, psychological parameters of anger, stress, and panic would have to be accurately observed for an emergency evacuation in a virtual world. Simulating how agents can learn from the virtual environment to find the nearest exit in an emergency evacuation is very important. The agents experience various emotions such as anger, stress, and panic as they try to find their way out of the building. Agents also react to environmental factors like smoke, which can exacerbate the animated agents' speed and direction. This simulation will provide useful training and education.

For military purposes, training is imparted through computer models, fighting equipment, and weapon simulators. Superficial environments are generated to represent a very high level of war theatres. One of the advantages of such a collaborative virtual system instruction is knowledge gathering and pattern detection about the individuals involved in the training, which is not very effective in the case of traditional instruction methods. By creating hypothetical war situations with increasing levels of complexity, behavior patterns are analyzed and from that, accurate behavior models can be determined to evaluate critical parameters such as trust, real world interaction, response time, emotional quotient, and leadership. Apart from being a cost-effective way of training personnel in a synthetic environment, CVE also serves as a flaw-detection technology**,** thereby creating a cyclic process and dependency between training and technological improvement.

Predicting a person's behavior in an emergency becomes very difficult because human behavior is unpredictable when it comes to making decisions in emergency situations. Real- time evacuation drills are very expensive and costly to perform and are not able to simulate real dangers. For example, if there is a gun shooting or fire and smoke in a building at a busy city, it can lead to many fatalities both inside and outside the building. There is a need for emergency personals to be trained on how to respond to these situations. Inside the building, there is a need for safe evacuation of the people as well as planning for the SWAT team to handle the situation and save lives. Outside the building, the traffic has to be cleared, people have to be evacuated from the city block, and medics have to take care of the injured people. A CVE provides a platform to conduct simultaneous training for such emergency situations where the sense of "presence" develops when a user is immersed in a virtual environment. CVE make it possible to conduct experiments with people to explore crowd behavior in a megacity evacuation using VR to achieve high levels of presence. Evacuation training of occupants in a real-time environment is very complicated because it is expensive and dangerous. On the other hand, CVE offers an excellent way to demonstrate and train personnel on how to respond to emergency threats and help in decision making. Our proposed collaborative megacity VR environment (Fig. 1) was developed using Unity 3D, a graphical game development platform. Unity 3D allows incorporation of different programming scripts like JavaScript and C# scripts, which allow controlling computer-simulated agents. Unity 3D also allows integration with Oculus Rift, a head-mounted display, and provides a first controller view of the environment. Fig. 1 shows our proposed megacity CVE in which the disaster has just occurred. The scenario shows an officer, emergency response vehicles, police car, and an injured person lying on the ground in need of care.

The focus of this paper is to develop agents' behavior for emergency response such as the evacuation in a multiuser crowded VR megacity environment. We have modeled hostile behavior, non-hostile behavior, selfish behavior, leader-following behavior for computer-controlled agents in the CVE. The rest of the paper is structured as follows. Section II briefly describes the work done previously. Section III describes the collaborative megacity VR environment. Section IV describes the modeling and simulation of a collaborative VR megacity environment in different phases. Section V describes the CVE and simulation results. Section VI lists conclusion and future work.

2. Related Work

According to the Occupational Safety and Health Administration (OSHA) [11], evacuation training is important for occupants in a specific setting, such as a school or office, since evacuees must be aware of their responsibilities, meeting places, potential hazards, and emergency equipment. It is important that evacuation training scenarios vary and not be so routine that when the alarm sounds in a drill, participants ignore it thinking that the drill is an ordinary occurrence. Ignoring practice evacuation drills can lower participants' chance of survival should a real emergency happen [12]. The need for evacuation training goes beyond training participants to evacuate a facility on land. It is also useful in training airline pilots to conduct airplane evacuations as seen in [13]. An example of a successful evacuation training program can be seen in [14] where a pre-test and a post-test assessing the participants' knowledge gain in proper evacuation methods revealed a positive knowledge gain among participants, meaning that the program was effective. Evacuation scenarios help in discovering potential evacuation behavior patterns and evacuation improvements. A study conducted in [15] suggested that evacuees are more confident and less hostile while evacuating with an evacuation assistant than those evacuating without an evacuation assistant.

Computer simulations can provide insight into how evacuations should be carried out. A VR-based simulation built in [16] concluded that evacuation time is less when agents communicate with each other and when there are trained leaders. A simulator built in [17] aims to train traffic operators on how to direct traffic patterns during evacuation. The simulator consists of a replica of a typical real-life traffic control center, built with systems that allow the user to control traffic as he or she would in real life. It also features an agent-based traffic behavior model where drivers (represented as agents) behave according to their personality and type. A mixed-reality game developed in [18] enlightens system designers on how to build Mass Casualty Incident (MCI) information systems. The game features artificial intelligence–based patients and paramedics. When the game was evaluated, it verified that knowing patient location via MCI systems decreases evacuation time. A VR-based training simulation built with haptic (touch) interfacing was implemented in [19].

Alemeida et al. in [20] built a VR environment that studied users' compliance with safety warnings regarding potential safety hazards in the environment. Out of the 14 subjects that evaluated the environment, 71% said that they noticed the warning about possible falling objects in the environment, 50% said that they read the warning, and only 29% actually complied with the warning. Mitzushina et al. in [21] built a system that combined Oculus Rift with a haptic racket, fusing immersion with haptic interfacing. In that system, when the user hits the badminton shuttle in a virtual badminton game, the racket produces haptic feedback to the user. When the system was demonstrated, it gave users a sense of interaction along with the shuttle's impact.

Musse et al. [22-24] have developed the ViCrowd system to automatically generate human crowd behaviors based upon group behavior instead of individual behavior. They have presented three types crowd-controlling behavior: programmed behavior, reactive or autonomous behavior, and guided behavior. Our proposed megacity VR environment follows the three ViCrowd strategies of controlling the crowd behavior as proposed by Musse: 1) multilevel hierarchy behavior formed by crowd, groups, and agents; 2) rule-based behaviors or reactive behaviors, such as scripted and interactive control; and 3) group-based behaviors in which agents are simple structures and the groups are complex structures.

Johnson [25] explained that usable agents could be seen in computer-based environments. These agents are called animated pedagogical agents that are able to communicate back and forth with a learner. This environment is very stimulating and conducive for learning and can be adapted to foster interaction for new users using entertainment as a tool. Arango et al. [26] further explained that entertainment involving multilearners at the same time, often seen in video games, is currently being explored in virtual environment. Such environments are able to encourage learning by leveraging the power of web technologies and the familiarity of the learners to video game entertainment. The entertainment is able to work successfully in scenarios where the learning can best be communicated through the video game environment.

Crossland [27] reiterated that emergency training could be useful in reducing the stress and making emergency staff members perform their work better. This is analogous to staff members switching to an autopilot mode, going through the steps they have been trained to do, and acting like a robot during the emergency situation. Supervision of staff members is also important. Sharma et al. [9] proposed using simulators as a way to test unique situations that may come up when performing emergency evacuation of a plane. This simulator, called AvatarSim, relies on fuzzy logic to model the range of emotions, such as panic and stress, that an agent can experience in an emergency. It is also shown that, socially, people are rough on each other and only go toward exits that they can see in an emergency.

Johnson et al. [28] moved on to evaluate how to measure which virtual environment a user will find useful in a simulation. The important criteria to use in the selection process are the visual methods used in the virtual environment to arouse the emotions and mental state of the users to meet their goals. Bruder et al. [29] explained why superior a virtual environment creates a visual manipulation of the sight of the user (illusion) viewing the simulation to match the real world. Katsionis et al. [30] piggybacked on measuring the emotional state of the user when working with a virtual environment in an educational simulation. Sobota et al. [31] provides a laboratory to perform research on to study connections between interface communicating with an information system (LIRKIS). Sharma et al. [32-34] have used VR as a tool for training and education. They have also used immersive collaborative virtual environments for conducting virtual evacuation drills for subway evacuation [35] and university campus evacuation [36] for disaster preparedness and emergency response training.

3. Collaborative Megacity VR Environment

The collaborative megacity VR environment was developed by using 3D modeling software such as 3DS Max and Google sketchUp. Unity 3D gaming platform was used to program the environment. The proposed collaborative environment has a cloud connectivity that allows the users to connect as a client avatar. The participants can view the collaborative virtual environment in two ways: immersive environment and non-immersive environment. In the immersive environment, the users wear Oculus Rift head-mounted display and navigate in the environment as autonomous agents whereas in non-immersive environment, the users use a desktop computer, keyboard, and mouse to navigate in the environment as autonomous agents. The immersive collaborative VR environment also offers a unique way for training in emergencies. We have used game creation as a metaphor for creating an experimental setup to study human behavior in a megacity for emergency response, decision-making strategies, and what-if scenarios. The environment contains threats such as fire, smoke, biohazard, and a gunman. We present two ways for controlling crowd behavior: 1) by defining rules for agents and 2) by providing controls to the users as avatars to navigate in the VR environment as autonomous agents with a keyboard/ joystick along with an immersive VR head set in real time. Our contribution lies in our approach to combine these two methods of behavior to perform virtual drills for emergency response and decision making**.**

3.1 Oculus Rift

Oculus Rift is a head-mounted display that allows the user to immerse themselves inside the CVE. The collaborative megacity campus environment is designed for the Oculus Rift HMD to give the user a complete immersion. During the development in Unity 3D platform, the 3D model was converted to an Oculus Rift prefabrication by adding the oculus prefabs and scripts. This allowed the player/user to navigate in the megacity environment to develop a sense of presence.

Fig. 2: Shows the Oculus Rift version of the Megacity CVE

The participants as avatars can enter the collaborative VR environment of the megacity as autonomous agents while wearing Oculus Rift. While adding the player to the CVE environment scene, the default camera was replaced with the Oculus Rift camera prefab, which resulted in the two-screen view as shown in figure 2. While wearing the Oculus Rift, the left part of the screen will be the left eye's view and right part will be the right eye's view. The player is then subsequently added to the photon cloud network, which then creates a room in the Photon server that allows the clients to join the room.

3.2 Client/Server

For the client/server networking, we have included a plug-in called Photon cloud networking that allows multiple users to participate in CVE from anywhere on the Internet. Photon Unity Networking (PUN) enhances the features of Unity's built-in networking. Photon cloud has a collection of PCs with the Photon server running on them. The cloud of servers offers as hassle-free service for hosting multiplayer games or CVE.

As shown in Fig. 3, the CVE for megacity is first connected to the cloud of servers on the photon cloud network. The host/player then creates a room on the server with a valid room ID. The room created is available for all the client avatars who want to the join the CVE. The desktop environment has the option to communicate via chat with the other avatars who enter that room. A client communication channel allows clients to communicate with each other in the CVE.

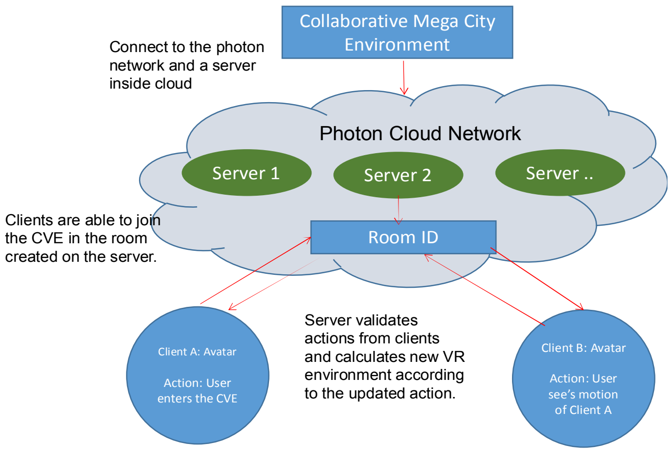

Fig. 3. Networking diagram for CVE for megacity using photon networking asset tool in Unity 3D

After connection is established, the photon network monitors movement change in the CVE so that every avatar's motion is visible to all the avatars present in the CVE. The movement of an avatar in the environment can be described in five stages as shown in Fig.3.

1. An action (enters the CVE in megacity) is performed by the user.
2. The action is submitted to the photon cloud network servers.
3. A server validates the action and calculates the new CVE.
4. CVE world state change propagates to all the client avatars.
5. All the clients as avatars are able to see the motion of the other avatars.

The megacity urban emergency response environment implements a client/server-based network by allowing users to connect to other hosts for a collaborative environment. With a collaborative environment, the photon cloud service can create rooms based on special application ID numbers.

3.3 Agent Behavior

Our proposed CVE for megacity uses an experimental design approach to assess human behavior characteristics during emergency response such as evacuation. Some predominant behavior characterized by evacuation includes stress, panic, anger, selfish, altruistic, and trust amidst confusion. Our contribution lies in modeling the behaviors and emotions and assigning them to the virtual agents to simulate the conditions experienced in real-world evacuation situations. Two kinds of agents are used in our environment: computer-controlled agents and user-controlled agents. Behaviors attributes are assigned to the computer-controlled agents.

We have implemented triggered responses for computer-controlled agents. For computer-controlled agents, the presence of smoke or fire may cause the agents to panic (trigger panic behavior), whereas in the presence of a user-controlled agent, it may illicit calm behavior in the agent (trigger calm, or goal-seeking behavior). The computer-controlled agents are designed to exhibit behaviors such as goal-seeking and path-following behavior. Fig. 4 shows the implementation of smoke and fire as well as user-controlled agents and computer-controlled agents (red and blue agents) in our proposed collaborative VR megacity environment.

Fig. 4. Red and blue computer-controlled agents together with a user-controlled agent.

Evacuation usually follows a simple sequence of detection, reaction, and most importantly decision making. Most evacuations have a high tendency leading to a crowd stampede that brings some form of collective behavior such as panic, stress, anger, and wandering. This CVE application for megacity has modeled these behaviors and assigned them to virtual computer-simulated agents in the multiuser environment to simulate real-life evacuation. It also makes use of intelligent signs such as exit signs and maps intended to guide people to safe exit. Trust and leader-following behavior are some artificial intelligent behaviors that are coupled with the waypoint algorithm to achieve the desired goal for efficient virtual agents to make a safe evacuation As mentioned earlier, we have incorporated user-controlled characters as avatars and computer-controlled characters as agents in our proposed megacity CVE. The participants as avatars can enter the collaborative VR environment in megacity as autonomous agents. On the other hand, the computer-controlled characters as agents are implemented with different behaviors such as the following:

1. Hostile Agent Behavior. Hostile agents are the red agents in the collaborative environment who create diversions and distractions for user-controlled avatars. They are aggressive agents who distract the avatars during evacuation. Characteristics of their hostile behaviors include refusal to follow emergency response leaders, pushing other agents out of their way, and the displaying of panic body language.
2. Non-Hostile Agent Behavior. Non-hostile agents are green agents in the collaborative environment. They have group behavior associated with them and goal-following behavior implemented. During evacuation they navigate toward the assigned goal. A secondary goal of group behavior is also associated with the non-hostile agents. As a result, the non-hostile agents try to group together while navigating toward the goal.
3. Leader-Following Agent Behavior. Leader-following agents are the blue agents in the CVE. They have a proximity sensor associated with them. As a result, when the user-controlled avatars are in proximity, they follow the avatars.
4. Goal-Following Agent Behavior. Goal-following agents are purple agents in the CVE. These agents are calm agents. They calmly navigate to an assigned goal when the evacuation behavior is triggered in the CVE.
5. Selfish Agent Behavior. Selfish agents are orange agents in the CVE. At the start of the simulation some computer-controlled agents could be assigned as selfish agents. Selfish agents may give false information and it will be up to the user-controlled agent to determine which information is useful in completing their current objective (evacuation).

4. Modeling and Simulation of Collaborative VR Megacity Environment

Modeling for the megacity environment was done using 3D Studio Max and Google sketch Up, whereas, the interactivity, server/client interaction, agent behavior, navigational behavior was implemented using Unity 3D, a game development engine. Unity 3D enables the incorporation of C# programming as well as java scripts for the implementation of algorithms for behavior and navigation. The entire megacity VR environment was implemented in four different phases

4.1. Phase 1: The Modeling Process

Phase 1 consists of the modeling process for developing the megacity environment. First, we used Google Sketch Up to develop a basic megacity layout. Inside the basic megacity layout in Sketch Up, we first focused on one city block for the emergency threat response.

Fig. 5. Megacity CVE with police cars at the threat

We have modeled three kinds of threat scenarios such as bomb threat, gunman threat, and biohazard threat at the city block. Once all of the buildings on the focal point of the city were detailed, we added realistic street color and street signs to the roads. Next, we imported police vehicles, fire trucks, and ambulances inside the environment. After adding emergency vehicles to the environment in Sketch Up, we then exported the megacity from Sketch Up to Unity 3D. In addition to adding individual buildings, we then added components to the city such as fire hydrants, stop signs, trees, grass, rocks and rocked pathways, streetlights, trash cans, benches, statues, fire, smoke, a central water fountain in the middle of the park, and active humanoid agents. Lastly, we added streetlights and police sirens in the scene using C# programming.

4.2. Phase 2: Unity Programming Including Photon

During Phase 2, we used C# to program the functionality for the traffic lights, the police sirens, and human behavior. To program the traffic lights, we wrote an algorithm that would show the logic of a traffic light's color order and the logic of two-way intersection traffic lights' correlation to one another. In addition to the traffic lights, the algorithm for the police sirens consisted of a red light and a blue light flashing each alternately for 0.5 seconds. The 3D models and avatars are then added with appropriate waypoint algorithms enabling them to navigate to the desired goal. Features such as wind sound are also added to bring realistic feel to the user. Fig. 5 shows our modeled megacity environment, which includes fire and smoke. This phase also involved incorporation of oculus head-mounted display and connection of the Photon client/server network. This phase also involved adding cars and other animations that are required to make the megacity environment look more realistic and natural as well as giving the user the opportunity to walk in the city.

4.3. Phase 3: Behavior Modeling Process

The algorithm for human behavior consists of different behaviors for different agents in the CVE. For instance, blue agents depict leader-following behavior. The blue agents follow the emergency response leader (police, SWAT official) to the evacuation point (Fig.4). Hostile agents are the red agents in the collaborative environment who create diversions and distractions for user-controlled avatars. Non-hostile agents are green agents in the collaborative environment. They have group behavior associated with them. Leader-following agents are the blue agents in the CVE. They have a proximity sensor associated with them to trigger leader-following behavior. Goal-following agents are purple agents in the CVE. These agents are calm agents. Selfish agents are orange agents in the CVE. Participants are able to take on different roles such as civilian, police officer, firefighter, and SWAT member. Leaders are also able to control and trigger traffic lights.

5. Simulation, Results, and Future Work

One goal of this research is to demonstrate that virtual evacuation drills can be performed in multiuser immersive megacity environment for disaster preparedness and response. We have tested our approach using 10 clients running at the same time. Fig. 7 shows five user-controlled agent as a police officer interacting in the megacity multiuser environment. The environment incorporates smoke and fire. The users are able to use Oculus Rift to immerse themselves in the VR environment and are able to turn around 360 degrees. This makes the user feel immersed in the CVE. Fig. 6 shows a user-controlled agent as an avatar that can be seen as a third-person view. Fig. 6 also shows an ambulance responding to fire in a megacity CVE.

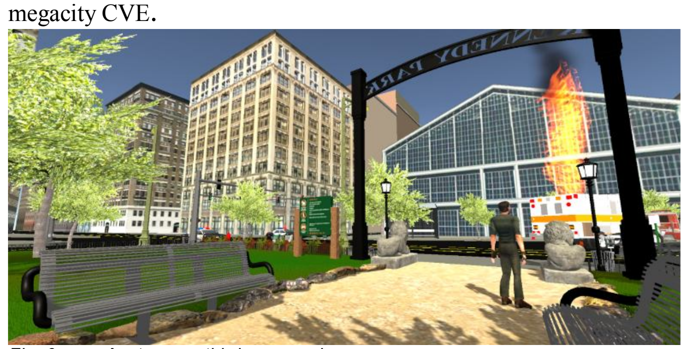

Fig. 6. Avatar as a third-person view.

We have modelled three kinds of threat scenarios such as bomb threat, gunman threat, and biohazard threat at the city block in the megacity. Fig. 7 shows bomb threat scenario where there are police vehicles, fire trucks, and ambulances inside the environment. An explosion is triggered at the city block leading to fire and smoke. We have modeled behavior attributes such as hostile, non-hostile, selfish, and leader-following behaviors for computer-controlled agents. Through this experimental approach in CVE, emergency personnel can be trained on how to respond to emergencies safely and securely by following proper procedures. The commander can give instructions to the team members on the decision-making strategies to follow in case of emergencies. User-controlled characters as avatars are able to enter the CVE to interact with the computer controlled characters as agents. The blue agents have leader following behavior. As a result, blue agents follow the avatars in the CVE. The users are able to wear Oculus Rift to immerse themselves as avatars in the CVE and are able to turn around a 360 degree. The motion sensor detection on the Oculus rift allows tracking the user head moment. This leads the user to visualize the virtual megacity environment and other agents in the VR environment.

Fig. 7. Police officer responding to an injured civilian in a Megacity CVE

Stress, panic, and anger could be induced in the CVE through the inclusion of smoke and fire. It is not possible to include smoke and fire in real-time evacuation drills due to legal and safety considerations, whereas in a CVE environment one can include smoke and fire as people's lives are not at risk. Thus, we can get valuable data on human behavior and emergency response for decision-making strategies. While the system as a whole is a subject of continuing development, the existing functions have demonstrated the feasibility of our approach. From our current tests, we have been able to observe that some participants do not exhibit behaviors consistent with the notion that they were responding to the crowd realistically. Our future goal is to perform a larger pilot experiment for evacuation drills and emergency response in a collaborative virtual environment after getting necessary approvals from the institution review board. Future work will also involve developing more behavior characteristics (altruistic, panic, etc.) and emotions for computer-controlled agents.

6. Conclusions

In this paper, we presented an experimental design approach to gather data on human behavior and emergency response in a megacity environment among a set of users as avatars (user-controlled agent) in an immersive collaborative VR environment. We have used the Unity 3D gaming engine for creating the collaborative server/client environment on a cloud. We have used game creation as a metaphor for creating an experimental setup to study evacuation behavior and human behavior in a megacity for emergency response and decision-making strategies. The proposed environment contains hazards such as fire, smoke, biohazard, and a gunman. We have modeled behavior attributes for computer-controlled agents, which include hostile, non-hostile, selfish, and leader-following behaviors.

Collaborative virtual evacuation drills can also help to see how long it takes emergency responders to report to a certain location and respond to emergency situations. The data collected can be used to educate emergency personnel on how to reduce response times. Emergency personnel can be trained to respond to a variety of emergencies safely and securely without ever being exposed to real-world dangers. The CVE environment for megacity can act as a training tool to assess the amount of information users as avatars actually retained and how equipped they are to respond to an emergency. Police officers and fire safety personnel can act out the procedures to follow in an emergency, which will ensure that they are paying attention and are aware of the proper procedures. Our proposed CVE for megacity may not replace real-world training, but it can be used to supplement training or to refresh skills related to following proper procedure in emergencies.

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