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Collaborative Virtual Reality Environment for a Real-time Emergency Evacuation of a Nightclub Disaster

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Abstract

The increased replication of human behavior with virtual agents and proxies in a multi-user or collaborated virtual reality environment (CVE) has influenced the eruption of scholastic research and training. The capabilities of the user experience for emergency response and training in emergency and catastrophic situations may be highly influenced by the use of computer bots, avatar, and virtual agents. Our contribution and proposal for the concerted collaborated Virtual Reality nightclub environment consequently warrants the flexibility to run manifold scenarios and evacuation drills in reaction to emergency and disaster preparedness. Modeling such an environment is very essential because it helps emulate the emergencies we experience in our routine lives and provide a learning platform towards the preparation of extreme events. The results of the user study to measure presence in the VE using presence questionnaire (PQ) are discussed in detail, and it was found that there is a consistent positive relation between presence and task performance in VEs. The results further suggest that most users feel that this application could be a good tool for education and training purposes.

1. Introduction

Human behavior varies widely during an emergency situation. A significant number of studies have conducted that shows many lives are lost during evacuation exercises in places of public assembly. These include stadia, subways, libraries, public buses, and nightclubs among a host of several others. In 2001, the 'stampede incident' in Ghana took the lives of over one hundred and twenty people. Similarly, the incident at a nightclub in Chicago, IL in 2003 took the lives of about twenty-one people and injured several others and subsequently in 2016 Orlando, nightclub shooting in Florida took the lives of about forty-nine people and a lot more casualties. It must also be noted that in most of these incidents reported, non-adaptive human behavior such as clogging exits and trampling, contribute considerably to fatal injuries and death rather than an actual cause of emergencies such as fire or explosion [1]. It could also be mentioned that there have been some regulatory provisions governing exit designs particularly prescribed in building codes to guide evacuation procedures, but the big questions that stay on our mind are that, are these measures of intervention adequate enough to guarantee human safety during an emergency situation? It is obvious there is much to be desired.

The collaborative virtual reality environment affords us the platform for training purposes and provides useful information to support emergency evacuation personnel to boost efficiency in their professional practice. The results of this study will provide us with useful information on human behaviors under extreme conditions and subsequently afford emergency responders and professionals to engage in a more efficient evacuation procedure and safer decision-making strategies. The effectiveness of the virtual environment has been linked to the sense of presence reported by the users. We have used presence questionnaire (PQ) to measure presence in VE. Knowledge from this study will also serve as a reference to assess the effectiveness of current safety and evacuation processes in order to better strategize to curb injuries and fatalities during a real-life evacuation exercise.

Fig. 1 shows fire explosion and accompanying smoke at the Kiss Night Club disaster

This paper primarily focuses on the modeling simulation of evacuation drill in a collaborated virtual reality environment in real time, the modeled environment is the Kiss nightclub fire in Santa Maria in Brazil (refer fig.1). In order to understand human behavior under such critical circumstance, we have also modeled human behavior with mecanin animation, waypoints algorithm, and programming scripts to better enact similar behaviors experienced in emergency evacuation drill by the live actors. Hostile behavior, non-hostile behavior, and leader following behavior incorporated in virtual agents provide the synergy goal. We have developed two different kinds of modeled environments, Immersive environment and non-immersive virtual environment. The immersive environment makes use of a head mounted display such as the Oculus rift device and enable the provision of sufficient interaction with virtual agents. The non-immersive virtual agents, on the other hand, make use of the joystick, keyboard and mouse to achieve the same objective. Additionally, the collaborated virtual environment is connected to a photon network that has a server and a cloud service. This makes it possible for a user to connect or login and participate in an evacuation drill.

Going forward, it is imperative to conduct a study on human behavior (fear, anger, trust, anxiety, confusion) in such emergency in order to comprehend the thoughts of evacuee in attempts to efficient evacuation processes to minimize injuries and deaths. It is an enormous challenge and almost impossible, to conduct training and studies using live or human actors in a real-time environment of that nature due to the high risk of lives and legal implications, but VR gives a good platform to conduct evacuation drills for emergency response as long as the 'sense of presence' exist. In this way, the use of virtual reality technology in modeling simulated evacuation drill in real time using a multi-user environment or a collaborated virtual reality environment is an excellent platform to understand human behavior during such crisis for learning and training persons during the evacuation. The CVE platform can be used as a training and educational tool by exploring the environment in Virtual Reality. Many will argue that a real-world evacuation drill should be considered for evacuation training but we can only imagine the millions of dollars that will be spent in simulating live evacuation drill in a stadium, in a train, on an aircraft, and in a nightclub not to talk of the risk and person-hours. As indicated by B.Sheridan [2], the use of virtual reality technology is a user-friendly tool for persons that are particularly accustomed to learning using shapes, three-dimensional figures, symbols and colors.

The use of VR technology in emergency exercise will even afford us the opportunity to have an idea and be better informed on the effects of changes in psychological parameters such as anger, stress, and panic during an emergency evacuation. We also stand to gain positive experience through this useful training and education conducted in VR environment as virtual agents interact with environmental factors such as smoke and how they respond to these factors and navigate to their goal.

The rest of the paper is structured as follows. Section II briefly describes the related work for CVE, virtual crowd behavior, disaster evacuation drills in CVE. Section III describes the implementation of the CVE in four phases. Section IV presents the evaluation and results of the user study. It also describes the user study setup and the experimental procedures used to run the experiment. It also contains the evaluation and results from the study. It also includes the post analysis of survey questions and summarizes the user responses. Section VI discusses the limitations of the study. Section V discusses drawn conclusions and proposed future work. Finally, Section VI states acknowledgments.

2. Related Work

As indicated by the Occupational Safety and Health Administration [3], it has explicitly discredited the consistent and conventional nature on how evacuation training is carried out in various environmental settings. It is common to experience individuals ignoring the sounds from alarm and siren in public assembly's example in workplace and schools because many think is a usual occurrence, thus should there be a threat situation there will be the possibility of high levels of causalities. Owing to this the organization deem it appropriate and important for observing routine training designed for a specific setting rather than a blueprint for all. It is also imperative for evacuees to be knowledgeable about potential hazards and emergency equipment in their immediate settings Bernades et al [4]. Over the past few decades, most evacuation training drills are largely limited to drills performed in building facilities as argued by O' Connell et al. [5]. The evacuation drill training in other settings other than the land must not be marginalized. Evacuation simulation drill training in ships and airplanes can be very useful to ship crewmembers and passengers on aircraft. In an attempt to understand evacuees' behavior during the evacuation, a study conducted by Wagner [6] established that persons being evacuated showed lack of confidence and often exhibited hostile behaviors whiles navigating to safety without evacuation assistant or aid. On the contrary, a contrasting observation is made when an evacuation assistant is deployed.

A study conducted by Alemeida et al. [7] gives us an idea of a measure of the responsiveness of the degree to which evacuees comply with safety warning pertaining potential safety hazards in a given environmental setting. Some observation made from this study using a collaborated virtual reality environment showed that half of the participants involved in the exercise confirmed that they read the warning signs about possible falling objects but just about 29% of that population complied with those warning. Virtual agent's behavior modeling gave rise to a significant number of studies and the development of Vi crowd behavior. Crowd behavior focuses on aggregate rather than single or individual behavior Musse et al. [8-10] enacted and modeled three different crowd controlling behavior peculiar to emergency evacuation exercise. These behaviors included reactive behavior, guided behavior and programmed behavior to emulate real-life behaviors experienced in an emergency evacuation situation.

Johnson et al [11] reaffirmed through his studies the positive learning outcomes achieved by learners through the synergy of animated pedagogical agents and difficult learning concepts. Crossland [12] emphasized the importance of emergency training and how it can revolutionaries our thoughts and alleviates stress whilst booting efficiency in working habits among emergency evacuation staff or professionals. Sharma et al. [13] iterated the importance of simulating unique situations that are peculiar to a given emergency occurrence; his proposal included the use of avatar simulation with fuzzy logic incorporated as a component of the avatar. This provides a larger range to various emotions such as panic, stress, and joggling between those emotions with changes in the emotion parameters thus providing an efficient enactment of live emergency evacuation.

According to Wang X et al. [14], Human behavior is an extremely difficult factor to emulate even in real life and in emergency evacuation simulation. In order to study human behavior under a condition such as emergency evacuation, a framework was developed and this fostered the building of a human behavior library achieved through a BIM based cloud gaming environment, this platform afforded participants accessibility to perform an evacuation exercise. As participants connect to the game it has the capability to collect varying behavior experienced during the exercise resulting in a larger pool of data of human behavior. The repository of human behavior library formed the basis of the agent-based modeling, where human behavioral data is captured and added as a component of the virtual agent. The behavior added to the virtual agents in the immersive and non-immersive virtual environments emulate the behavior of humans in the real world thus decisions made by an avatar in such extreme conditions are an exact representation of decisions that would be made by humans.

Nikolai et al., [15], further explained the significance of comprehending behavior under extreme condition such as emergency evacuation coupled with decision making by evacuee amidst the process and its collective impact leading to crowd behavior. They reiterated that a safe evacuation procedure curbing lives lost and fatalities must be premised on profound knowledge on how evacuees make movement decisions in such environment. To consolidate such assertion an experiment was conducted using over five hundred participants in an interactive virtual environment. Three different directional information was provided which included static information such as signs, dynamic information (movement of the simulated crowd), memorized information and combination of this directional information. The focus was to make participants to choose exit routes under the influence of the varying directional information. It was only realized that crowd movement and memorized information did not have a profound effect on the participants exit rout choices in isolation but the combination of the two together with signs did. This attests to the behavior of participant's observing keenly on signs during such catastrophic situations. Sharma et al. [16] also emphasize on the usefulness of computer simulations, it presents a user-friendly interface using powerful virtual tools to conduct evacuation drills in real time that are otherwise very difficult costly and dangerous to conduct in the real world. Simulation over several decades has evolved as an important tool for emergency response and is very central in assessing the vulnerability of a space as well as for training, planning, and decision-making.

Sharma et al [17] further explained in a study conducted the importance of combining genetic algorithm with neural networks and fuzzy logic to assess how intelligent virtual agents can readily adapt behavior attributes assign to them. The adaptive behavior is centered on the ease with which a virtual agent will respond to changing changes in the environment. This is an attempt to provide a modeled agent that will emulate precisely realistic human emotional behavior under normal emergency conditions.

According to Lindell, Prater and Wu [18] preparation and warning times in evacuation time analysis are central to a successful evacuation. A study conducted by Lindell and Perry [19] emphasized the relevance of evacuation planning in emergency management. Additionally, this research paper highlights the relevance of gaining useful information on crowd behavior and using that knowledge to enhance evacuation drill processes. Bowman et.al [20-21] reiterated how crowd behavior affects evacuation drill by employing the use of VR gaming approach. Sharma [22] has also explained the use of virtual reality agents in a simulated environment for the study of human behavior attributes during an emergency situation has significantly instigated a compelling need in educational research largely in disaster preparedness. He further explained that modeling such an environment can be used as a platform for training and decision making among fire responders, traffic clearance, swat teams and other emergency responders.

Sharma et al. [23] have indicated that there has been a surge in interest in the use of virtual reality platforms for learning and training purposes. He explained the importance of understanding modeled emotions such as anger, panic, and stress shown during extreme events and emergencies. This was made possible through the use of the fuzzy logic application and subsequently integrated into the avatar as a component within the virtual environment. This was evident in his research carried out for simulation of panic behavior in a library building. Again Sharma et al. [24] have established the importance of virtual agent's possibility to easily exhibit their adaptive behavior tendencies, with changing environmental conditions to emulate real-world behaviors. Virtual agents are able to show fear and panic behavior attributes when there is a fire outbreak in the modeled environment. This behavior is made possible through the employment of genetic algorithm with neural network together with fuzzy logic. Sharma et al. [25] have indicated that the use of computer simulations is obviously a desired tool for experimentations and training for emergency and disaster evacuation drills because it eliminates the risk of the dangers exposed by using live actors. They are also inexpensive and do not pose the risk of legal issues relative to conducting a live evacuation drill. Additionally, Sharma et al. [26] have also incorporated a goal-oriented artificial agent-based model to emulate human behavior parameters. This artificial intelligence collectively employed fuzzy agent–based, geometric and social force models. According to Sharma et al. [27], emulating group behavior through the use of an avatar is important and provides very useful data for emergency responders to assist in training personnel and making evacuation decision strategies. He conducted a study by modeling group behavior that emulates human behavior attributes such as emergent human social behaviors including queuing and herding behaviors. Sharma et al. [28] pointed out the usefulness of integrating virtual systems for battlefield simulations that have enemies' outpost and minefields in a multi-agent system. The data collated and findings from the simulations assist commanders in devising strategic planning and also affords them an opportunity to prescribe remedial measures for anticipated challenges.

3. Implementation of the CVE

The collaborated/multiuser virtual reality environment was developed using Unity 3D gaming engine software and sketch up application software, whiles virtual agents were also modeled using the make human application software. The concerted modeled environment makes use of photon network that enables cloud connectivity and multi-user capability. With cloud connectivity, a participant has an option to engage other computer bots as a virtual agent. The implementation was done for both immersive environments as well as the non-immersive environment. With non-immersive environment participants are able to navigate to their goals using a desktop computer, joystick and keyboard while the immersive environment makes use of the head-mounted device, the HTC vive that give the participant a complete immersion of the modeled nightclub. The HTC vive technology provides the capability platform for a user to be fully immersed in the CVR kiss nightclub environment and interact with the environment. The implementation of the nightclub CVE was done in five phases**:**

3.1 Phase I: Modelling and Unity 3D

We have created a realistic environment by using UNITY 3D gaming engine, 3D max, and google sketch up for the modeling platform. The environment has been modeled to scale using data from the internet on the actual dimensions of the Kiss nightclub. We have incorporated C# behavior scripts, looping, and key triggered animations, and implementation of RAIN Navigation (AI scripts) to create behavior attributes for both user and computer controlled agents.

Fig. 2: shows some of the virtual agents running to safety

Programming virtual agents and some virtual objects were central in achieving the desired evacuation drill results. The use of intelligent signs and some consistent colored light flickering functionality to emulate nightclub setting was made possible through C# programming. The lightening of ambulances together with environmental hazards such as smoke and fire were all-possible through programming and written algorithm. Fig. 2 shows the modeled kiss nightclub with smoke and fire with the virtual agents navigating to safety. The modeled virtual agent in the concerted CVR environment had waypoint algorithm attached as a component to enable them to navigate towards their goal in the environment. The collective interactions by the agents and the environmental hazard provided a more realistic feel for both immersive and non-immersive participants.

3.2 Phase II: User and Computer Controlled Agent Behavior

The sense of presence and reaching an adequate belief that the CVR environment is real is very central to the research work. Subsequently, as drills can be performed it will guarantee the safest and efficient evacuation procedures are followed to curtail fatalities and casualties. It is also imperative to factor behaviors of evacuees as it has an overwhelming tendency to affect the evacuation process. This subsection of the paper discusses the aggregate behavior such as hostile, non-hostile and wandering behavior that are commonly experienced during an emergency evacuation.

Evacuation usually follows a simple sequence such as detection, reaction and most important decision making. During catastrophic situations such as fire evacuation, chances are that evacuee's motions are randomized leading to crowd stampede and clogging of exits. Behaviors such as panic, wondering and even anger are predominantly discernible among a host of other behaviors. This section of the paper discusses how these behaviors are achieved. A section of the computer bots are made to be hostile, their hostility is seen in their distraction and detraction tendencies coupled with their level of aggression. They are seen to deviate from the intended evacuation procedure, pushing other virtual agents, abject refusal to cooperate with emergency responders, displaying intense state of panic and totally confused. Virtual agents that are assigned non-hostile behavior are non-aggressive much more cooperative, guided and coordinated movement, and they show high cooperation to emergency responders and goal following behavior as they navigate through the environment. Some of the computer bots through programming and written algorithm in addition to the incorporation of sensors assume the leader following behavior, by virtue of this capability. Controlled users or participants who navigate within the range of proximity of the avatar that has the leader following behavior, will eventually follow that avatar. Additionally, the computer bots that are assigned selfish behavior usually give misleading and mixed messages, which leave the user-controlled agent to decide whether to use the information provided or ignore the information or use discretion to make a decision on which route to pursue.

3.3 Phase III: Photon Unity (CLIENT/SERVER) Networking

Multiple users' participation, engagement, and communication is achieved through photon cloud network (plug-in). Photon unity networking capability affords participants from any part of the globe to connect to the CVE environment via the internet. As indicated in fig. 3 the CVE kiss nightclub is connected to the clusters of servers on the photon cloud network. Users are able to create a room on the server using a unique application ID numbers to connect to the environment. Other users/players are also able to join the room to participate in the drill. Once a full connection is established, the photon network makes it possible for all users to view and engage other virtual agents in real time. Additional functionality as communication channel makes it possible for participants to communicate amongst themselves.

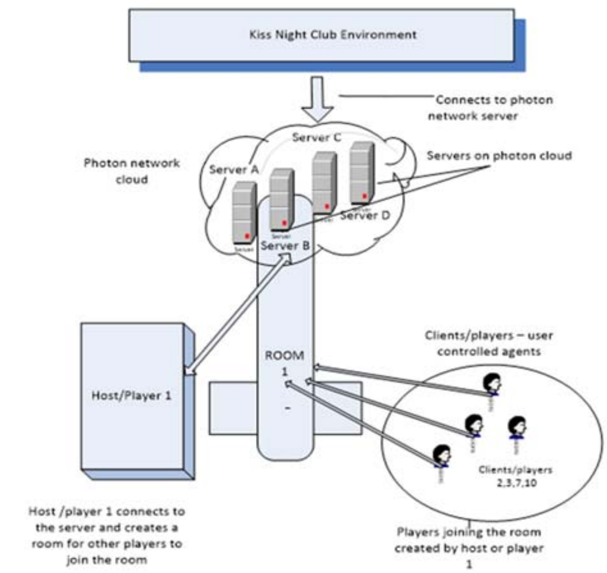

Fig. 3: Photon Server/ Client Cloud Networking for CVR kiss Nightclub

3.4 Phase IV: Implementing of the Immersive environment using HTC Vive

HTC Vive

The components of the HTC Vive (an immersive VR system) include an HMD, two hand controllers (for bilateral hands) and motion –tracking base stations. The display is generated from the computer by the HMD whereas the base stations (located within a particular distance from each other), define the play area within which the user's motions can be emulated in the set environment. There is consistent communication between the HMD and the base stations in order to track the position and orientation of the user within the environment. Tracking of the user's movement is also possible from the inbuilt sensors into the HMD. The hand controllers serve as an interactive tool with the design objects within the application. The controllers are used for choosing and orchestrating objects via the use of a virtual laser to guide the user. The left and right controllers are used for generating the menus and selecting the objects from the menu for navigation respectively.

Fig. 4: Menu for the left controller

Menu design

The menu design includes options for turning the water on and off, fire on and off, evacuation on and off as well as an option for restarting the application. Fig. 4 shows the menu option to trigger smoke and fire in the modeled environment using the two controllers. The 'water-on' option enables a fire brigade to throw water on the nightclub fire. The left controller is attached to the menu, whereas the right controller is used for selection.

Fig. 5: HTC Vive Controller with menus for selection

The water-off and fire-off options stop the dispensation of the water and fire respectively. The evacuation option triggers the evacuation process for the virtual agents. Fig. 5 shows the CVE nightclub environment with fire and smoke.

Grabbing

Users in the nightclub virtual environment can grab 3D objects using the HTC Vive hand controllers. The trigger button situated on the right controller is used to place objects in their preferred locations by selecting, holding, dragging and releasing the trigger as shown in fig. 6.

Fig. 6: Grab option for right-hand controller

4. User Study, Evaluation, and Results of CVE

Virtual Reality (VR) environments for disaster training and response appears promising in its ability to bridge the gaps of other commonly established training formats. Specifically, the immersive nature of VR training offers a unique realistic quality that is not generally present in a classroom or web based training. This work primarily establishes the possibility of conducting evacuation drills in a collaborated virtual environment in an attempt to provide useful information for disaster preparedness and response in a more efficient and safer way to curb lost lives and injuries. We have demonstrated our approach-using user controlled agents and computer controlled agents (computer bots) in CVR environment nightclub. The environment also has smoke and fire incorporated and the presence of it agitates the triggered response for the computer bots causing the virtual agents to readily display their attributed behaviors such as the hostile, non-non hostile, selfish, leader following, panic, anger, wondering among other behaviors. The use of the head mounted display afforded participants to be immersed in the kiss nightclub environment. The users are then able to completely interact with other avatars and move around the environment autonomously.

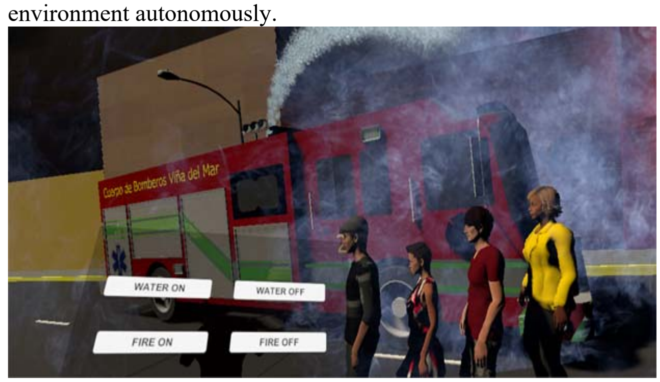

Fig. 7: HTC Vive Controller used to turn ON the fire and smoke

4.1 User Study

This section discusses the user study setup. It then provides details on the general test setup, the procedures, and the post-analysis survey to run the experiment. We have used presence questionnaire (PQ) to measure presence in VE. Finally, it discusses the results of the post-analysis survey. The goal of this user study was to allow a user to navigate inside the nightclub disaster immersive environment using HTC vive and controllers. The user had the ability to start fire and smoke, start the evacuation, put off fire, pick up safety cones and place them, and navigate in the environment. The purpose of the study was to collect data for users of different ages (above 18 years) who participated in the virtual reality nightclub disaster environment. We performed the user study for the immersive environment using HTC vive to measure the sense of presence in the immersive virtual environment.

As a preliminary study, a group of 21 people participated in the experiment. Some of the participants had significant experience using immersive interfaces such as the Oculus Rift and the HTC vive. The participants were not paid for the user study, and their participation was voluntary. Adult participants (above 18 years of age) were selected from the campus. Participants were faculty, staff, students, and visitors on campus. The participants were recruited through the use of posted flyers around the campus. The users were asked to participate in the immersive environment for the simulated evacuation of a nightclub disaster application scheduled for a 10–15-minute session. Upon arrival, the participants were explained the study procedures and how to navigate inside the virtual environment. First, each user stood in front of a computer configured with the VR application. The setup involved an immersive environment that allowed the user to use the HTC Vive HMD to get the immersive experience and to control the camera POV. The user was able to use the controllers to move around in the environment. The controllers also had the transport facility to transport themselves to a different location by clicking the controller. However, the users were recommended to use the navigation option (to move forward, left, and right). During the session, the participants navigated in the virtual environment by avoiding obstacles on their way autonomously. After the task was complete, the participants were given a demographic questionnaire, including questions on their technical experience.

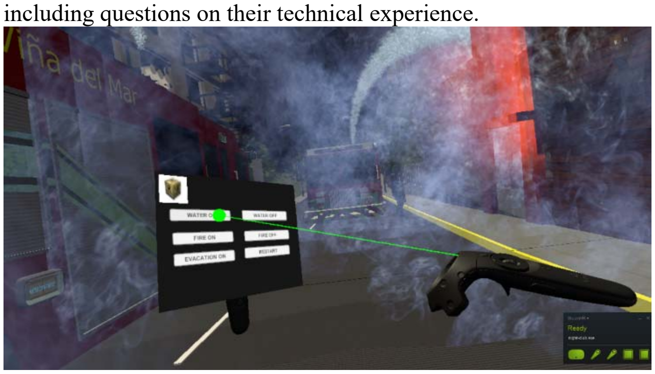

Fig. 8: Turning water on through the HTC vive controller.

In addition to demonstrating that evacuation, drills can be performed in CVR environment. It is also equally imperative to acknowledge that we can gather valuable data on human behavior in such emergency. Emergency responders will benefit from efficient evacuation procedures that can inform safer decision-making strategies. Fig. 7 shows people exiting out from the nightclub. It also shows the fire brigade throwing water on fire and smoke. Fig. 8 shows the menu attached to the left controller. The right controller is used to trigger the water on.

4.2 Evaluation

This section covers the evaluation questions, the collected data, and a summary of the results. As expected, the results from our user study confirmed our prior assumptions, showing that the use of an HMD (HTC VIVE) improves the overall task performance and gives the user a sense of presence in the environment during a disaster event.

TABLE I. Survey Questions and Results

Questions	Results – Raw Data			Average Score
1. What is your age?	18-24 25-34 35-44 45-54 55-64 65-above	3 1 2 5 1 0 0	14.29% 57.14% 23.81% 4.76% 0.00% 0.00%	
2. What is your gender?	Male Female	1 6 5	76.19% 23.81%	
3. Can this application be used for educational or training purposes?	NOT AT ALL X X SOMEWHAT X X COMPLETELY	3 0 0 1 5 6 6	14.29% 0.00% 0.00% 4.76% 23.81% 28.57% 28.57%	5.23
4. How much were you able to control events?	NOT AT ALL X X SOMEWHAT X X COMPLETELY	0 0 0 3 5 9 4	0.00% 0.00% 0.00% 14.29% 23.81% 42.86% 19.05%	5.66
5. How responsive was the environment to actions that you initiated (or performed)?	NOT RESPONSIVE X X MODERATELY RESPONSIVE X X COMPLETELY RESPONSIVE	0 0 1 2 4 7 7	0.00% 0.00% 4.76% 9.52% 19.05% 33.33% 33.33%	5.8
6. How much did the visual aspects of the environment involve you	NOT AT ALL X X SOMEWHAT X X COMPLETELY	0 0 2 2 4 6 6	0.00% 0.00% 10.00% 10.00% 20.00% 30.00% 30.00%	5.33
7. How natural was the mechanism which controlled movement through the environment?	EXTREMELY ARTIFICIAL X X BORDERLINE X X COMPLETELY NATURAL	1 0 0 3 4 1 0 3	4.76% 0.00% 0.00% 14.29% 19.05% 47.62% 14.29%	5.42
8. How compelling was your sense of agents moving toward the exist during evacuation in the virtual environment?	NOT AT ALL X X MODERATELY COMPELLING X X VERY COMPELLING	0 0 2 4 6 5 4	0.00% 0.00% 9.52% 19.05% 28.57% 23.81% 19.05%	5.23
9. How much did your experiences in the virtual environment seem consistent with your real world experiences?	NOT CONSISTENT X X MODERATELY CONSISTENT X X VERY CONSISTENT	0 1 2 5 0 4 9	0.00% 4.76% 9.52% 23.81% 0.00% 19.05% 42.86%	5.47
10. Were you able to anticipate what would happen next in response to the actions that you performed?	NOT AT ALL X X SOMEWHAT X X COMPLETELY	0 2 1 4 3 5 6	0.00% 9.52% 4.76% 19.05% 14.29% 23.81% 28.57%	5.28
11. How compelling was your sense of moving around inside the virtual environment?	NOT COMPELLING X X MODERATELY COMPELLING X X VERY COMPELLING	0 0 2 4 5 6 4	0.00% 0.00% 9.52% 19.05% 23.81% 28.57% 19.05%	5.28
12. How closely were you able to examine objects?	NOT AT ALL X X PRETTY CLOSELY X X VERY CLOSELY	0 0 1 4 1 6 8	0.00% 0.00% 5.00% 20.00% 5.00% 30.00% 40.00%	5.52

13. How well could you move or manipulate objects in the virtual environment?	NOT AT ALL X X SOMEWHAT X X EXTENSIVELY	0 0 2 2 6 4 7	0.00% 0.00% 9.52% 9.52% 28.57% 19.05% 33.33%	5.57
14. How much delay did you experience between your actions and expected outcomes?	NO DELAYS X X MODERATE DELAYS X X LONG DELAYS	1 0 1 2 4 0 3 1	47.62% 4.76% 9.52% 19.05% 0.00% 14.29% 4.76%	2.80
15. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?	NOT PROFICIENT X X REASONABLY PROFICIENT X X VERY PROFICIENT	0 1 1 4 3 3 9	0.00% 4.76% 4.76% 19.05% 14.29% 14.29% 42.86%	5.57
16. How helpful was HTC Vive for the user experience	NOT AT ALL X X SOMEWHAT X X COMPLETELY	0 0 2 4 3 4 7	0.00% 0.00% 10.00% 20.00% 15.00% 20.00% 35.00%	5.23
17. Were you involved in the experimental task to the extent that you lost track of time?	NOT AT ALL X X SOMEWHAT X X COMPLETELY	3 0 2 2 2 6 5	15.00% 0.00% 10.00% 10.00% 10.00% 30.00% 25.00%	4.66

The PQ use a seven-point scale format that is based on the semantic differential principle by Dyer et.al. [29] and Bailey & Witmer [30]. The PQ instructions asked respondents to place an ''X'' in the appropriate box of the scale in accordance with the question content and descriptive labels. An exemplary item from the PQ is shown in Fig. 9.

7. How natural was the mechanism which controlled movement through the environment?
|________|________|________|________|________|________|________|
EXTREMELY ARTIFICIAL   BORDERLINE   COMPLETELY NATURAL

Fig. 9. An exemplary item from the Presence Questionnaire.

Table I lists the post-analysis survey questions and summarizes the user responses. The first two questions request the user age and gender. The remaining questions were designed to measure the overall feeling the user had toward operating in the immersive environment based on PQ. Considering seven-point scale format, it is possible to calculate the average between 1 and 7 for each question. Column average score in table 1 represents the same average score for questions 3 to 17.

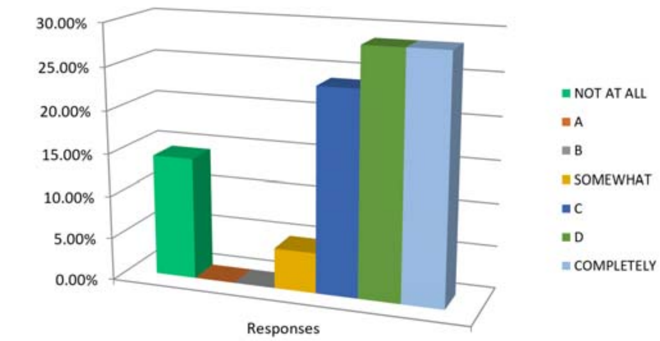

Fig. 10: Shows positive users feedback on can this application be used for educational or training purposes?

Data Implications

As seen in the Table 1 data, the population consisted of 76.19% male and 23.81% female. Seventy-one percent (71%) of all users were age 34 or younger, and the remaining 29% were 35 to 54 years old. All the participants reported that the head movement camera control is natural and intuitive and required short adaptation times. Fig. 10 shows if this application can be used for educational or training purposes to support emergency evacuation personnel to boost efficiency in their professional practice. Overall, one can see that the users were generally receptive to this application. The users found it particularly compelling to moving around inside the virtual environment as indicated by responses to question 11.

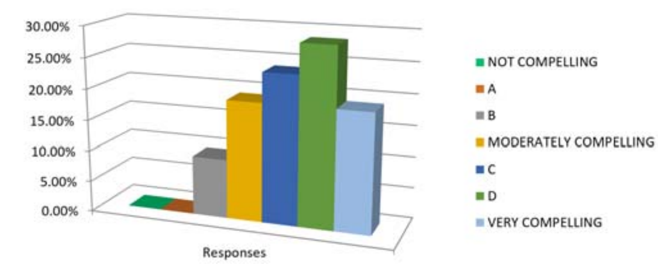

Fig. 11: Shows positive users feedback on how compelling was the sense of moving around inside the virtual environment?

Fig. 11 show that 90% of the participants in the user study found that it was compelling to moving around or navigate inside the immersive virtual environment.

5. Conclusions and Future Work

The conventional performance-based test, especially fire emergency evacuation drill is obviously expensive to perform in the real world due to challenges with safety issues, accompanying risk and legal aspects. It is even more difficult and complex to gather real-life data for useful analysis amidst such emergencies. It is, therefore, a step in the right direction to engage virtual reality technology for evacuation drill training to suffice efficient strategies in catastrophic situations to prevent injuries and fatalities. Regarding the survey questionnaire, the prominent results can be summarized as follows:

- 90% of the participants found it compelling to view the agents moving toward the exist during the evacuation in the immersive virtual environment?

- 90% of the participants found it compelling to moving around or navigate inside the immersive virtual environment?
- 90% of the participants found it easier to move or manipulate objects in the virtual environment?
- 95% of the participants found it easier to examine or pick up the objects in the environment through the HTC vive controller?
- 95% of the participants found themselves proficient to move and interact in the virtual environment at the end of their experience?
- 90% of the participants found it HTC Vive user experience helpful.

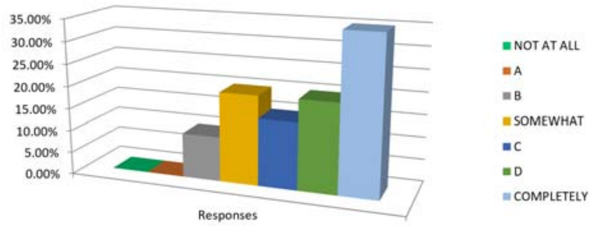

Fig. 12: Shows positive users feedback on how helpful was HTC Vive for the user experience

As stated earlier, a preliminary user study was performed from a group of 21 participants who participated in the experiment. Some of the participants had significant experience using immersive interfaces such as the Oculus Rift and the HTC vive. Fig. 12 shows a positive feedback from the participants of the user study on the user experience of navigating in the immersive VR environment using HTC Vive. The proposed CVR environments make use of emulated behavior in the emergency by defining rules for computer bots, additionally, controls are given to participants as virtual autonomous agents to navigate the environment and finally controls with keyboard and head mounted display in real time. The analyses of these combination controls make it possible to better understand human behavior under such extreme catastrophic conditions. Knowledge and data obtained by performing the evacuation drill in the CVR kiss nightclub will facilitate a more efficient evacuation procedure. Emergency responders get to benefit from education on time management during 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 evacuation drill in real life more efficiently.

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