Iyer, S. et al. (Eds.) (2022). Proceedings of the 30th International Conference on Computers in Education.
Asia-Pacific Society for Computers in Education

Immersive Function for Allocating Disaster Situations for a VR-based Evacuation Training System

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Abstract: In this paper, we describe an immersive function that annoys evacuation trainees by enabling an evacuation training designer, which is used to easily allocate disaster situations (e.g., fire and debris), in a virtual reality-based evacuation training system. This immersive function uses a head-mounted display and intuitive controllers to meet requirements, such as high immersiveness. Through a preliminary comparative experiment, we discovered that the immersive function can effectively annoy the trainees despite having insufficiency, such as weak expression of time-variable disaster situations.

Keywords: Disaster situations, evacuation training, head-mounted display, virtual reality

1. Introduction

We must prepare to survive unpredictable natural and artificial disasters. For example, evacuation training is common preparedness. However, traditional evacuation training is not always effective for successful evacuation during real disasters because of its monotonousness. Therefore, participants in traditional evacuation training must concentrate on following a predetermined evacuation route and will not be given opportunities to think regarding how to evacuate. Thus, evacuation training should make disaster situations expressed realistically to prompt thinking regarding how to evacuate. Real-world evacuation training has difficulty simulating disaster situations (e.g., fire and debris) to ensure participant safety. We must explore another evacuation training approach to eliminate this difficulty, and using virtual reality (VR) is a promising approach. VR-based evacuation training can ensure participant safety and can realistically express disaster situations in a virtual world.

It has been used in numerous instances (Khanal et al., 2022). In particular, it has been actively integrated into serious games. For example, an immersive VR serious game (IVRSG) for earthquake evacuation training promotes reflection-in-action while focusing on immediate feedback and spiral narratives (Feng et al., 2022). An IVRSG for school fire preparedness (e.g., evacuation and extinguisher usage) expresses fire emergency realistically using a cave automatic virtual environment and a fire dynamics simulator (Mystakidis et al., 2022). From another perspective, VR can be used to analyze human behavior for successful evacuation during disasters. For example, wayfinding behavior in a multilevel building was analyzed between head-mounted displays (HMD) and desktop VRs (Feng et al., 2022). Another research revealed that route choices during evacuation were affected by the behavior of their neighbors (Fu et al., 2021). Mitsuhara et al. (2021) focused on observing participant behavior during an earthquake in a virtual world. They prototyped a VR-earthquake-simulator system, where an earthquake suddenly occurred in a virtual world and disaster situations were generated at allocated locations (for fires) or based on a simple physical simulation (for objects scattered by shakes). Considering how to extend the prototype system to VR-based evacuation training, we found that disaster situations should be allocated at intended positions in the virtual world to annoy participants during evacuation. Such annoyance indicates that the participants encounter dangerous situations by prompting them to think of how to avoid these situations while making evacuation training impressive.

On the basis of this background, we implemented an immersive function for allocating disaster situations in a simple VR-based evacuation training system. In this function, an evacuation training designer wearing an HMD allocates disaster situations by pointing at the position using intuitive controllers.

2. Requirements

The immersive function aims to satisfy the following requirements that annoy participants during evacuation:

1. Providing high immersiveness.
2. Easily allocating disaster situations to intended positions.
3. Expressing time-variable disaster situations.

Requirement 1, which is satisfied using an HMD and intuitive controllers, is important because it allows an evacuation training designer to allocate disaster situations subjectively while making the designer feel like a participant. Requirement 2, which is related to Requirement 1, is satisfied by enabling the designer to point out the intended positions of disaster situations using controllers. Requirement 3, which simulates real disaster situations (e.g., fire spread), is satisfied by designating time-variable data to disaster situations.

3. Function Overview

We adopted Oculus (/Meta) Quest 2 as the HMD and intuitive controller. The implementing environment was Unity with tool sets or assets, such as Android Software Development Kit, Native Development Kit, Java Development Kit, and Oculus Integration.

3.1. Virtual World

A virtual world is required to allocate disaster situations. Currently, the immersive function focuses on outdoor evacuation training, where participants evacuate to a safe building. This means that a three dimensional (3D) city model with at least buildings and roads is required. However, creating such a 3D city model from scratch is difficult. Therefore, we adopt an open-data city model provided by the PLATEAU project, which is organized by the Ministry of Land, Infrastructure, Transport, and Tourism Japan (see https://www.mlit.go.jp/plateau/ for details). To optimize the city model for Oculus Quest 2, we transformed the city model to Filmbox format and performed mesh integration and polygon reduction for lightweight processing. Furthermore, we applied Occlusion Culling for minimum rendering when Unity rendered the city model.

3.2. Disaster Situations

The immersive function processes allocated disaster situations as a scenario associated with a virtual world. The scenario is an aggregate of the allocated disaster situations. Each disaster situation has a position (x, y, and z in Unity coordinates) and a rotation angle in the scenario. The immersive function provides six types of disaster situations (Table 1 and Figure 1). Each type can be allocated to the ground and/or building wall. Currently, only fire varies (slightly spread) according to time passage. This scenario is recorded as an Extensible Markup Language (XML) file and loaded later into the system.

Table 1. *Allocatable Disaster Situations*

Disaster Situation	Allocatable Position
Fire	Ground and Wall
Explosion	Ground and Wall
Injured Person	Ground
Rain (Rain Drops)	Ground
Smoke	Ground and Wall
Debris	Ground

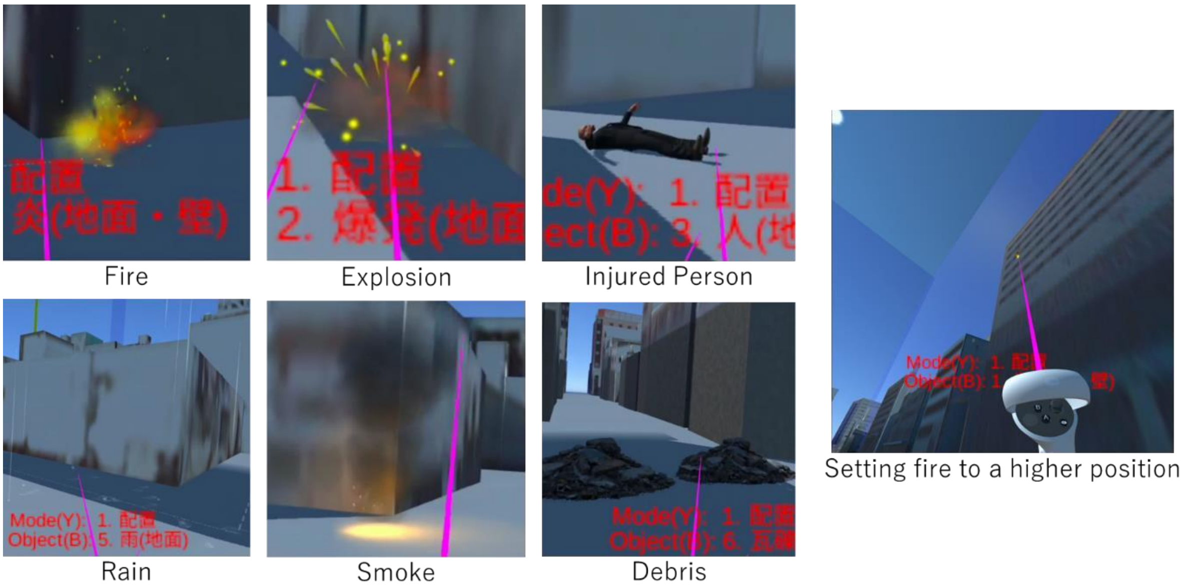

Figure 1. Screenshots of disaster situations allocated in a virtual world.

3.3. Usage

An evacuation training designer wears an Oculus Quest 2 and activates its immersive function. The designer allocates disaster situations along with the following flow:

1. Create a new scenario or select a loadable scenario.
2. Walk through the virtual world (corresponding to the scenario) by operating a joystick on the controllers.
3. Press the Y button to change the mode among *Allocate*, *Delete*, and *Instructions*. Currently, the immersive function allows the designer to only delete the last-minute allocated disaster situation. All disaster situations can be deleted by repeating this deletion.
4. Press the B button to select a disaster situation to be allocated.
5. Point the position to allocate the selected disaster situation inside the screen of the designer using laser pointers, which are emitted from the rendered bottom of the controllers. When allocating fire, explosion, or smoke to a higher position, the designer points the position upward (shown in the rightmost screenshot in Figure 1).
6. Press the A or X button to allocate the selected disaster situation. Disaster situations, such as fire, explosion, and rain, entail sounds that become louder as a participant moves closer to the disaster situation.

4. Preliminary Experiment

In February 2022, we conducted a small-scale preliminary comparative experiment at Tokushima University (a Japanese national university located in a coastal area facing the Pacific Ocean) to examine whether the immersive function performs as intended. In this experiment, a virtual world was created from the 3D city model of Numazu (a Japanese city located in a coastal area facing the Pacific Ocean), which was provided by the PLATEAU project.

4.1. Settings

4.1.1 Participants

The participants were 12 university students who were unfamiliar with disaster management or Numazu city. They were divided randomly into two groups:

- ★ Group A (N = 6): participants, as evacuation training designers, were required to allocate disaster situations to three areas in the virtual world.
- ★ Group B (N = 6): participants, as evacuation trainees, were required to evacuate from designated start to designated goal locations (safe buildings) in the three areas, which include disaster situations allocated by Group A participants.

4.1.2 Procedure

(1) Group A

Each of the Group A participants used three different allocation methods to allocate disaster situations in three areas.

- ★ Method A: they allocated disaster situations using the immersive function while wearing Oculus Quest 2 in a flat space of approximately 3 m × 3 m inside a soundproof room (Figure 2-a).
- ★ Method B: they allocated disaster situations using a desktop personal computer (i.e., the allocating function, which consists of a keyboard-and-mouse operable 3D view) and a general liquid crystal display (LCD), which are set in a student room of approximately 20 m × 5 m (Figure 2-b). They moved around the virtual world via keyboard operations. Then, they changed their eye direction and pointed to the allocating position via mouse operations.
- ★ Method C: they wrote disaster situations (e.g., fire and debris) on a paper Numazu map, which was set on a table in a soundproof room (Figure 2-c). They were allowed to allocate disaster situations only to the ground. We allocated the written disaster situations to the virtual world. A different area in Numazu city was assigned for each method. However, the linear distance between the start and goal locations was unified at 250 m for all areas. The area and the cityscapes had almost the same sizes. Group A participants were prompted to allocate disaster situations that could annoy evacuation trainees (i.e., Group B participants) in the VR-based evacuation training. Creating dead ends was allowed but not promoted.

To eliminate the order effect, each Group A participant completed the allocation tasks in a different order (Table 2). During the tasks, we video-recorded the screen for Methods A (Oculus Quest 2), B (LCD), and the map for Method C. There was no time limit to complete the tasks, and the participants answered a questionnaire after the tasks.

Table 2. *Order for Allocating Methods (Areas) Imposed on Group A Participants*

Participant	Order
A1	A ❼ B ❼ C
A2	A ❼ C ❼ B
A3	B ❼ A ❼ C
A4	B ❼ C ❼ A

A5	C ❼ A ❼ B
A6	C ❼ B ❼ A

(2) Group B

Each of the Group B participants wore Oculus Quest 2 and performed evacuation (i.e., moved from the start to the goal location) in the three areas based on a sequential order to allocate methods (areas) similar to the corresponding participants. For example, participant B1, who corresponds to participant A1, completed evacuations in the sequential order of Methods A, B, and C (i.e., Areas A, B, and C). We video-recorded the screen of the Oculus Quest 2 during the evacuations. The participants answered a questionnaire regarding the evacuation each time they completed an evacuation. They responded to the questionnaire, which asked regarding the overall VR-based evacuation training, after completing the last evacuation.

Figure 2. Snapshots of the three allocation methods and the Numazu map that illustrates the areas.

4.2. Results

(1) Group A

Table 3 shows the quantitative data of the Group A participants in each allocation method. Task time duration (TTD) indicates the time (seconds) that each participant spent completing the allocation task. The number of allocated disaster situations (NADS) indicates how many disaster situations each participant provided in an area. The number of reallocation times (NRT) indicates how many disaster situations the participant deleted by quickly changing their positions. The mean values of TTD were 507.3, 413.1, and 239.0 s for Methods A, B, and C, respectively. Here the mean value of Method A was approximately twice that of Method C. The mean values of NADS were 77.5, 48.2, and 9.5 for Methods A, B, and C, respectively. Here, the mean value of Method A was approximately eight times that of Method C. The mean values of NRT were 5.5, 1.0, and 0, respectively. Here, the mean value of Method A was the highest.

Table 4 shows the results of the questionnaire given to Group A participants. The mean value of a five-degree Likert scale question (QA1) was 4.2. The mean ranks based on items (QA2–QA5) were remarkably inconsistent.

Table 3. *Quantitative Data for Group A Participants*

Participant	Method A (Area A)			Method B (Area B)			Method C (Area C)		
	TTD	NADS	NRT	TTD	NADS	NRT	TTD	NADS	NRT
A1	647	130	0	674	89	0	335	13	0
A2	939	168	29	573	73	2	397	9	0
A3	338	36	0	354	16	0	220	8	0
A4	459	8	5	372	30	0	143	9	0
A5	415	62	0	385	44	1	264	11	0
A6	246	61	0	121	37	3	75	7	0
Mean	507.3	77.5	5.5	413.1	48.2	1.0	239.0	9.5	0
SD	250.4	60.0	11.2	192.3	27.5	1.3	119.3	2.2	0

Table 4. *Questionnaire Results for Group A Participants*

Likert Scale Question ~~(Option = 1: Strongly disagree, 2: Disagree, 3. Neutral, 4: Agree, 5: Strongly agree)~~	Mean
QA1. Do you think you allocated disaster situations that annoyed the evacuation trainees?	4.2

Mean rank by item			
Please provide a rank (1–3) for the allocation methods.	Mean rank by methods		
	A	B	C
QA2. How about high immersiveness?	1.2	1.8	3.0
QA3. How about high operability?	1.8	1.8	2.0
QA4. How about highly easy?	2.2	1.8	1.5
QA5. How about high enjoyment?	1.5	1.8	2.5

(2) Group B

Table 5 shows the quantitative data of Group B participants for each allocation method. Evacuation time duration (ETD) indicates the time (seconds) that a participant spent to complete the evacuation. The number of disaster situation encounters (NDSEs) indicates how many disaster situations the participant observed during evacuation. We counted NDSE manually from the video-recorded screens, and two or more disaster situations allocated to the same position were counted as one disaster situation. The mean values of ETD were 148.1, 103.6, and 131.5 s for Methods A, B, and C, respectively. Here, the mean value of Method A was the highest. The mean values of NDSE were 5.7, 4.7, and 4.3 for Methods A, B, and C, respectively.

Table 6 shows the results of the questionnaire (five-degree Likert scale questions) given to Group B participants. The mean values of QB1, which was asked after completing each evacuation, were 3.7, 2.3, and 3.3 for Methods A, B, and C, respectively. Here, the mean value of Method A was the highest. The mean values of QB2–QB9, which were asked after completing the last evacuation, were higher than 3.0.

Table 5. *Quantitative Data of Group B Participants*

Participant	Method A (Area A)		Method B (Area B)		Method C (Area C)	
	ETD	NDSE	ETD	NDSE	ETD	NDSE
A1	140	13	117	8	109	5
A2	433	10	60	3	127	5
A3	118	3	67	3	63	5
A4	66	3	160	6	103	4
A5	67	2	171	5	280	5

A6	65	3	47	3	107	2
Mean	148.1	5.7	103.6	4.7	131.5	4.3
SD	143.0	4.6	53.5	2.1	75.7	1.2

Table 6. *Questionnaire Results for Group B Participants*

Likert Scale Question (Option = 1: Strongly disagree, 2: Disagree, 3. Neutral, 4: Agree, 5: Strongly agree)	Mean		
	A	B	C
QB1. Do you think you were annoyed until you reached the goal?	3.7	2.3	3.3

Likert Scale Question (Option = 1: Strongly disagree–5: Strongly agree)	Mean
QB2. Do you think you felt immersed during the evacuation training?	3.8
QB3. Do you think you felt urgent during the evacuation training?	3.2
QB4. Do you think you felt scared during the evacuation training?	3.7
QB5. Do you think you felt uneasy during the evacuation training?	3.3
QB6. Do you think you felt happy during the evacuation training?	3.5
QB7. Do you think you easily operated the first-person view avatar?	3.5
QB8. Do you think you comfortably viewed the screen?	4.2
QB9. Do you think you increased awareness of disaster management by participating in the evacuation training?	3.8

4.3. Consideration

(1) Group A

The mean values of all items in the quantitative data decreased on the order of Methods A, B, and C. For TTD, the mean value of Method C was remarkably lower than the values of Methods A and B. Although the low mean value indicates efficient allocation, the mean value of Method C was remarkably lower than the values of Methods A and B for NADS. These results may indicate that for Methods A and B, the participants concentrated on thinking and allocating disaster situations. The participants did not reallocate disaster situations for NRT in Method C. Although the mean values were not necessarily high even in Methods A and B, the former can be the easiest method to reallocate (i.e., allocate and delete) disaster situations. Because of the time of presenting QA1, we could not identify the method that was most effective for allocating annoying disaster situations. However, the high mean value indicates that every method made the participants feel capable of allocating disaster situations. This indicates that the quantitative data can be used to evaluate the methods. It can be determined from TTD and NADS that Group A participants required approximately 6.5, 8.6, and 26.5 s to allocate each disaster situation in Methods A, B, and C, respectively. Therefore, we assume that Methods A and B prompted the allocation, which resulted in an efficient allocation. However, Method C did not prompt or entail difficulty during the allocation.

For QA2–QA5, the mean ranks of Method B were moderate and those of Method A were better than those of Method C, except for the easiness of the allocation method (QA4). The mean ranks for operability (QA3) and easiness (QA4) of Method A were unfavorable. These results may have been caused by the difficulty of pointing out the position of a disaster situation. The unfavorable mean ranks in Group A may have occurred because the participants were prompted to consider how disaster situations should be allocated. Thus, Group A participants were taught how to annoy participants by allocating disaster situations. The unfavorable mean ranks will be evaluated differently from an efficient or effective perspective. Although writing on a paper is still easy even in the digital age, Methods A and B were superior to Method C in terms of TTD and NADS. Method A was not only the highest in TTD and NADS but also the best in terms of immersiveness (QA2) and enjoyment (QA5).

On this basis, we can conclude that Method A (i.e., the immersive function) was the most useful for the evacuation training designers to allocate disaster situations.

(2) Group B

For ETD and NDSE, the mean values showed no remarkable differences among the methods. Although the mean value for the NADS of Method C was the lowest, that of ETD of Method C was moderate. These results may depend on participant behavior (e.g., evacuation routes) and features (e.g., a sense of direction). However, Method C efficiently annoyed evacuation trainees despite the small NADS. For annoyance (QB1), the mean value of Method A was higher than the values of Methods B and C. This result may indicate that the high immersiveness in Method A made the evacuation training designers feel like they were evacuation trainees, thus resulting in allocating disaster situations that annoyed the trainees.

For QB2–QB9, the mean values were relatively favorable. The mean value of immersiveness (QB2) may have resulted from using the HMD. The mean value of scare (QB4) was slightly higher than the values of urgency (QB3) and uneasiness (QB5). Through free descriptions, we found just one comment expressing scare, which may have been caused by the immersive function: "*I was surprised when I turned a corner and found an injured person.*" We assume that this disaster situation may not have been allocated unless an evacuation training designer viewed it from the angle of a trainee. The mean values of enjoyment (QB6) and operation easiness (QB7) were moderate but acceptable. The high mean value of comfortability in viewing (QB8) may be caused by the performance of the HMD. Finally, the mean value of awareness for disaster management (QB9) was favorable. This may indicate that pseudo-evacuation experiences in the experiment can be enhanced via VR-based evacuation training.

From the above, we assume that Method C provided the most efficient evacuation training in annoying the trainees, and VR-based evacuation training can replace traditional (real-world) evacuation training or can be accepted as an alternative when conducting traditional evacuation training is difficult.

5. Conclusion

This paper describes an immersive function for allocating disaster situations that annoy evacuation trainees in VR-based evacuation training. The immersive function, which functions on Oculus Quest 2, was implemented to satisfy several requirements, such as providing high immersiveness, easily allocating disaster situations to intended positions, and expressing time-variable disaster situations. Through a small-scale preliminary comparative experiment, we concluded that the immersive function can satisfy immersiveness and can effectively annoy the trainees. However, the immersive function may have difficulty pointing to the position of a disaster situation as intended, which is insufficient to express time-variable disaster situations.

The experiment had limitations, such as few participants, narrow participant demographic information, and low questionnaire reliability. Therefore, to make effectiveness clearer, we must conduct a large-scale experiment with many participants and in more reliable settings. Furthermore, we must improve the immersive function and integrate it into our VR-based evacuation training. For example, the improved immersive function should help evacuation training designers configure disaster situations in detail (e.g., size, intensity, interaction, and animation). It may also be required to display a plane view (mini map) for the designers to grasp the big picture for allocating disaster situations in the city model.

We focused on examining whether the immersive function is useful for allocating disaster situations, but another focus is its usefulness in disaster education. We would like to examine its educational effect in our next experiment.

Acknowledgements

We thank T. Saito for his great effort in this study. This work was supported by the Japan Society for the Promotion of Science Grants-in-Aid for Scientific Research (Grant No. 18H01054).

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