Improvement awareness of disaster management using virtual reality-based tsunami disaster drills

Kadoya Koki[1*], Yamato Yuya[1], Hayashida Koichi[2], Yoshida Masaho[1] and Shen Zhenjiang[3]
1. Department of Civil Engineering, National Institute of Technology, Fukui College, Fukui, JAPAN
2. Technical Support Center, National Institute of Technology, Fukui College, Fukui, JAPAN
3. School of Environmental Design, Kanazawa University, Kakuma machi, Ishikawa prefecture, JAPAN
*kk2001tb@gmail.com

Abstract
Virtual reality has the potential to be a unique tool to experience simulated disasters in a dynamic and immersive environment. Researchers thus developed an experience-based tsunami drill in a virtual reality space using a tsunami evacuation simulation on a head-mounted display. A 3D model of Mikuni-Minato area, Sakai City, Fukui Prefecture, Japan, was built based on data. Questionnaires survey were supplied to 28 participants who were residents of the Mikuni-Minato area. The questionnaire included items on the effectiveness of tsunami simulation, evacuation behavior, awareness of disaster management and possible future actions after the evacuation drill.

The findings reveal that the evacuation drill effectively improved awareness of disaster management among local residents. In particular, 46.4% stated "I decided to improve the evacuation route," 67.9% stated "I realized that disaster drills were important," and 60.1% stated "Will prepare disaster goods." While the study confirmed the effectiveness of VR-based drills using head-mounted devices, we suggest further improvements to make the simulations more realistic.

Keywords: Virtual reality, tsunami disaster drill, head-mounted display, disaster management

Introduction

Practical evacuation drills for earthquake and tsunami readiness are common features in Japan, which is especially prone to both calamities[13]. The drills involve the participation of local residents and take place at schools or other facilities that serve as disaster management centers; many are focused on training residents in effective evacuation[8].

In the event of a disaster, we must accurately assess the condition of the disaster and must be proactive[6]. Evacuation drills allow competent authorities to establish a system for raising the awareness of disaster management among local residents. Japanese authorities conduct annual formalized trainings as part of routine drills for disaster preparedness. There is a concern that residents might become uninterested by such repetitive drills over time[22], leaving the drills ineffective at raising awareness of disaster management.

*** Author for Correspondence**

Yet, disaster drills can only be effective if they are routine rather than a one-time event. One challenge is the impracticality of making local residents continually participate in drills[15,16]. We thus call for a revamp of existing disaster drills.

In this study, we developed an experience-based tsunami drill in a virtual reality space using a tsunami evacuation simulation on a head-mounted display (HMD) to understand changes in awareness of disaster management among local residents. VR can help us visualize tsunami disasters under different conditions and environments such as location, season and varying degrees of infrastructure damage. The findings from drills aided by VR can help update existing formalized disaster drills.

Review of Literature

There is a modest corpus of literature on the uses of VR for disaster preparedness. Examine the effectiveness of a disaster drill using Google Street View[2] and propose a disaster drill method using smart glasses to improve the participation rate of drills[11]. As these kinds of studies employ VR tools and are conducted outdoors, they require safety protocols as well. The study of indoor evacuation drills may involve information and communication technology (ICT) devices such as in the work, who developed a comprehensive scenario simulation of tsunami disasters as an educational tool for tsunami disaster management[5]. Also develop a tsunami evacuation training system as an educational rule using mobile functions[7]. A virtual evacuation drill system was developed using Google Street View to safely conduct ICT-based evacuation drills regardless of weather conditions[23]. Propose a tablet PC-operated gamified evacuation drill that presents the digital learning content as scenes in branching stories[14]. State that a whole-body experience in learning physical concepts leads to a positive attitude[26]. State that a combination of virtual and virtual realities is an innovating educational method to update learning materials and improve and stimulate learning comprehension[27].

Conduct and evaluate a real disaster drill assuming a post-earthquake scenario in order to examine all issues pertaining to practical disaster drills[10]. Conducting a disaster drill without designating an evacuation site, can affect active learning[20]. Tsunami-related evacuation and disaster management education help to reduce damage from a tsunami[25]. It is also critical to establish disaster drills targeted at older adults, who are more vulnerable to disasters[24]. Examine evacuation routes to develop a tsunami

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emergency response plan for coastal communities[1]. Conduct a practical tsunami evacuation drill assuming an actual disaster and discuss its feasibility[9].

Examine successful tsunami evacuation drills to impress upon the importance of evacuation drills[12]. Claim that an immersive experience application that simulates a disaster using VR can lead to an accurate image of the disaster risk and raise crisis awareness[21]. Find the means to identify an alternative route in the event of road blockages. Determine the shortest evacuation route based on a discrete optimization algorithm derived from the abilities of ants and this route led to faster evacuation in an emergency than using a conventional evacuation route[3].

The present research is novel in that a tsunami drill was developed using an immersive VR-type system, which enables viewers to imagine what a disaster might look like from a bird's eye view of the townscape. The system used in this study can be used as a tool for future disaster education. The study showed that hands-on disaster evacuation drills have the potential to improve the disaster awareness of local residents. This research is also highly applicable to actual disasters, as the experience gained from the training can be used in actual disasters.

Material and Methods

Here, we describe the main systems of the tsunami evacuation drill developed for this study, namely, a 3D model for a bird's-eye view of the townscape, a tsunami simulation and a simulated collapse of a building. The target area of this study is the Mikuni-Minato area in Sakai City, Fukui Prefecture. Mikuni-Minato has many historical town areas and is located along the Kuzuryu River. In the event of an earthquake, tsunami run-up into the adjacent Kuzuryu River and building collapse on narrowed roads are predicted to cause road blockages.

Development of 3D model of townscape and simulation systems

Creation of 3D model: The 3D model of Mikuni-Minato area required for the simulation was created using data from the basic map information download service provided by Geospatial Information Authority of Japan, map creation software VectorMapMaker and architectural 3D CAD SkechUpPro. VectorMapMaker creates a 2D map drawing, recognized as a line segment within SkechUpPro, which is then used to start a 3D model. The SketchUpPro extension recognizes VectorMapMaker's contour lines and reproduces a topography (Figure 1). Figure 2 shows the Mikuni-Minato area created by the above method.

Creation of a tsunami simulation: We created a simulation of the Mikuni-Minato area, Sakai City, Fukui Prefecture, Japan, with a tsunami of estimated height hitting a predicted inundated area. The reference material for the tsunami height used in this simulation is the Sakai City Tsunami Evacuation Planning Manual[19] of Sakai City, Fukui Prefecture. The tsunami simulation was created using Autodesk 3dsmax. The 3D model created in section 3.1.1 was imported into 3dsmax. Next, a rectangular fluid box was set at the predicted tsunami height using a fluid tool. The height of the box was set to the maximum estimated height of 8.68 m in the event of an earthquake caused by a fault near the Wakasa Knolls, as assumed in the *Sakai City Tsunami Evacuation Planning Manual*. Figure 3 shows the tsunami simulation. A guide was installed along the width of the fluid box. This guide is for fluid flow across the entire 3D model with as little loss as possible. This simulation does not include an entire tsunami area.

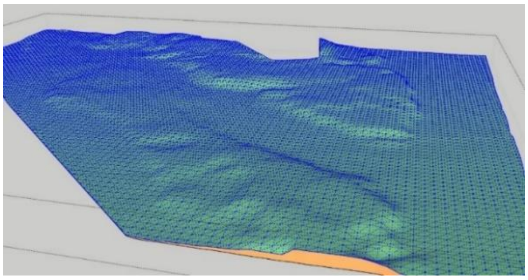

Figure 1: 3D model of Mikuni-Minato area (reproduction of topography)

Figure 2: 3D model of Mikuni-Minato area (reflection of the building)

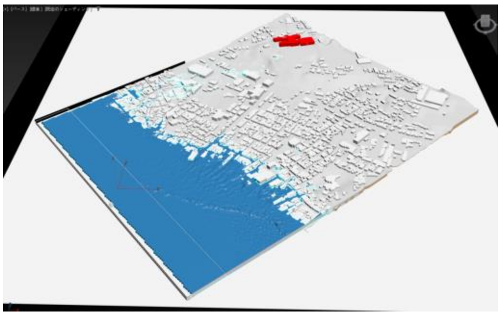

Figure 3: Tsunami simulation

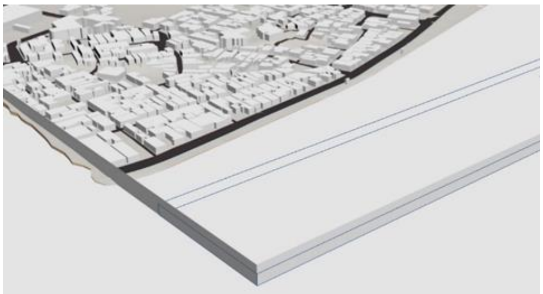

Figure 4: Installation of rectangular guide

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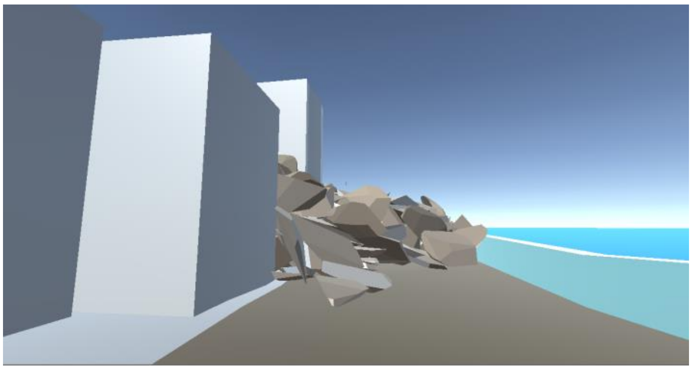

Figure 5: Road blockage caused by collapsed buildings

In an actual event, tsunami waves flow continuously through both sides of the cross section; without the guide, the tsunami would simply flow out horizontally. Therefore, the installation of a guide is important in recreating a scenario of the tsunami hitting the width of the entire town (Figure 4). The tsunami simulation was created using the Timeline tool of Unity3D, a general-purpose game engine, so that it can be replayed in VR.

Creation of a building collapse simulation: The simulation of a building collapse was created based on the 3D model. Unity3D "RayFire" asset was used to create the simulation. Buildings were selected based on the collapse rate map[19] of Sakai City and the collapses were generated to simulate road blockages. The criteria for selecting collapsing buildings were those with a total destruction rate of 40% or more and those in relatively old age found in our field survey. The asset is capable of collapsing buildings that are predicted to collapse by gravity by subdividing the building into smaller pieces. This study does not consider horizontal vibrations caused by earthquakes and buildings that collapse under their own weights (Figure 5).

Evaluation in the awareness of disaster management among local residents through experience-based disaster drills: In this study, local residents were requested to participate in the tsunami simulation. We analyzed changes in their awareness of disaster management after the experience-based disaster drill. In the tsunami simulation, participants enter a virtual townscape; they are confirmed about the area inundated by a tsunami. Then, the local residents must plan an evacuation route to the evacuation site and act accordingly. During the evacuation, we simulate the collapse of some buildings. As the evacuation route available in the actual disaster drill is not accessible, local residents must plan an alternative route. After the disaster drill, a questionnaire is administered and changes in the awareness of disaster management among local residents are analyzed based on their answers. The questionnaire includes items on the effectiveness of tsunami simulation, evacuation behavior, awareness of disaster management and possible future actions after the evacuation drill.

Results and Discussion

Here, we examine the effectiveness of using VR for tsunami simulation experiment and discuss the results thereof.

The experiment: The experiment was conducted in May 2022 as a "tsunami evacuation drill experience" (Figure 6). Twenty-eight local residents of the Mikuni-Minato area participated in the experiment. The participants were aged between 30 to 79 years, with an average age of 62.9 years. The experiment was conducted in a rotation of three booths where the participants took turns. Each booth was equipped with an assigned staff member to explain the experiment and with one notebook PC and one HMD (Microsoft HoloLens2) connected to the network.

The image of the evacuation route in the experiment is shown in figure 7. After the start, the shortest route is to proceed to the north (upward in the figure 7). However, the road blockage caused by collapsed buildings requires the participants to choose a route as shown by the red arrow.

After a briefing is given, they participate in the simulation (Figure 8). The experience was conducted in the following order: (1) experiencing a tsunami through the tsunami simulation and (2) identifying an alternative route in the building collapse simulation.

Tsunami simulation: In this simulation, a tsunami image was projected in the VR, which was viewed by participants. The duration of each person's the experience should be about 5 minutes in order to prevent physical discomfort owing to virtual sickness. VR allowed us to confirm how a tsunami crashes into the townscape and where an individual is standing in the image while comparing it with the map. In the first image seen in this simulation, a tsunami enters the Mikuni-Minato area (Figure 9).

After a brief explanation of how to move as a player, participants wear HoloLens2 and search for an alternative route while moving by using a game controller. After starting, some surrounding buildings collapse. A tsunami warning siren starts and participants start to move. As the shortest routes to the evacuation center, the elementary school, are blocked off, participants must plan an alternative route to the center.

Tables 1 and 2 summarize the effectiveness of the simulators.

Figure 6: Explaining how to operate while viewing VR

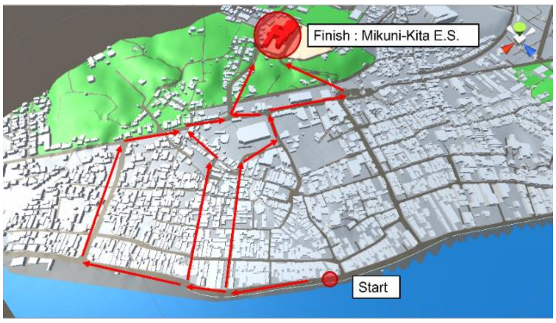

Figure 7: Image of evacuation route

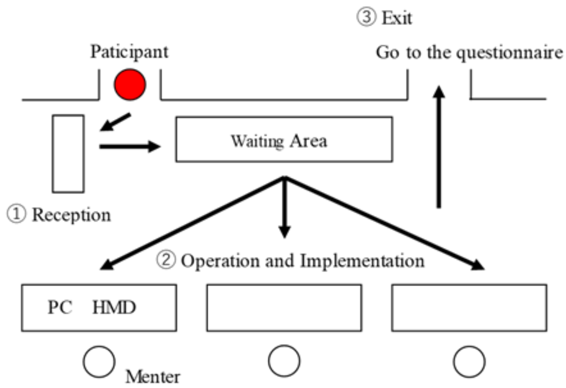

Figure 8: The flow of tsunami drill

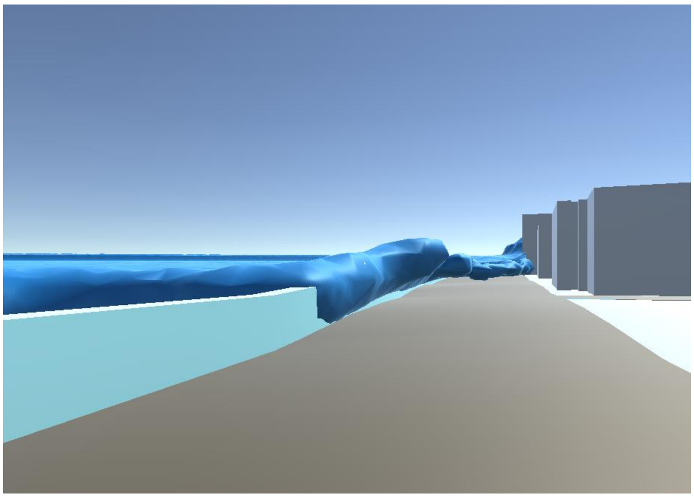

Figure 9: Tsunami strikes

Table 1
Q: Do you think a virtual tsunami drill will be useful? (Number of responses, %)

I very much think so	I think so	I do not really think so	I do not think so
7 (25.0)	18 (64.3)	2 (7.1)	1 (3.6)

Table 2
Q: Did you understand the evacuation route? (Number of responses, %)

I have a better understanding	I have a better understanding to some extent	I do not have a better understanding to some extent	I do not have a better understanding
8 (28.6)	13 (46.4)	4 (14.3)	3 (10.1)

In response to the question about a virtual tsunami drill in table 1, 25.0% answered “I very much think so,” 64.3% answered “I think so,” 7.1% answered “I do not really think so,” and 3.6% answered “I do not think so.” In response to question about understanding of the evacuation route in table 3, 28.6% answered “I have a better understanding of it,” 46.4% answered "I have a better understanding of it to some extent," 14.3% answered "I do not have "a better understanding of it to some extent," and 10.1% answered "I do not have a better understanding of it." We consider because they experienced a series of evacuation drills that they had never experienced before, such as an evacuation drill based on a simulated tsunami and an evacuation drill with collapsed buildings.

In addition, the participants understood how their town might be attacked by entering their town in a virtual world. However, some participants commented that the lack of reality made it difficult to understand the disaster situation and that the amount of information provided was small.

The tsunami simulation was observed while wearing HMD and from a bird's-eye view after the disaster drill. This simulation provides an experience that cannot be obtained in a tsunami evacuation drill in which participants simply walk through the town. By experiencing the height of a tsunami, it is possible to increase the sense of fear of tsunami and lead to active evacuation behavior. The tsunami simulation not only teaches local residents about the dangers of tsunamis, but also serves as a teaching tool to show how a tsunami can strike a town.

Changes in evacuation behavior: Tables 3 and 4 summarize evacuation behavior. To the question "Are you able to plan a route even if the road is blocked?" in table 3, 7.1% answered "I will be able to do it well" and 64.3% answered "I will be able to do it." In response to the question "How has your awareness of disasters changed? (choose one or more answers)" in table 4, 46.4% answered "I decided to improve the evacuation route" and 67.9% answered "I realized that disaster drill was important." Further, 60.1% said "I decided to be always prepared" and 70% answered that they could plan an evacuation route in the event of road blockages caused by earthquakes.

However, 30% of the participants answered that they could not, with some saying that they were lost because the simulation was not realistic and others saying that they did not fully understand the roads in the town. After experiencing this study, some participants decided to improve the evacuation route and others decided to always be prepared, indicating that the disaster drill systems are effective. However, some participants commented that the simulations did not seem to be realistic enough to feel they were doing actual evacuation.

When identifying an alternative route in the event of a road blockage, the participants were asked in the experiment to choose a safe route rather than the shortest route to evacuate. The experiment yielded responses such as "I thought about improving my evacuation route" and "I learned that disaster drills are important." It was clear that viewing scenes that could not be reproduced in an actual town changed their awareness of evacuation behavior. As an issue, the reproducibility of the townscape is low, so it is necessary to reproduce the townscape using a 3D scanner. In addition, reproduction of collapsed utility poles, would lead to a more detailed understanding of alternative routes.

Possible future actions: Tables 5 and 6 summarize possible future actions. In response to the question in table 5 "As a member of a local voluntary organization for disaster management, would you like to teach, spread and raise awareness of disaster management knowledge for local residents?", 65.4% answered "I will be able to do it well" and 34.6% answered "I will be able to do it." In response to the question in table 6 "Would you like to participate again?", 92.3% answered "I want to experience it again" and 7.7% answered "I do not want to experience it anymore."

As the disaster drill that the participants had experienced in the past did not include a tsunami attack or building collapse, they were willing to share their experiences in this experiment with those who were not able to participate in this study. This system attracted the interest of local residents who were eager to experience the system again. Some participants stated that they had virtual sickness and that they would like to be well prepared for the next time and that they would like to see a realistic simulation of the event like in the Metaverse.

Table 3
Q: Are you able to plan a route even if the road is blocked? (Number of responses, %)

I will be able to do it well	I will be able to do it	I will not be able to do it much	I will not be able to do it
2 (7.1)	18 (64.3)	7 (25.0)	1 (3.5)

Table 4
Q: How has your awareness of disasters changed? (choose one or more answers) (Number of responses, %)

I decided to improve the evacuation route	13 (46.4)
I realized that disaster drills were important	19 (67.9)
I decided to gather information about disasters	10 (35.7)
I decided to participate in disaster management activities	5 (17.9)
I decided to be always prepared	17 (60.1)
Other	2 (7.1)

Table 5
Q: As a member of a local voluntary organization for disaster management, would you like to teach, spread and raise awareness of disaster management knowledge for local residents? (Number of responses, %)

I will be able to do it well	I will be able to do it	I will not be able to do it much	I will not be able to do it it
17 (65.4)	9 (34.6)	0 (0)	0 (0)

Table 6
Q: Would you like to experience it again? (Number of responses, %)

I want to experience it again	I do not want to experience it anymore
24 (92.3)	2 (7.7)

In this experiment, an evacuation drill was conducted in VR. Therefore, conducting the experiment indoors ensured safety and eliminated instability in implementation due to weather conditions. Evacuation drills using HMDs were an unprecedented form of implementation. Therefore, it was clear that the training had an impact on the change in disaster awareness of the local residents. Furthermore, the experience of the tsunami simulation motivated many participants to act proactively against possible future scenarios.

Conclusion

This study was conducted to develop an experience-based tsunami evacuation drill on VR using HMD and to conduct drills with the participation of local residents in order to understand changes in their awareness of disaster management. We summarize our findings as follows: First, the drill using HMD simulated a tsunami attack and building collapses, introducing a novelty to conventional disaster drills. Second, an experience-based tsunami drill on VR using HMD can effectively improve awareness of disaster management among local residents. Changes in the awareness of disaster management were evident based on the positive responses to the following items in the questionnaire: “I decided to improve the evacuation route,” “I realized that disaster drills were important,” and “I decided to be always prepared.”

Third, as some participants commented that the simulation as a whole did not accurately duplicate reality, we strive to further improve the simulations. In future research, we simulated possible road blockages in Mixed Reality. We plan to create a disaster management map by viewing the created 3D model of the Mikuni-Minato area that also includes features that ordinary maps do not include such as hazardous areas, parking lots and open spaces for alternative routes.

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