Tsunami Evacuation Drill System Focusing on Mobile Devices

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Abstract—Natural disasters, such as tsunami, claim lives of many coastal residents every year. Therefore, tsunami evacuation drills are important for costal residents to survive tsunami. We developed a tsunami evacuation drill system that enables participants to evacuate and move to a shelter while occasionally glancing at a map-based tsunami simulation on mobile devices. The system has the following advantages: (1) a practitioner can easily customise the simulation, (2) the simulation can be displayed on a web browser and (3) the participants' evacuation routes can be recorded and displayed on the simulation system. We conducted a preliminary comparative experiment with 18 university students and found that the developed system was accepted more by participants using a tablet rather than by those using smartglasses.

Keywords—tsunami evacuation drill, map-based tsunami simulation, web system, mobile devices, disaster education

1 Introduction

Devastating natural disasters occur worldwide [1]. In Japan, for example, the 2011 Great East Japan Earthquake and Tsunami caused enormous casualties and damages. Particularly, the tsunami claimed lives of many coastal residents [2]. When a powerful earthquake occurs, coastal residents are required to speedily evacuate to a tsunami shelter. Failing to participate in evacuation drills may result in them not moving towards a shelter, being unaware of the location of and routes to such shelters. As evidenced by a successful case in Kamaishi, Japan [3], tsunami evacuation drills are important for coastal residents to survive tsunami. To bequeath lessons from past devastating earthquakes and tsunamis, evacuation behaviours are being actively examined and analysed [4].

Evacuation drills, regarded as simulated disaster experiences, are regularly conducted in schools, companies and local communities; however, they have not been fully established regardless of the type of disaster. Traditional evacuation drills often request participants to simply follow a fixed (recommended) evacuation route to a fixed shelter under a fixed scenario (disaster assumption). Such evacuation drills involve no decision-making by the participants against more complex disaster situations (such as selecting a safer route to avoid potential dangers); moreover, they do not help participants experience adverse emotions (e.g. urgency, fear and anxiety) that may be evoked during actual evacuation scenarios. In other words, traditional evacuation drills are not realistic or immersive. It is difficult to make evacuation drills realistic in the real world just by sounding a pseudo earthquake early-warning alarm.

An approach to implement realistic evacuation drills is to use virtual reality (VR) systems that emulate calamitous worlds entirely with three-dimensional computer graphics (3DCG). There have been many VR-based evacuation drills that enable participants to evacuate by trial and error in safe-to-use, immersive, interactive and gamified calamitous worlds. For example, a reported VR-based serious game [5] focuses on earthquake evacuation from a building and has a framework for customising settings to realise adaptive training. However, calamitous worlds in VR-based evacuation drills are not necessarily identical to the real world.

If evacuation drills are conducted in the real world at locations where participants live and perform their daily activities, they can practically learn how to evacuate (e.g. deciding an appropriate shelter and the route for evacuating). Augmented reality (AR), which superimposes digital information such as 3DCG onto real-time computer vision, can be used for realistic evacuation drills in the real world. Recently, AR-based evacuation drills have emerged and received considerable attention [6]. For example, a reported AR-based evacuation training game [7] requires participants to evacuate from a building while viewing disaster situations (e.g. fires) superimposed onto real-time vision captured by a mobile device. Previously, we developed AR-based evacuation drills wherein participants could view superimposed 3DCG of disaster situations (e.g. fires and debris) through their mobile head-mounted displays [8][9]. AR-based evacuation drills are expected to be popularised with high-performance mobile devices becoming commonplace. However, they still face challenges such as inaccurate superimposition (e.g. geometric registration). Therefore, visualising a virtual approaching tsunami is more difficult for AR algorithms than VR.

Mobile devices are indispensable to making tsunami evacuation drills seem realistic, by displaying a virtual approaching tsunami in the real world. In other words, participants are expected to evacuate to a shelter while occasionally glancing at the approaching tsunami on their handheld devices. We focused on the map-based tsunami simulation as a method for visualising a virtual approaching tsunami and then developed a tsunami evacuation drill system for tablets, smartphones or smartglasses [10][11].

This study describes the extended and reconstructed contents from two previous publications [10][11] and is organised as follows. Section 2 outlines an ideal tsunami evacuation drill. Section 3 describes the developed system. Section 4 reports on a preliminary comparative experiment. Finally, this paper is concluded in Section 5 by presenting the prospects of the developed system.

2 Tsunami evacuation drill

Japan is an earthquake- and tsunami-prone country. Huge earthquakes occur in seas close to Japan, and depending on their epicentre, a resulting tsunami can arrive at the coast within minutes after the earthquake. Therefore, tsunami evacuation would require coastal residents to speedily reach a shelter. Tsunami evacuation drills are thus conducted in a time-sensitive manner. Except in special cases (e.g. evacuation by car for disabilities), tsunami evacuation is performed on foot to avoid traffic congestion (evacuation obstruction).

Tsunami evacuation is often considered unsuccessful depending on the following reasons:

- Coastal residents either start evacuating late or do not evacuate.
- They do not sprint to a tsunami shelter.
- They do not know the locations of tsunami shelters or cannot decide which shelter or route to take.
- They unknowingly head to an inappropriate place (e.g. their own house) that is not designated as a tsunami shelter.

2.1 Requirements

Practitioner: To prepare for a tsunami evacuation drill, a practitioner (e.g. schoolteacher, employee manager and local community leader) creates a scenario based on tsunami assumptions (e.g. speed, arrival time and inundated areas). Learning from the 2011 Great East Japan Earthquake and Tsunami, tsunami evacuation drills should require practitioners to do the following:

- Create a scenario from various viewpoints beyond dominant assumptions—even scientific assumptions created by government or research institutes. (*Requirement 1*)

Participant: Considering the above causes of unsuccessful tsunami evacuation, tsunami evacuation drills should require participants to do the following:

- Become conscious of a virtual approaching tsunami (e.g. speed and spread) indicated in the scenario. If this requirement is satisfied, they will realise the importance of speedy evacuations. (*Requirement 2*)
- Think of appropriate evacuation behaviour after experiencing the simulated evacuation. If this requirement is satisfied, they will be able to decide the best shelter and route. (*Requirement 3*)

During tsunami evacuation drills, participants should move to a shelter while imagining an approaching tsunami. If they perceive through imagination that a tsunami is near, they will be self-motivated to sprint to the shelter. However, participants may not be able to spontaneously imagine such a scenario accurately. Therefore, instead of relying on their imagination, we need to show them a virtually approaching tsunami.

2.2 Ideal model

During a tsunami evacuation drill, if participants sprint but fail in evacuating (i.e. they do not reach a shelter within a specified time limit), they may lose self-efficacy and be unmotivated to participate in the next drill or sprint to the shelter in real evacuation. If a virtually approaching tsunami is overwhelming, the impact would be significant. Therefore, to increase participants' self-efficacy and motivation, tsunami evacuation drills should include more educational viewpoints.

As an educational viewpoint, we encourage participants to reflect on their evacuation behaviours (e.g. speed and route) in the drill. If reflecting on their failures, the participants will be motivated to try another route in the next drill or sprint faster to the shelter in real evacuation. Considering the requirements, we propose a three-phase model that leads to an ideal tsunami evacuation drill (Figure 1).

Preparation: This phase is applicable for practitioners. For a tsunami evacuation drill, they create a scenario from predominant tsunami-related assumptions and the features of the drill (e.g. purpose, area, date and participants). The practitioners are expected to observe the previous evacuation and reflection phases to improve the subsequent drill.

Evacuation: Participants receive the practitioner's instructions (including tsunami assumptions) and start evacuating to a fixed shelter or their decided shelter. In this phase, they need to avoid dangers (e.g. injury caused by traffic accidents and falls), and an accompanying person (e.g. practitioner) should help in ensuring their security.

Reflection: After the evacuation phase, the participants reflect on their evacuation behaviours. For example, a participant who was unable to evacuate will analyse the causes of failure and determine possible appropriate behaviour. After this phase, the participants can re-try the same drill scenario or try another scenario drill, i.e. move to the evacuation phase.

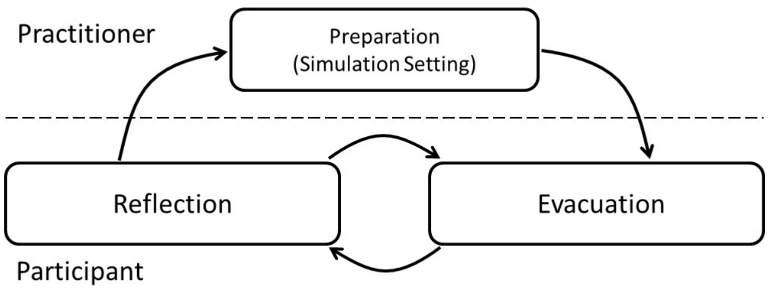

Fig. 1. Model of a tsunami evacuation drill

3 System

Mobile devices are indispensable for realistic tsunami evacuation drills in the real world. Nowadays, various mobile devices, including wearable ones (e.g. smartglasses), are emerging that can run such drills on a web browser. Considering this situation, we developed a tsunami evacuation drill system that works on a web browser. In other words, the system is a web application and does not rely on operating systems, unlike standalone application software.

3.1 Map-based tsunami simulation

A typical information source for a coastal area to learn about threats from a tsunami is an area-specific tsunami hazard map that shows shelters and inundation depths estimated from dominant tsunami assumptions. However, this map does not depict the speed and spread of the tsunami over time. Even if the participants see a tsunami hazard map in advance, it will be difficult for them to imagine an approaching tsunami during a tsunami evacuation drill. Thus, we implemented the function of a map-based tsunami simulation as the core part of the system. This function presents the speed, spread and inundation depth of a virtually (simulated) approaching tsunami in animation overlaid on Google Maps.

Many map-based tsunami simulation systems with high accuracy have been developed and applied to various types of evacuation (e.g. [12] and [13]). However, such systems do not necessarily cover all coastal areas or provide easy operations. In other words, practitioners cannot necessarily rely only on these systems for tsunami evacuation drills. Therefore, our map-based tsunami simulation aims to be easy to use and applicable to any coastal area, rather than focusing only on accuracy in the simulation result.

3.2 Composition

The system herein, developed in JavaScript and PHP, adopted a client–server framework (Figure 2). The server has the main modules and databases. The client used in the evacuation phase is defined as a mobile device equipped with Global Positioning System services and a wireless Internet communication unit to acquire and transmit participants' current locations. Practitioners and participants must use the system through ID-and-password-based user authentication.

The map-based tsunami simulation consists mainly the following modules and databases. These modules generate Google Maps-based user interfaces.

Simulation Setting Module: This module enables practitioners to set a tsunami simulation as a scenario and save the scenario in the scenario database. The saved scenario can then be edited and copied.

Simulation Execution Module: This module loads a scenario selected by a participant into a web browser and then starts the scenario, i.e. it executes a map-based tsunami simulation. Next, this module draws shelters and the approaching tsunami (animation of the simulation result) on Google Maps and simultaneously plots the participant's current location by receiving the location via the Geolocation API at three-second intervals. The current location and time elapsed from the start of evacuation are transmitted to the server and recorded in the evacuation log database. Furthermore, the approaching tsunami displayed on one participant's client device can be sequentially reflected on other participants' client devices via the server. In other words, all the participants of the same drill can see the same approaching tsunami displayed on their mobile devices.

A tsunami's speed and spread differs greatly between sea and land. Therefore, this module simulates an approaching tsunami by changing the calculation and expression methods on the coast (i.e. at the boundary between sea and land). Every 500 m on the straight line connecting the earthquake's epicentre and the starting location of evacuation, the coast is automatically detected from the elevation or water depth obtained by the Google Maps Elevation API. This module divides the straight line connecting the epicentre and the coast at every 500 m and calculates the approaching tsunami's speed (S) at each point. The tsunami arrival time to the coast (t_c) is the total time required for the tsunami to propagate to that point. S (m/s) is calculated from the gravitational acceleration (g) and the water depth (d) as follows:

$$S = \sqrt{gd}$$

Reflection Module: After loading an evacuation log selected by a participant or practitioner, this module draws the approaching tsunami and the participant's evacuation route as an animation synchronised with the elapsed time. This animation can start from a specific elapsed time. The evacuation route is drawn as a line connecting each current position of the participant, and a marker representing the participant is synchronously plotted along the route.

Scenario Database: Each scenario is saved as relational database tables and comma-separated value (CSV) files. The data formats are shown as follows:

```
Basic Settings = (scenario name, password, latitude of
epicentre, longitude of epicentre, starting location of
participants, tsunami speed on land)
  Area = (mesh size, number of meshes in latitude,
number of meshes in longitude, upper-left latitude,
upper-left longitude, lower-right latitude, lower-right
longitude)
  Shelter (i) = (i-th shelter, upper-left latitude,
upper-left longitude, lower-right latitude, lower-right
longitude)
  Mesh (i, j) = (i-th mesh in latitude, j-th mesh in
longitude latitude, longitude, inundation depth, tsu-
nami arrival time)
```

Evacuation Log Database: For each participant and scenario, evacuation logs are saved in a relational database table and saved in a CSV file. The data format is shown as follows:

```
Log = (user id, latitude, longitude, elapsed time)
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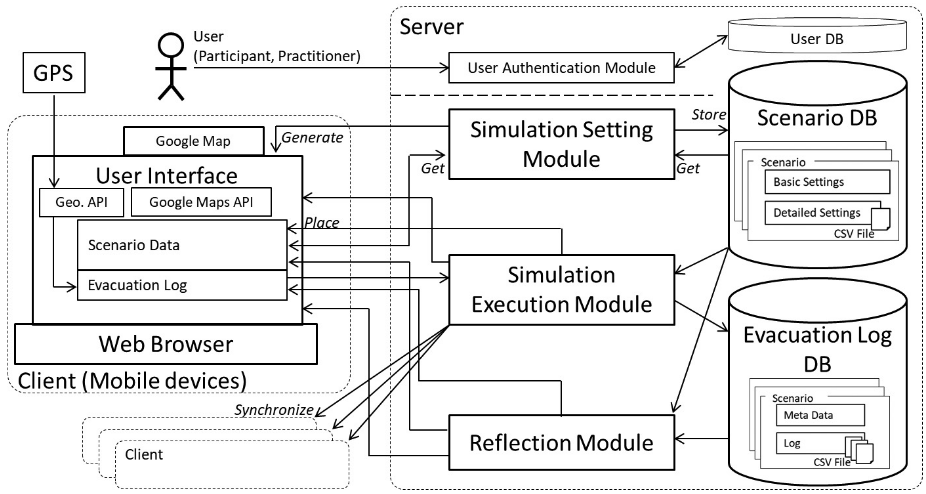


Fig. 2. System composition

3.3 Preparation phase

Practitioner: After successful user authentication, a practitioner creates a scenario along the following procedure to prepare for a tsunami evacuation drill.

(i) Inputs basic settings:

- Scenario name
- Scenario password (to limit participants)
- Latitude and longitude of an earthquake's epicentre (limited to the sea)
- Latitude and longitude of the starting location of evacuation in the drill
- Tsunami speed on land (km/h)

(ii) Designates a coastal area (rectangle) conducting the drill on the map and then selects a mesh size (10, 20 or 50 m). As a result, the coastal area is automatically divided into meshes.

(iii) Determines the inundation depth (eight levels from 0 to 10.0 m or more) of each mesh displayed on the map. Each inundation depth is distinguished by a unique colour (Figure 3a).

(iv) Selects one or more meshes wherein the tsunami is expected to approach first and then enters the time (seconds) from the occurrence of the earthquake to the arrival of the tsunami in the selected mesh(es) (Figure 3b). The tsunami arrival time to the adjacent meshes is automatically calculated from the input tsunami speed on land. The arrival time can be manually set for each mesh. Finally, the tsunami arrival time (t_m (i, j)) is set for all meshes.

(v) Sets tsunami shelters (rectangular areas) on the map (Figure 3c). The locations and area sizes can be changed.

(vi) Saves the scenario.

Using the above procedure, even practitioners who have no expertise in managing a tsunami can easily create various scenarios, i.e. set up the tsunami simulation with various assumptions. For example, they can create a severe scenario that can intentionally increase the failure probability of participants in evacuating, by setting an earthquake epicentre closer to their coastal area than dominant epicentres estimated from scientifically observed data. The advantage provided in this phase would thus satisfy Requirement 1.

Practitioners may create scenarios more easily using a desktop computer or laptop, rather than a mobile device, owing to the display size and the more familiar keyboard/mouse interface.

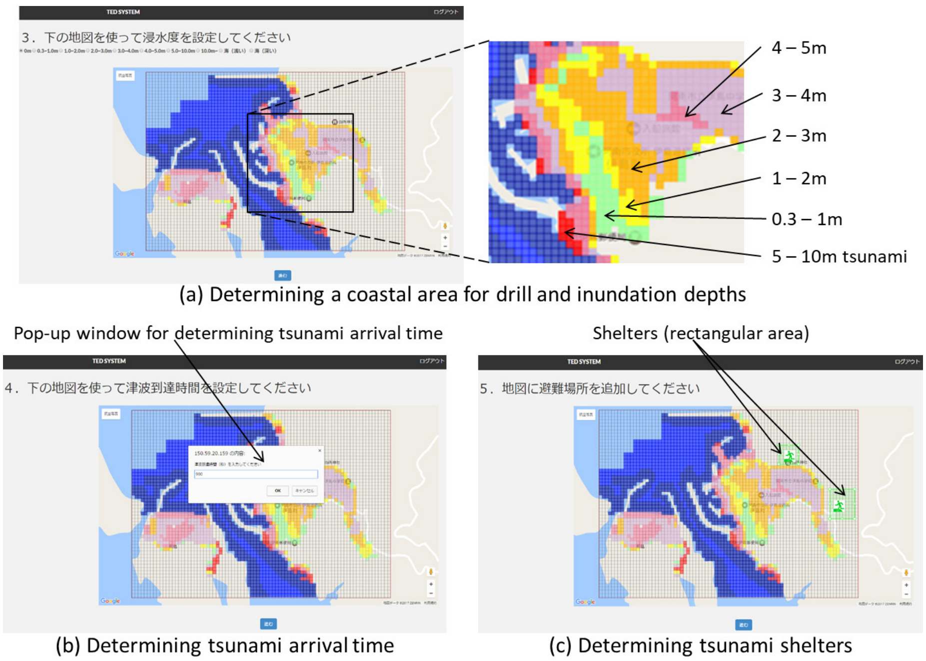


Fig. 3. System's user interfaces in the preparation phase

3.4 Evacuation phase

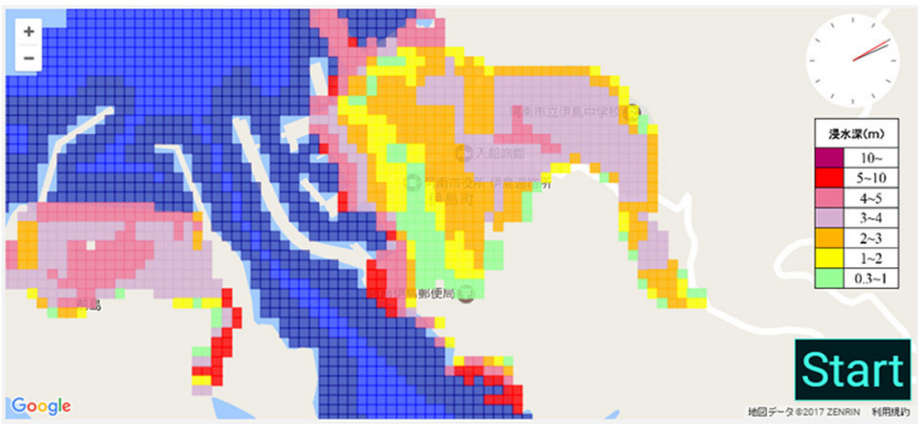
Participant: A participant reaches the starting location and signs in to the system from a web browser on their mobile device. Next, the participant selects a scenario and starts the evacuation drill by tapping the Start button. Before tapping the Start button, the participant can set the value of time elapsed from an earthquake occurrence as the starting time of their evacuation (t), as instructed by the practitioner. For example, this setting allows for detecting scenarios wherein participants start evacuation late and face difficulty reaching a shelter within a time frame. Over the sea ($t < t_c$), an approaching tsunami is drawn as a circle on a wide-area map (Figure 4a). On land ($t \geq t_c$)), an approaching tsunami is drawn by painting meshes that satisfy $t \geq t_m$ (i, j) with a designated colour corresponding to the inundation depth (Figure 4b).

While relocating (preferably sprinting) to a shelter, a participant can occasionally glance at the simulation platform, which displays the details of the approaching tsunami, shelters and their current location, along with the elapsed time since t and the estimated tsunami arrival time. By glancing at them, the participant can change their evacuation behaviour (e.g. speed and route) adaptively to positional relations among the approaching tsunami, shelters and their current location. When the participant reaches a shelter, their evacuation phase finishes—the participant judges their own success or failure of evacuation by checking on the map whether they were caught by the tsunami. The advantage provided in this phase would satisfy Requirement 2.

When participating in the same drill (with the same scenario simultaneously), multiple participants are expected to synchronise while starting the drill. In this case, one participant signs in to the system as a host user and requests other participants to share the approaching tsunami displayed on their mobile devices.

Practitioner: The practitioner can view the locations of an approaching tsunami and that of a selected participant on the map in real time.

(a) Tsunami on sea (expressed with circle)



(b) Tsunami on land (expressed with colored meshes)

Fig. 4. System's user interfaces in the evacuation phase

3.5 Reflection phase

Participant: A participant selects their evacuation log and reflects on evacuation behaviours, which are difficult to memorise objectively during the evacuation phase. Regardless of a successful or failed evacuation, the participant can realise various facts from the synchronised animation of the approaching tsunami and their evacuation route while recalling their internal emotional and physical conditions (e.g. anxiety and fatigue) during the evacuation phase. The advantage provided in this phase would satisfy Requirement 3.

Practitioner: A practitioner can simultaneously view multiple evacuation logs of their created scenario to observe the evacuation behaviours (Figure 5). For example, when students reflect on their evacuation behaviours, a practitioner (teacher) can demonstrate characteristic logs to the students in a classroom using a large-size display, and consequently the students determine success or failure factors and think of appropriate evacuation behaviour.

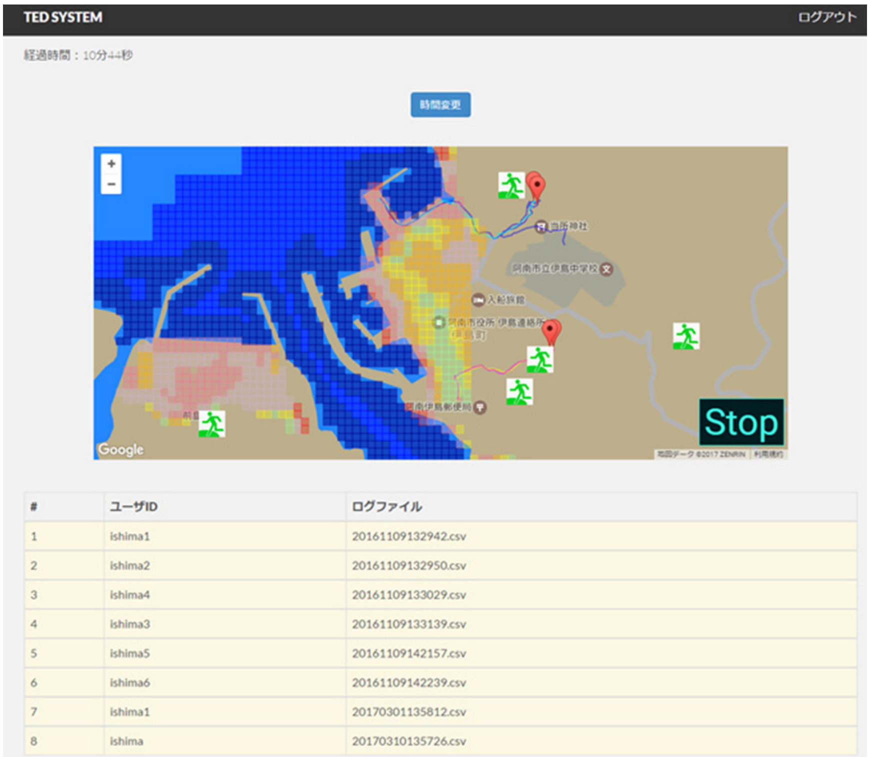


Fig. 5. System’s user interface in the reflection phase

3.6 Related work

There have been a few similar tsunami evacuation drill systems using mobile devices. For example, a reported mobile application [14] encourages a participant to determine proper evacuation routes by presenting them with inundation depth at their current location based on actual data from the 2011 Great East Japan Earthquake and Tsunami. Another mobile application [15] enables a participant to evacuate (move) to a shelter while viewing an approaching tsunami and their current location displayed on a digital map. Furthermore, this application enables participants to evaluate their evacuation behaviour (speed and route) from the evacuation log overlaid on the map. Its latest version focuses on informing the participant of the approaching tsunami via audio to avoid any possible danger owing to visual inattention. Our developed system is quite similar to previously discussed systems but unique in that it works on a web browser and practitioners can customise the tsunami simulation based on their own tsunami assumptions.

If extensively regarded as a location-based system available for disaster evacuation training, our proposed system may be categorised into an alternate reality game (ARG), which involves mapping the real world onto a part of virtual gaming worlds. As stated in [16], ARG for emergency response training based on simulation or storytelling technologies has promise and potential. Our proposed system lacks a storyline but can be extended via integration with our scenario-based evacuation drill systems [9].

4 Preliminary experiment

An elementary concern herein is whether participants can glance at the map-based tsunami simulation while moving around (sprinting) in a real-world panic-inducing situation. If they face difficulty operating as planned, the system may not satisfy Requirement 2. To examine this concern, we conducted a preliminary comparative experiment (small-scale tsunami evacuation drill) focusing on different mobile devices.

4.1 Settings

Mobile Devices: In the evacuation phase, tablets, smartphones and smartglasses are available that can run a web browser. For this experiment, we used an eight-inch tablet (1200 × 800 px) and transparent smartglasses (900 × 600 px), because we assumed that it is easier to view simulations on tablets than on smartphones owing to the display size and that smartglasses are most suitable for using the system that may require participants to sprint. Originally, the smartglasses used in this experiment do not suppose that users view information while moving outside.

Participants: Eighteen university students were randomly divided into two groups: ten participants in the tablet-user group (Group A) and eight participants in the smartglasses-user group (Group B).

Area: This experiment was conducted around the university campus in a small area with sparse traffic with consideration for participant safety (Figure 6). The participants were familiar with the area. The university campus is in a coastal area anticipating devastating damages from a huge earthquake and resulting tsunami.

Scenario: The same starting location and shelter, approximately 400 m between the two, were designated for all the participants. The earthquake epicentre was set based on dominant assumptions, but the time limit for evacuation was intentionally set to 60 s. When the participants started evacuation, the approaching tsunami was already close at 200 m. The tsunami speed on land was set to 30 km/h. The participants were not informed of the time limit and the tsunami settings. In other words, the participants were required to sprint immediately and reach the shelter.

Procedure: The participants visited the starting location at different times and were informed that they had to reach the shelter when the system expressed an approaching tsunami. Thereafter, participants of Group A held the tablet and those of Group B wore the smartglasses to start evacuation. During the evacuation phase, the participants could glance at the simulation (the approaching tsunami) through the system (Figure 6). After reaching the shelter, the participants answered a questionnaire (five-degree Likert scale questions and an open-ended question) primarily concerning the usability.

Fig. 6. Area and snapshots of the experiment
(The right map is extracted from OpenStreetMap: https://www.openstreetmap.org/copyright/en)

4.2 Results

Immediately after the drill started, all the participants sprinted to the shelter. Three and four participants among Groups A ($N = 10$) and B ($N = 8$), respectively, succeeded in evacuating just on time, i.e. reaching the shelter just before the tsunami arrived. In this experiment, we did not measure the evacuation time that depends sensitively on the participants' physical performances and traffic situations. All the participants took not the shortest route but an alternative route including a wider street. Evacuating through wider streets is a recommended behaviour.

Concerning all questions in the questionnaire, the mean values of Group A were higher than those of Group B (Table 1). We examined differences in the mean values between the two groups using Student's t-test, assuming a normal population and homoscedasticity. As a result, significant differences were found in Q2, Q3, Q4 and Q7 at the 1% level and Q1 and Q7 at the 5% level.

The participants' comments obtained from the open-ended questionnaire were almost negative against this type of drill that requires using mobile devices. All participants of Group B stated that it is extremely difficult and dangerous to sprint while glancing at the simulation through smartglasses, and four participants emphasised that smartglasses' low visibility (low luminance and obscure real vision by superimposing the simulation) caused the difficulty and danger. Four participants of Group A stated that it is highly difficult and dangerous to sprint while glancing at the simulation through the tablet. In addition, they emphasised that it was a burden to sprint while holding the tablet. Four participants of Group B attributed their failed evacuation to the smartglasses, whereas no participants of Group A attributed their failed evacuation to the tablet.

Table 1. Questionnaire result

Questions: ***Do you agree that …?*** **(Options = 1: Strongly disagree–5: Strongly agree)**	**Mean (SD)**	
	Group A	**Group B**
Q1. You used the system easily.	4.5 (0.84)	3.12 (1.35)
Q2. You evacuated without any burden.	3.2 (1.22)	1.5 (0.75)
Q3. You evacuated without facing any danger.	4.1 (0.99)	2.37 (1.06)
Q4. You could view the tsunami simulation while sprinting.	3.1 (1.10)	1.62 (0.51)
Q5. You grasped the speed of the approaching tsunami.	3.5 (1.26)	2.87 (1.35)
Q6. You grasped the spread of the approaching tsunami.	3.7 (0.94)	2.87 (1.35)
Q7. You felt a sense of urgency in this drill.	3.8 (1.03)	2.12 (0.83)
Q8. This drill is useful for surviving tsunami.	3.9 (0.99)	2.75 (1.28)

4.3 Considerations

The ratio of participants who succeeded in evacuation was higher in Group B (50%) than in Group A (30%). We attributed this to the fact the participants of Group B did not tend to glance at the simulation while sprinting. In other words, they concentrated on sprinting after glancing once at the simulation simultaneously time as the drill started.

For Q1, the mean value of Group A (4.5) was favourable and significantly higher than that of Group B (3.12). In both groups, the participants took the same steps (i.e. signed in to the system, selected the scenario and tapped the Start button) to start evacuation. The smartglasses needed a dedicated wired controller (an input device). Participants of Group B may have rated the usability lower owing to not only the low visibility but also being unskilled in tap operations via the controller. Therefore, we should improve the system usability after considering the characteristics of mobile devices to be used. For example, voice input may be a versatile approach to the improvement. Concerning Q2, the mean value of Group A (3.2) was intermediate but significantly higher than the unfavourable mean value of Group B (1.5). The mean values of both groups may have been caused by low portability (in holding the tablet) or low comfort (in wearing the smartglasses). This result indicates that the tablet was better than the smartglasses. Concerning Q3, the mean value of Group A (4.1) was favourable and quite higher than that of Group B (2.37). The participants of Group A may have avoided danger by sprinting without frequently glancing at the simulation. Conversely, the participants of Group B may have felt discomfort from the low visibility (the smartglasses obscuring real vision). This result indicates that the tablet was better than the smartglasses in ensuring safety.

The participants' answers to Q4–7 are strongly associated with whether Requirement 2 is satisfied. Concerning Q4, the mean value of Group A (3.1) was intermediate but significantly higher than the unfavourable mean value of Group B (1.62). Although we had predicted that it would be somewhat difficult to glance at the simulation while sprinting, we confirmed in this experiment that it was extremely difficult to glance at the simulation through the smartglasses while sprinting. This result is supported by the negative comments from Group B. Thus, we would venture to say that tablets may be better than smartglasses for participants to glance at the simulation while sprinting. Concerning Q5 and Q6, the mean values of Group A (3.5 and 3.7) were relatively favourable and higher than those of Group B (2.87 and 2.87); however, there were no significant differences. Inside Group B, the mean values of Q5 and Q6 were higher than that of Q4. These results may indicate that only the participants who glanced at the simulation grasped the tsunami's speed and spread. Three and five participants of Group B answered '1' and '2' to Q4, respectively, and three among those five participants answered '4' to Q5 and Q6. From these results, we believe that the system (the map-based tsunami simulation) can convey the approaching tsunami effectively. Concerning Q7, the mean value of Group A (3.8) was favourable and significantly higher than the unfavourable mean value of Group B (2.12), which resulted from the participants who hardly glanced at the simulation. If the participants occasionally glanced at the approaching tsunami, the mean values would be expected to become higher. This result indicates that the system can make tsunami evacuation drills realistic. Concerning Q8, the mean value of Group A (3.9) was favourable and significantly higher than that of Group B (2.75). This result also may have depended on whether the participants glanced at the simulation but indicates that this type of drill is useful and should be improved further.

As shown above, the system's usability was better on the tablet than the smartglasses but not necessarily enough even in the tablet. Although contrary to our prediction that smartglasses are better suited for the system, the results indicate that tablets may be more suitable for the system in terms of usability and safety. Furthermore, smartphones with high portability and moderate visibility (e.g. display size and luminance) may be most suitable for the system. Originally, the smartglasses used herein were not meant for outdoor use. We believe that better results can be obtained if we use another type of smartglasses such as ones available for sports. Simultaneously, however, we realise that essential improvements are needed if the system is used in smartglasses. Overall, the results were disappointing; however, we obtained useful information in that the system can convey an approaching tsunami (speed and spread) and alert the participants effectively. Focusing on this positive result, we would like to conclude that the system could satisfy Requirement 2 and contribute to making tsunami evacuation drills seem realistic.

4.4 Limitations

The participants comprised a small number of university students. Moreover, the findings are based on only subjective evidence (i.e. questionnaire results). For example, we obtained no objective data regarding the number of instances the participants glanced at the simulation while sprinting. To discuss the usability and training efficacy in further detail, we need additional participants under different age brackets and the use of devices (e.g. eye-tracking glasses) for collecting objective data.

5 Conclusion

This study described a tsunami evacuation drill system including a map-based tsunami simulation that expresses a virtual approaching tsunami set by a practitioner. When using the system on mobile devices (e.g. tablets, smartphones and smartglasses) that can run a web browser, participants can glance at the simulation platform while relocating (preferably sprinting) to a shelter in the real world. The simulation displays the location of an approaching tsunami and that of a participant on Google Maps in real time. The participant can reflect on evacuation behaviours by viewing their evacuation logs or those of other participants' logs. We expect that through the evacuation and reflection phases, the participant can become conscious of the approaching tsunami and contemplates proper evacuation behaviours. The preliminary comparative experiment (small-scale tsunami evacuation drill), whose participants were university students, focused on comparing the system's usability between a tablet and smartglasses. Results indicated that the system can be used better on the tablet than in smartglasses, and they implied that smartphones may be most suitable for using this system.

We have not yet conducted an experiment focusing on other demographics and using smartphones. We should clarify whether the indication is universal and the implication is reasonable; however, simultaneously, we believe that smartglasses that are developed with better visibility than those used in this study for participants sprinting outdoors would be the most suitable for the system. Smartglasses such as Google Glass have received attention as a new technology, but they have still not been popularised. As revealed in [17], for the adoption of smartglasses, people are interested in look-and-feel factors. In addition, as revealed in [18], the adoption of smartglasses is influenced by not only the functional benefits and technological innovation but also by social norms. As stated in [19], features such as simulation, engagement and hands-free access are important in the application of wearable technologies, including smartglasses. To popularise using smartglasses for tsunami evacuation drills, we should sufficiently consider the abovementioned facts in addition to the usability and safety.

While waiting for suitable smartglasses for our system, we will keep improving the system and conducting experiments.

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