Increasing tsunami risk awareness via mobile application

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Abstract. In the information and communication technology era, smartphones have become a necessity. With the capacity and availability of smart technologies, a number of benefits are possible. As a result, designing a mobile application to increase tsunami awareness has been proposed, and a prototype has been designed and developed. The application uses data from the 2011 Great East Japan Tsunami. Based on the current location determined by a GPS function matched with the nearest point extracted from the detailed mesh data of that earlier disaster, the application generates the inundation depth at the user’s location. Thus, not only local people but also tourists visiting the affected areas can understand the risks involved. Application testing has been conducted in an evacuation experiment involving both Japanese and foreign students. The proposed application can be used as a supplementary information tool in tsunami evacuation drills. It also supports the idea of smart tourism: when people realize their risks, they possess risk awareness and hence can reduce their risks. This application can also be considered a contribution to disaster knowledge and technology, as well as to the lessons learned from the practical outcome.

1. Introduction

Through data coverage and the capability of mobile technology, it is possible to utilize the everyday technology, such as mobile applications, in a disaster risk reduction context. Many mobile applications have been developed to warn and provide information during disasters [1, 2, 3]. Some applications related to tsunami disasters have been developed; for example, a mobile application for estimating the building damage from a tsunami [2]. That application has various uses: ordinary people use it to help their decision-making when a tsunami warning is announced; drill participants also use it to support their decision-making; disaster risk analysts and researchers use it to help write their reports; town planners or local disaster policy makers use it in designing disaster preparedness plans; and engineers and architects use it to consider the height, function, and material when constructing buildings [2].

The purpose of this study is to create a practical Information and Communication Technology (ICT) application for tsunami disaster risk reduction. This application is expected to overcome the domain problem of long-term tsunami risk awareness level.

The following section provides background; the third presents the research design and methodology; the fourth describes the mobile application development; the fifth describes the experiment and its results; and the last discusses the findings and conclusions.
2. Background
As van der Akker [4] suggested, some typical steps, including a literature review and expert consultation, are necessary for a preliminary investigation. Our expert consultation included the former head and current officer of the Crisis Management Division at Kesennuma City, Miyagi Prefecture, Japan. All participants experienced the 2011 Great East Japan Tsunami. Although many people and agencies possessed a high level of risk awareness due to the danger and damage of the 2011 tsunami, the concerned local organizations began nonetheless to consider how to maintain such an awareness level for future generations. Thus, some activities such as disaster education and disaster evacuation drills were necessary.

Disaster experience can help people prepare for the future events [5]. Disaster education and information campaigns are necessary to alert people to an awareness of disaster risks [6]. Despite the high risk awareness of a tsunami following the 2011 Great East Japan Tsunami, with the passing of time, maintaining a high level of tsunami risk awareness is a problem, especially for new generations and new visitors to the affected areas. What we can do, especially for this new generation, is to provide preparedness and practical exercises. Disaster drills are important activities that allow participants to practice how to proceed after receiving a warning alarm. Nevertheless, we cannot directly evoke the image of a disaster for people who have not experienced it. In addition, such people may not understand the importance of conducting the practice drills. They are probably difficult to proceed during a normal situation because they cannot imagine their surroundings being flooded in a tsunami. We might take advantage of Augmented Reality (AR) to allow participants to see, hear, and feel the situation of a tsunami during a practice drill. In any event, as implementing development costs may be high, this might be considered as the domain problem of this study.

Kendra and Wachtendorf [6] identified and described the concept of three terms: “community”, “innovation”, and “community innovation”. Community innovation could be “a feature of pre-disaster mitigation and preparedness and of post-disaster response and recovery” [6, p. 317]. This study proposes a new, practical application that is simple but efficient. Thus, some practical measures must be taken to increase and maintain tsunami risk awareness via a special tool used in disaster evacuation.

Experts will tell you that a variety of requirements are needed to increase tsunami awareness. We examined feasibility by keeping in mind the available data and technology. As a result, we designed a tool that will show the inundation depth at users’ current location so that they can imagine the height of a tsunami exactly where they are. When used in a tsunami drill exercise, this tool is expected to increase users’ realization, which in turn will increase their tsunami risk awareness.

3. Research Design

3.1. Methodology
Following the design science approach [7], this study develops an instantiation as the design artefact. Research used software development to create a prototype. Based on the availability of inundation depth data in the affected area of the 2011 Great East Japan Tsunami, we designed, and developed a user-friendly disaster mobile application prototype using Xcode, an integrated development environment, with Swift language.

By checking the nearest detailed 100-m mesh data at the current location detected by the GPS function, the application retrieved inundation depth data of the closest location point from its Core Data (i.e., database).

After we designed the user interface of the application, we discussed it with experienced experts in the disaster and emergency management department of Kesennuma City to obtain feedback before
proceeding to the implementation phase. After the implementation, we developed the application prototype. Then, we conducted the evacuation experiment.

3.2. Study areas
For this prototype, only data from Kesennuma City and Matsushima Town in Miyagi Prefecture were included. The study area selection was chosen according to the following criteria. First, Kesennuma City experienced various levels of tsunami height in 2011. Second, Matsushima Town, although it did not experience such a high tsunami, is a tourist area frequented by many Japanese and foreigners.

4. Mobile Application Development
This sub-section describes our mobile application analysis and design in terms of their scope, feature, scenario, process flow, database, and user interface.

4.1. Scope
This application is designed to allow users to monitor previous inundation depths at their current location.

4.2. Feature
This application checks the current location via the GPS function, then shows the map and inundation depth data.

4.3. Scenario
This application provides tsunami inundation depth information for all tsunami drill participants.

4.4. Database
The database of this application contains the inundation depth of each position (latitude and longitude). The data were extracted from 100-meter mesh data using ArcGIS.

4.5. User interface
To make our application simple and user-friendly, it was designed to contain only three views: (1) Home (see Figure 1); (2) Tsunami check (see Figure 2); and (3) Application information.
5. Evacuation Experiment

5.1. Experiment design
To test this application, we arranged an evacuation experiment and selected Matsushima Town as our testing area. Matsushima Town is a popular travel destination for both Japanese and foreign visitors, as it has one of the three most scenic views in Japan. It was also one of the areas affected by the 2011 Great East Japan Tsunami, which damaged the town’s infrastructure, in particular the central tourist area.

The experiment was prepared in July 2016 and conducted in August 2016. Table 1 shows the demographics of experiment participants, which included 2 Japanese and 3 British high school students. We included foreigners because we also wanted to investigate how they would handle an evacuation drill. The day before the experiment, all participants were given a short lecture covering basic knowledge of natural disasters and disaster mitigation.

The starting point was set at Fukuura Island, in Matsushima Bay, connected to the inland area by a 252-meter bridge. Although damaged by the 2011 tsunami, the bridge has been repaired. The experiment design setting is described in Table 2. Participants were given 10 minutes to evacuate to a place they considered safe. GPS loggers were used to track their evacuation routes, together with video cameras recording their evacuation behavior. In addition, following the suggestion that the pilot test might involve interviews or focus groups [8], we conducted interviews. Feedback and opinions were recorded after the evacuation to preserve participants’ feelings and experiences.
### Table 1. Demographic profile of participants.

| No.     | Nationality | Grade | Gender |
|---------|-------------|-------|--------|
| Sample 01 | Japanese    | 12    | Male   |
| Sample 02 | Japanese    | 11    | Female |
| Sample 03 | British     | 11    | Female |
| Sample 04 | British     | 11    | Female |
| Sample 05 | British     | 11    | Male   |

### Table 2. Experiment design setting.

| No.         | Experiment                        | Participants           | Area              | Internal device | External device |
|-------------|-----------------------------------|------------------------|-------------------|-----------------|-----------------|
| Exp. 01     | Tsunami evacuation individually  | Sample 01, Sample 02   | Matsushima Town   | -               | GPS logger<sup>a</sup>, Video recorder<sup>b</sup>(Sample 01) |
|             | (10 minutes)                      |                        |                   |                 |                 |
| Exp. 02     | Tsunami evacuation individually  | Sample 03, Sample 04,  | Matsushima Town   | -               | GPS logger<sup>a</sup>, Video recorder<sup>c</sup> |
|             | (10 minutes)                      | Sample 05              |                   |                 |                 |
| Exp. 03     | Tsunami evacuation as a group     | Group 01 (Sample 01,   | Matsushima Town   | Mobile          | GPS logger<sup>a</sup>, Video recorder<sup>b</sup> |
|             | (10 minutes)                      | Sample 02)             |                   | application     |                 |
| Exp. 04     | Tsunami evacuation as a group     | Group 02 (Sample 01,   | Matsushima Town   | Mobile          | GPS logger<sup>a</sup>, Video recorder<sup>c</sup> |
|             | (10 minutes)                      | Sample 02, Sample 03)  |                   | application     |                 |

<sup>a</sup> Recorded all samples.
<sup>b</sup> Recorded only Sample 01.
<sup>c</sup> Recorded only Sample 05.

### 5.2. Results

The participants had never visited this area before testing, and they were from different schools. Thus, they were similar to travelers. The only difference was that Japanese participants could read tsunami evacuation-related signs written in Japanese. Most of the signs in that area were written in both Japanese and English. Limited information was given to participants, including a scenario of a forthcoming tsunami. The overall results are shown in Table 3.
### Table 3. Experiment results.

| No.     | Sample/Group | Sample behavior                                      | Result              |
|---------|--------------|------------------------------------------------------|---------------------|
| Exp. 01 | Sample 01    | Evacuated to high ground in the island area          | Completed (Safe)    |
| Exp. 01 | Sample 02    | Evacuated to high ground in the island area          | Completed (Safe)    |
| Exp. 02 | Sample 03    | Followed Sample 05                                   | Completed (Safe)    |
| Exp. 02 | Sample 04    | Followed Sample 05                                   | Completed (Safe)    |
| Exp. 02 | Sample 05    | Evacuated to inland area using coastal road heading to evacuation area | Completed (Safe)    |
| Exp. 03 | Group 01     | Evacuated to inland area climbing up to high ground  | Completed (Safe)    |
| Exp. 04 | Group 02     | Evacuated to inland area climbing up to high ground  | Completed (Safe)    |

During Exp. 01, both Sample 01 and Sample 02 checked the map before making decisions. We found from Exp. 01 that Samples 01 and 02 evacuated separately from the starting point. However, both decided to find a route to the island. The route taken by Sample 01 in Exp. 01 is shown in Figure 3. Sample 01 decided to evacuate first to the middle of the island by climbing the hill because it was higher ground than the starting point. With limited information, Sample 01, via trial and error, encountered many dead ends. However, stopping at every sign and information board, he gathered as much information as he could.

During an interview, he mentioned that he wanted to climb to the highest area possible to observe the situation. As a result, he finally managed to reach the highest area on the island, a location higher than the inundation depth.
In Exp. 02, after checking the map as Sample 01 and Sample 02 did in Exp. 01, Samples 03, 04, and 05 decided to evacuate as a group. Sample 05 became a group leader and was followed by Samples 03 and 04. He and the group decided to cross the bridge to remain far away from the coast line. The evacuated route taken by Sample 05 in Exp. 02 is shown in Figure 4. After crossing the bridge, Sample 05 and the others checked the evacuation shelter sign, then began to go in the direction indicated. They went along the coastal road and then headed to the temple officially designated as the evacuation area. Samples 03 and 04 followed Sample 05 to that destination.

Interviews indicate that they decided to evacuate as a group because they were not familiar with the area or the language (Japanese). Sample 05, the fastest in the group, became the leader and could run to read the signs faster than the others. Although they could not read Japanese, they had no problem understanding the signs, since there were also pictures and some important keywords in English.

As a result, in 10 minutes, Samples 05 and 03 reached the temple designated as the evacuation area. Sample 04 reached the area near the temple. Considering the inundation depth, all were safe from the tsunami.
Figure 4. Evacuated route of Sample 05 in Exp. 02: Evacuated to inland area.\textsuperscript{a}

\textsuperscript{a} The satellite signal was delayed during the first period when Sample 05 crossed the bridge.

After that, we conducted Exp. 03 and 04. The difference from previous experiments was that each group was provided with tablets on which the proposed application prototype had been installed (see Figure 5).

In the Exp. 03, Samples 01 and 02 were assigned to evacuate together to safe place within 10 minutes. They could use the application provided to make their decision. Figure 6 shows their evacuated route. This time, Samples 01 and 02 decided to go to the inland area. After crossing the bridge, they immediately took a route to the high ground area. Using their application, they checked the inundation depth after reaching high ground and until they reached a safe area.
Exp. 04 was the last to be conducted. Figure 7 shows the evacuation route of Samples 03, 04, and 05. Although they crossed the bridge to the inland area, they did not use the same route as in Exp. 02, but tried to find a way to climb up the hill as soon as they reached land. They kept checking the application to monitor the inundation depth until they reached the top of the hill, where the application indicated an inundation depth of 0.0 meters. At that location, they mentioned that, in a real situation, they would have climbed to the top of the pavilion located on the hill.
One interesting point in Exp. 04 was that specific roles were allocated within the group. Sample 05 was the leader of the group, Sample 03 was assigned to carry the tablet to monitor the application, and Sample 04 helped Sample 05 decide on the route.

![Figure 7. Evacuated route of Sample 02 in Exp. 04: Evacuated to inland area.](image)

When the experiment was over, all GPS tracks were collected and mapped into the satellite map on Google Earth. Everyone gathered to see the others’ evacuated routes. We allowed all samples to explain their decision-making processes.

6. Discussion and Conclusions
This study attempted to solve the problem of reduced awareness of tsunami risk from a long-term perspective. Our research team designed a practical application using the available technology and data. We developed a mobile application prototype to inform users using previous tsunami risk data based on the 2011 Great East Japan Tsunami. In accordance with the action priorities in the Sendai Framework for Disaster Risk Reduction 2015-2030 [9], this mobile application prototype can support first priority action by allowing users to understand the risks involved when faced with a tsunami. This application is suitable for inclusion in tsunami disaster drills. Drill participants can use this mobile application to estimate tsunami inundation at their location and then check inundation levels again once they change location or evacuate elsewhere. Despite its simplicity, the application provides fundamental information for a disaster evacuation drill.

In addition to local users, visitors to tsunami-affected areas will also learn how many meters the inundation depth was in the previous tsunami. Thus, the application enhances tourist safety, which, in turn, supports the concept of smart tourism. As a result, there are at least three scenarios for using this application: (1) drill participants use it as a supplementary tool to check their risk during drill exercises; (2) the local population uses it to understand their risk once they remain in tsunami-affected
areas; and (3) tourists or visitors use it to realize their tsunami risk when they enter previous-tsunami-affected areas. In creating the idea from an available resource, this study contributes to a practice that provides risk awareness through peoples’ smartphones. This application is expected to become one of the ICT methods used to enhance awareness of tsunami disasters, along with smart tourism and active evacuation drill concepts.

There are many interesting findings from our experiment. Evacuation practice without inundation depth information (i.e., Exp. 01 and 02) sometimes limited decision-making. We found that before providing inundation depth information, students paid attention to arriving at the assigned evacuation area by following the signs but without considering alternate locations. In a real life situation, it might not be safe to use a coastline route (as chosen by Samples 03 to 05 in Exp. 02). On the other hand, when such information was known, they were likely to find high ground that was somehow nearer. As was observed in Exp. 03 and 04, students immediately chose to climb to high ground after crossing the bridge.

Although some samples could not use the Japanese language, they encountered no language barrier in understanding the signs showing routes to evacuation areas, as these were mainly pictures. To provide the necessary evacuation information, the use of a universal language (i.e., pictures) remains one of the best practices.

Examining the actions performed in Exp. 02, we found that leadership is also an important factor. The evacuation action in a real life situation is mostly performed as a group process, probably with family members, friends, colleagues, or others [5]. When practicing a leadership role during a drill, students can understand how they should lead, follow, or respond in a group.

In Exp. 03 and 04, we observed that there was communication among samples, as one sample in each group was assigned to keep monitoring the inundation depth using the application. With such information, all samples agreed that the disaster felt more realistic.

Nevertheless, based on the results of our evacuation experiment, we discovered two limitations. First, location conditions, such as road traffic, limited evacuation action. Second, the tested prototype required access to an Internet signal.

A future study is planned in which further experiments will be conducted, as well as product evaluation via usability testing following Biel et al. [10]. Moreover, comments and feedback from the experiment just described will be taken into account in creating the final version of the mobile application before launching it on the market.

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