Earthquake Simulator by Augmented Substitutional Reality

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Abstract
Earthquakes are natural disasters that we cannot avoid in our daily lives in some countries. Therefore, it is important to raise awareness of disaster prevention and prepare for earthquakes. One of the methods to raise awareness of disaster prevention is to use earthquake simulators. For example, mobile earthquake simulators reproduce actual shaking using a car equipped with a vibration device, and VR-based earthquake simulators enable users to experience earthquakes in a virtual space. However, such earthquake simulators that use special and imaginary environments are unrealistic. In this study, we propose a method to make users feel more realistic than the conventional earthquake simulators by applying substitutional reality. The proposed method gives shaking to the video of the user's current location and make real objects fall over using augmented reality.

Keywords
Earthquake simulator, Substitutional reality, Augmented reality

1. Introduction

Earthquakes are natural disasters that we cannot avoid in our daily lives in some countries. In addition, large earthquakes often threaten our lives. For this reason, it is important to raise awareness of disaster prevention and prepare for earthquakes on a daily basis.

One of the methods to raise awareness of disaster prevention is to use earthquake simulators. For example, mobile earthquake simulators using a vehicle reproduce the shaking that mimics an actual earthquake, and VR-based earthquake simulators [1, 2, 3] enable users to experience earthquakes in a virtual space by using a head mounted display (HMD). However, with the mobile earthquake simulators, the experience is limited to special environments such as cars, and earthquakes can only be experienced at special places such as events. In addition, while earthquake simulators using VR can be used anytime and anywhere using an HMD, they lack a sense of reality because they use imaginary environments and objects in VR space. Therefore, it is questionable whether they actually increase disaster prevention awareness.

To address this issue, an earthquake simulator using augmented reality (AR) that allows users to experience earthquakes in the location where they are has been proposed [4, 5]. In this method, to allow users to experience earthquakes using a video see-through HMD, the video images are shaken, and virtual objects such as furniture that are synthesized on the video images are moved or fallen over. However, the method basically assumes that the room for the experience has almost no furniture. If the environment has many pieces of actual furniture, it is necessary to draw the background image when the furniture is moved virtually. One option is to apply diminished reality (DR) technology [6, 7, 8, 9] to remove the furniture and draw the background image, but it is still difficult for the existing DR methods to remove the variously arranged furniture in high quality for real-time video.

In this study, we propose an earthquake simulator that allows users to experience realistic earthquakes in the location where they are by applying substitutional reality (SR) [10] with AR. This is also a concrete example of applying the idea in the literature [11]. Specifically, the proposed simulator presents the user with an omnidirectional image captured in the past at the user's current location to make the user believe that the video is the current scene. The simulator then shakes the video and makes real objects fall over in the video. Since the proposed method uses a past omnidirectional image as the scene of the current location, it is possible to prepare in advance the background image of the furniture that moves due to the earthquake by inpainting.

2. Proposed earthquake simulator

In this section, we explain the proposed earthquake simulator using substitutional reality. In the following, we first describe the generation of a virtual space that mimics a real scene, and the method for producing an earthquake.

2.1. Generation of virtualized real scene

We capture an omnidirectional image in advance as shown in Figure 1 using an omnidirectional camera at the position where users actually experience the proposed simulator. Next, as shown in Figure 2, we place a sphere in a virtual space and map the omnidirectional

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Figure 1: Omnidirectional image.

Figure 2: Sphere on which omnidirectional image is mapped.

image onto the sphere. The position of the white camera placed at the center of the sphere in Figure 2 becomes the viewpoint of the user.

2.2. Generation of falling virtualized real object

In this study, when producing an earthquake, we not only generate the shaking of video, but also cause objects to fall over. To do this, we place virtual objects that mimic real objects, which actually exist at the place, in a virtual space. For example, to make a cabinet fall over, a rectangular object is generated in the virtual space, and a photograph of the actual cabinet is mapped onto it. The object generated in this way is placed so that they overlap with the actual object in the field of view from the center of the sphere, as shown in Figure 3.

In addition, if we just place the virtualized real object, the object in the background remains in the view after it has fallen over. Therefore, we remove the object from the omnidirectional image, as shown in Figure 4. It is preferable to use inpainting [12, 13, 14, 15] to automatically remove the objects from the omnidirectional image, but if the quality of the inpainting result is not good in the target environment, we can remove it manually using a paint tool, etc.

Figure 3: Placement of virtualized cabinet.

Figure 4: Object removal on omnidirectional image.

2.3. Occurence of earthquake

We simulate an earthquake by shaking the sphere and the virtualized real objects, and then make the virtualized real object fall over towards the user. Specifically, we associate the virtualized real object in Figure 3 with the sphere in Figure 2, and shake them together. Note that, the behaviors of the sphere and the virtualized real object are not exactly the same because we use random values obtained using Perlin noise. In addition, since a large earthquake is composed of an initial tremor and a main tremor, we prepare two different magnitudes of shaking.

Next, we make the object fall over. Here, to make the user feel more fear of earthquakes and raise their awareness of disaster prevention, we make the object fall over towards the user. To do this, as shown in Figure 5, we place a small ball and a tilted plane, which the user cannot see during the experience, behind the virtualized real object. The small ball is rolled and hit against the object by an operation or a pre-set time, and the virtualized real object falls over towards the user through physical calculations. At this time, to prevent the virtualized real object that has fallen over from falling under the floor, a transparent plate with a thickness is placed in the sphere.

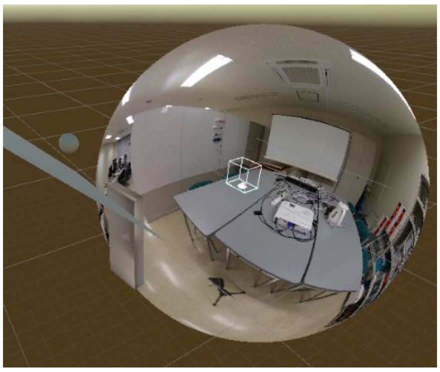

Figure 5: Method for falling over.

Figure 6: Appearance of experience.

Table 1
PC specifications.

OS	Windows 10
CPU	Intel(R) Core(TM) i7-10700K
GPU	NVIDIA GeForce RTX 2080 Ti
Memory	32.0GB

2.4. Introduction of sounds

To enhance the realism of the earthquake, we introduce sounds in addition to visual information. Here, two kinds of sounds of buildings creaking due to shaking are played at the time of small shaking and at the time of large shaking, respectively, corresponding to the magnitude of the shaking. We also add a sound for collisions with the floor after the object has fallen over. A rectangular object invisible to the user is placed at the floor position, and the sound is produced when the virtualized real object collides with the rectangular object.

3. Experiments

3.1. Overview

In this experiment, we asked participants to experience the developed earthquake simulator and evaluate whether it raises their awareness of disaster prevention. Ten male students in their twenties in Faculty of Information Science and Technology, Osaka Institute of Technology, participated in the experiment. We used RICOH THETA Z1 to capture the omnidirectional image, and HTC VIVE Pro2 as the HMD. We used Unity (2019.4.29f1) to develop the proposed simulator, and PC specifications for the experiment are shown in Table 1. The experimental scene is shown in Figures 1 to 5, and the background image of the falling object shown in Figure 4 was created manually using a paint software.

Figure 7: First user view.

3.2. Experimental procedure

To raise awareness of earthquake disaster prevention in the university laboratory, where the participants spend a lot of time, we conducted the experiment in a situation where an earthquake occurs while the participants are in the laboratory. First, as shown in Figure 6, the participants are asked to wear an HMD and sit on a chair placed in the same position where the omnidirectional image was captured. Next, the user is asked to look around while viewing the omnidirectional image to get familiar with the view shown in Figure 7. After that, they experience a small tremor representing the initial tremor, followed by a large tremor representing the main tremor. When the large tremor occurs, the mechanism for making the virtualized real object fall over is activated, and the virtualized real object falls over toward the participant as shown in Figure 8. After the experience, we asked the participants to answer the five questions, as shown in Table 2, on a 5-point Likert scale: 1 (strongly agree), 2 (somewhat agree), 3 (neither agree nor disagree), 4 (somewhat disagree), and 5 (strongly disagree). We also asked them to write comments freely.

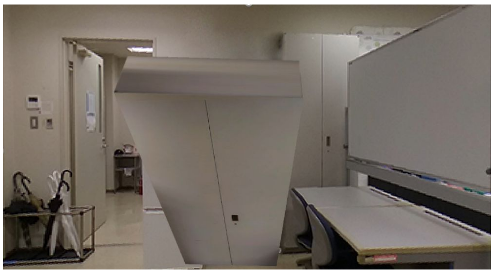

Figure 8: User view when cabinet falls over.

Table 2
Questionaire items.

Item	Question
Q1	Did you think the view you were seeing before the earthquake was real-time video?
Q2	Did you feel a sense of reality about the earthquake?
Q3	Did you feel a sense of reality about the falling over of the cabinet?
Q4	Did you feel fear?
Q5	Do you think this experience will increase the awareness of disaster prevention?

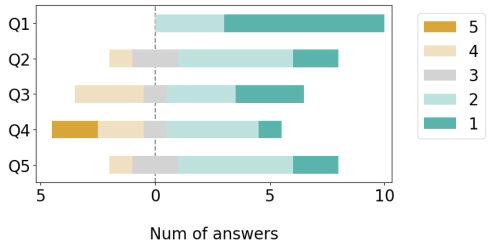

Figure 9: Result of questionnaire.

3.3. Results and discussion

The results of the questionnaire for five items are shown in Figure 9. We discuss the proposed simulator based on the results of the five questions.

Regarding Q1, since many participants agreed, we consider that we could reproduce the virtualized real scene that were close to the actual scene.

Regarding Q2, we consider that many people agreed with the reality of the earthquake because the shaking was divided into two parts: the initial tremor and the main tremor. However, since we created only one virtualized real object that was shaking, one of the participants commented that the shaking did not feel very realistic.

Regarding Q3, while many people also felt that the cabinet falling over was realistic, more people disagreed than for the previous questions. We think this is because the way the cabinet fell over looked like a light, weightless fall. In addition, some said that even though they were sitting in a position where the cabinet could not reach them even if it fell over, the cabinet seemed to be close enough to hit them in the virtual space, which made them feel like it was not realistic.

Regarding Q4, Approximately half of the participants agreed and half disagreed with feeling fear. Some of the comments from those who agreed are that he could recognize the danger of objects falling over, and that the shaking was greater than he had expected, which reminded him of the fear of earthquakes. On the other hand, some participants said that they felt less fear because only one object fell, and others said that if all the objects in the scene could be reproduced virtually, it would increase the sense of reality and fear. From these comments, we confirmed that we could create a sense of danger and fear by making the virtualized real object fall over towards the users during a large earthquake. However, the effect was limited because the content was not sufficiently developed this time.

Finally, regarding Q5, many participants thought that the proposed system increase the disaster prevention awareness. From this result, we think that it is effective to virtually experience an earthquake in the place where we actually spend a lot of time with the HMD using augmented substitutional reality.

Note that, one of the participants commented that if a system prepared multiple patterns of things falling over in advance and instructed people to respond according to the pattern, it would be more effective at increasing awareness of disaster prevention. From this comment, we consider that it would be more effective to raise awareness of disaster prevention by not just having people experience an earthquake, but also by having them practice what to do when an earthquake occurs.

4. Conclusion

In this study, we proposed a earthquake simulator that makes users feel more realistic by applying substitutional reality. The proposed simulator provides a shaking of the view image, which was captured at the user's current location, and falling over of a cabinet, which is a virtualized reality object. In future work, we will use the HMD's camera to switch between real-time and past images, as in the original substitutional reality [10], to create a more realistic earthquake experience.

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