Development of a VR Disaster Experience Environment Construction System with Automatic Object Material Recognition

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***Abstract*—The purpose of this study is to develop a new VR disaster experience environment construction system with the function which automatically recognizes real world objects' shape and materials in captured RGB-D images and makes their behaviors in a disaster simulation real. In this system, objects' materials are recognized by material recognition with machine learning. With the result of material recognition, this system calculates *feature values* which are values to decide objects' behaviors in the disaster experience. *Feature values* consist of *proportion of material, flammability* and *density* to decide the sound of collision, how easily objects burn in the fire and whether objects float in water in the flood respectively. An evaluation experiment was conducted to examine whether material recognition improves a sense of reality and fear toward VR disaster experience. The evaluation of the sense of reality toward where fire occurred in the fire experience with material recognition tended to be higher.**

Keywords— Virtual Reality; Disaster Experience; Material Recognition

I. Introduction

In recent years, as disaster education to raise awareness of disaster prevention, a method using virtual reality (VR) is attractive because it is more realistic than disaster videos and requires less equipment and less space than simulated experiences such as earthquake simulation vehicles or smoke evacuation. However, the creation of 3D models used in the disaster experience environment and the design of disaster scenarios must be done manually by experts. Moreover, in many cases, the environment experienced by the VR disaster simulation is different from the familiar environment in which the experiencers usually live, so it is difficult to link their daily lives with disaster and there are few points that can be referred to in terms of reviewing disaster countermeasures in the familiar environment. If we can experience VR disaster in the familiar environment without help of experts, we can review disaster countermeasures. Also, if we can recognize object's material and change object's behavior according to the recognition result, we can increase a sense of reality and fear toward VR disaster experience. The object's material can be set manually by experts, but it would take a lot of time and effort to create a disaster experience environment. If we can automatically recognize object's material, we can increase a sense of reality and fear while retaining the advantage that anyone can experience disaster in a familiar environment without the help of experts.

The purpose of this study is to develop a new VR disaster experience environment construction system with the function which automatically recognizes material of indoor objects. This system can construct a disaster experience environment in which we can experience not only earthquake but also fire and flood. In addition, we conducted an evaluation experiment to examine whether material recognition improves a sense of reality and fear toward VR disaster experience.

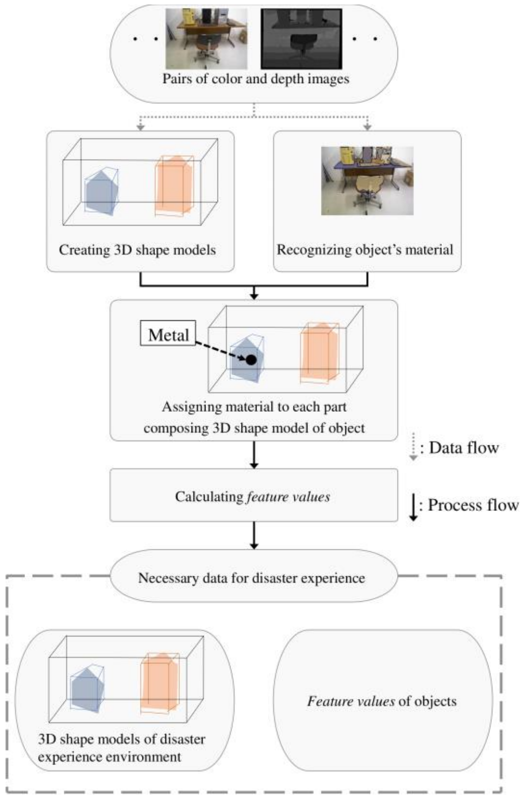

Fig.1 A system overview of VR disaster experience environment construction system.

II. Proposed System

A. System overview

Fig. 1 shows an overview of the proposed system. In this system, the indoor environment is captured by RGB-D camera. Then, 3D shape models of the disaster experience environment, which are polygons representing the color and shape of 3D objects, are created using pairs of color and depth images. The object's material is recognized by material recognition using machine learning. Next, based on the 3D shape models and the result of material recognition, material to each vertex of the 3D shape model of the object is assigned. Since indoor objects are generally composed of multiple materials, we assume that each object is not treated as an object composed of a single material, but as one composed of multiple materials. Then, we calculate *feature values* which determine object's behavior in disaster from the assigned material. There are three behaviors of objects that change depending on material when earthquake, fire or flood occurs: collision sound, burning or not burning, and floating or not floating in water. So, we set *proportion of material*, *flammability* and *density* as *feature values*, and develop a system that automatically calculate these values.

B. 3D shape model reconstruction

First, the indoor environment is photographed several times from various angles with RGB-D camera to obtain pairs of color and depth images. Then, by sequentially obtaining the camera pose relative to image pairs that have been read in so far, the camera pose of each image pair in the 3D coordinate system in the disaster experience environment with the first image pair is calculated. This process is called tracking. With pairs of color and depth images that have been processed by tracking, 3D point clouds of the indoor environment are created. This system used the tracking method developed by Dai et al [1]. In the created 3D point clouds, the ceiling, floor, walls and objects inside the room are not separated. Since the ceiling, floor and walls are the outermost points in point clouds and are almost flat, we recognize the six planes, which are the outermost points of the rectangle enclosing point clouds and omit these planes from point clouds to separate. The point clouds that remain after separating the ceiling, floor and walls are point clouds that represent the shapes of many objects placed in the room, but they are not separated by object, and it is not possible to move each object separately during the simulation. Therefore, segmentation is used to divide the point clouds into smaller groups so that points that are likely to be included in the same object are included in the same group. In this study, we used the segmentation method developed by Lu et al [2]. The segmented point clouds are reintegrated to create a 3D shape model of the object. If the object moves before the external force is applied, the disaster experience is likely to be unnatural. Therefore, the point cloud is integrated under the condition that the object is stable when no external force is applied. In this study, we used the method developed by Handa et al [3].

C. Material recognition with machine learning

In this study, machine learning is used to recognize the material of objects in the indoor environment. First, we recognize the material of objects in the color images, which we used to create 3D point clouds of the indoor environment. And we used the material recognition method developed by Xiao et al [4].

Next, we assign a material to each point that constitutes an object in the room. A flow of material assignment is shown as Fig. 2. As shown in Fig. 2(a), the 3D coordinates in the disaster experience environment corresponding to each pixel of image is calculated. As shown in Fig. 2(b), the material corresponding to each pixel is obtained. Then, by mapping the same 2D coordinates in the color image to each other, a material to the 3D coordinate in the disaster experience environment corresponding to each pixel is assigned.

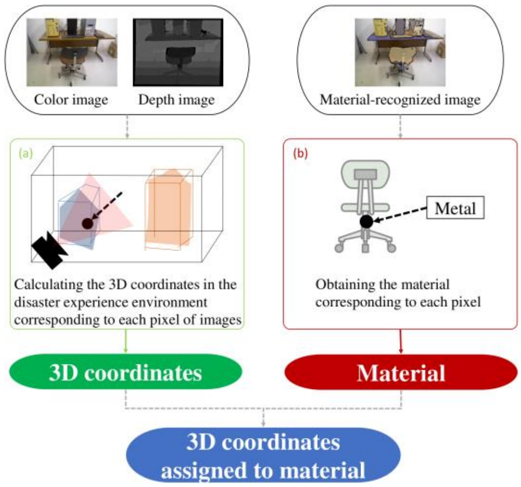

Fig.2 A flow of material assignment to each objects' point.

Table 1 A relation between *feature values* and object's behaviors.

Disaster	*Feature values*	Object's behavior
Earthquake	*Proportion of material* (glass, wood, metal and plastic)	Sound of collision and rupture
Fire	*Flammability*	Non-flammable, slowly flammable, well flammable and intensely flammable
	Proportion of material (glass)	Sound of glass rupture
Flood	*Density*	Floating on water or not
	Proportion of material (glass, wood, metal and plastic)	Sound of collision

D. Calculate feature values

Feature values are used to change object's behavior based on the kinds of material. Table 1 shows a relation between *feature values* calculated and objects' behaviors in the disaster experience.

1) Proportion of material

The sound of collision generated when objects collide depends on the material they are made of. In order to determine what kind of sound of collision is generated when objects collide, this system calculates the proportion of each material that constitutes an object: *proportion of material*.

We first selected glass, wood, metal and plastic as the materials to be recognized, considering that they are materials that are generally used indoors and generate sound of collision when they collide. At this point, *proportion of material* is calculated using the material assigned to 3D point clouds that constitute the object in Section II.C. Specifically, let q_m be the number of 3D point to which a material m is assigned, and q_{all} be the total number of 3D point constituting the object. *Proportion of material* P_m is calculated by the following equation $P_m = \frac{q_m}{q_{all}}$ (1). When an object whose *proportion of material* P_m exceeds a set threshold value collides with another object, the sound of collision related to that material is reproduced.

2) Flammability

Depending on the material of which they are made, indoor objects vary in flammability, from low flammability to high flammability. In this study, the flammability of an object is classified into four levels according to its *flammability*: non-flammable, slowly flammable, well flammable and intensely flammable.

As for the method for calculating *flammability*, based on the results of material recognition described in Section II.C, we divide the materials into flammable and non-flammable. At this point, the materials that are judged to be flammable are set by referring to the Kyoto City's designated flammable goods [5], and the materials that are judged to be non-flammable are set by referring to the Building Standard Law [6]. Next, we calculate *flammability* using 3D point cloud of the object. *Flammability F* is calculated by the following equation $F = \frac{g_s}{g_t}$ (2), where g_s is the number of 3D point assigned to flammable materials and g_t is the number of 3D point assigned to non-flammable materials.
Depending on *flammability F*, objects can be classified as non-flammable, slowly flammable, well flammable or intensely flammable. We set the range of classification so that the flammable objects would be natural. Moreover, we set the following three types of flammability values according to the classification results: whether the object burns, the degree of change in the size of the flame and the degree to which the color of the burning object changes to black.

3) Density

Some indoor objects float on water and some do not, depending on the materials they are made of. Therefore, *density* of an object to determine whether it floats on water or not during VR flood experience is calculated.

Indoor objects are generally not packed inside and are hollow. Therefore, we assume that the inside of the object is hollow and calculate *density*. First, the density of each recognizable material was set based on the results of material recognition in Section II.C, referring to Chronological Scientific Table compiled by National Astronomical Observatory of Japan [7]. Next, we calculate *density* of the 3D shape model of the object as shown in Fig. 3. If calculated *density* is greater than or equal to 1.0 g/cm^3, which is the density of water [7], the object floats in water.

E. The construction example

In this section, an overview of the system developed in this study and an example of disaster experience environment constructed are described. In this study, we used Unity version 2019.3.15f1 provided by Unity Technologies Inc [8]. As described in Section II.B, this system uses RGB-D camera, and ASUS Xtion PRO LIVE [9] is used for this purpose. Fig. 4 shows photographs of the actual room and the 3D shape models of disaster experience environment.

We describe the calculation of each *feature value* and the behavior of the object. As for the earthquake

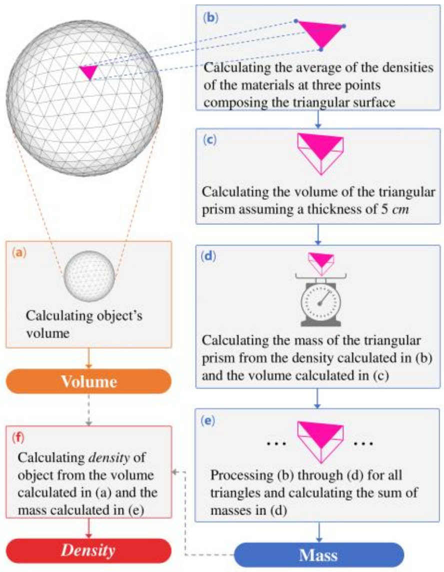

Fig. 3 A flow of *density* calculation.

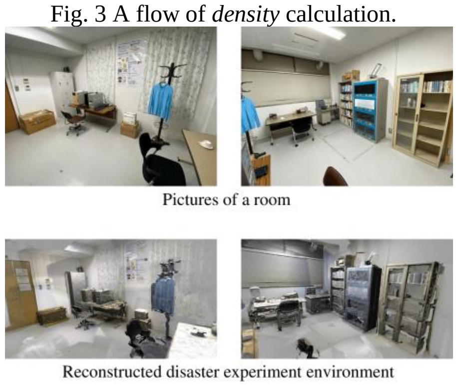

Fig.4 Pictures of a room (up) and reconstructed disaster experience environment (down).

experience, the threshold value of the force product that reproduces the sound of collision is 15 *kg*m/s*. If this threshold is exceeded, the rupture sound is reproduced. As for the fire experience, Fig. 5 shows an example of changing the size of the flame and the color of the object according to the classification result. As for the flood experience, we set *density* for each material as described in Section D.3).

III. Evaluation Experiment

A. Purpose of evaluation experiment

The purpose of this experiment is to evaluate whether the behavior of the objects in the disaster simulation increases a sense of reality and fear by recognizing the material of the objects and changing the behavior of the objects according to the recognition results. This experiment was conducted with the approval of the Research Ethics Committee for Human of the Graduate School of Energy Science, Kyoto University.

B. Evaluation experiment method

1) Procedure

First, the experimenter explained the experiment to participants and asked them to sign a consent form confirming their cooperation in the experiment. Then, they were asked to answer a questionnaire regarding

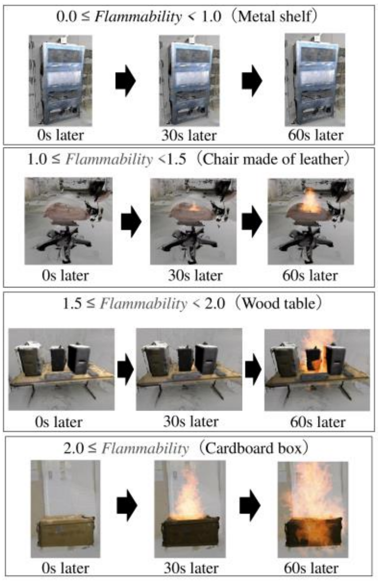

Fig.5 Examples of change of fire size and objects' color for *flammability.*

their personal attitude, such as gender, age, whether they had experienced earthquake, fire or flood, and whether they had experienced any traumatic events about disaster. Next, they wore the HMD, Oculus Rift [10], and experienced the disaster experience environment with and without material recognition. After each experience, they were asked to orally answer a questionnaire displayed in the VR space. If there was a difference in the answer of the items in the first and second questionnaires after questionnaires were answered, they were interviewed about the reasons for the difference. This process was repeated for three disasters. The order of disasters to be experienced was standardized as earthquake, fire and flood. In order to prevent the order effect of the experimental conditions from influencing the results, the order of the disaster experience environments with material recognition and without material recognition were counterbalanced.

2) Details about environment

Room 252 of Kyoto University Research Building No. 10 was used as the indoor environment for the VR disaster experience, and the disaster experience environment was constructed using this system. In this room [3580×5040mm^2], there are tables, PC, cardboard boxes, etc. These values of each object in the disaster experience environment without material recognition were randomly set.

3) Participants and questionnaire

The participants were 12 undergraduate and graduate students (8 males and 4 females). After each disaster experience, they were asked to answer the questionnaire items on a 7-point scale. Examples of questionnaires include "the sound of collision felt like an actual earthquake" and "where fire occurred felt natural."

IV. EXPERIMENTAL RESULTS AND ANALYSIS

The mean and standard deviation of all participants' responses for each disaster experience is calculated, and the results were compared using a corresponding *t*-test.

In the evaluation of the sense of reality of the earthquake experience, there was no significant difference between the experiences with and without material recognition in terms of object shaking and sound of collision. As for sound of collision, there were many scenes where multiple objects are colliding at the same time, so it is difficult to identify the source of the sound. There was no significant difference in the evaluation of the fear of the earthquake experience, in terms of images and sounds.

As for the fire experience, the evaluation of the sense of reality toward where fire occurred in the experience with material recognition tended to be higher. However, the evaluation of the sense of reality toward the size of fire and fear showed no significant difference. Some participants reported that there were no smell of the fire and no heat to be approaching, which could lead to this result.

As for the evaluation of the sense of reality of the flood experience, there was no significant difference in terms of the floating and sinking objects. In addition, as for the evaluation of the sense of fear about images and sounds, there was no significant difference.

V. FUTURE WORK

It is necessary to examine the evaluation of the disaster experience in the indoor environment where the participants actually live.

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