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Game-based Evacuation Drills using Simple Augmented Reality

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***Abstract*— Since conventional evacuation drills do not adequately simulate disaster situations, participants do not feel a sense of tension during evacuation. We developed a game-based evacuation drill (GBED) system that focuses on situational and audio-visual realities and scenario-based interactivity. To improve the visual reality in a GBED, we adopt simple augmented reality (AR) and a binocular opaque head-mounted display (HMD). The simple AR represents vague extensive disaster situations (i.e., rain, fog, smoke and fire) by superimposing the overall disaster situations (dynamic three-dimensional computer graphics) onto the real-time vision captured by a stereo camera (attached to the HMD).**

Augmented reality; head-mounted display; evacuation drills; disaster situations; disaster education, game-based learning

I. INTRODUCTION

Game-based learning (digital game-based/enhanced learning) has been attracting significant attention as a new paradigm for learning in the digital age [1]. This is because game-based learning encourages learners to think whilst having fun through game elements (gaming technologies) and accordingly increases learning motivation and effectiveness. There have been various game-based learning systems, such as an adventure game for learning intercultural business communication [2], a virtual reality-based role-play game for learning intercultural empathy, [3] and a competitive quiz game using social media for learning climate change [4].

Nowadays, the mobile computer industry (e.g., smartphones and tablet computers) has flourished. Accordingly, digital (virtual) game worlds and the real world are being integrated in game-based learning. For example, Klopfer and Squire [5] developed a story-based game that furnishes learners with scientific argumentation skills by letting them role-play detectives who identify the source of a pollutant from location-based environmental data. Sandberg et al. [6] developed a mobile English learning system that presents quizzes and puzzles about animals to learners in a public zoo. These systems use a global positioning system (GPS) to recognize locations.

Initially, we considered applying the abovementioned integration to evacuation drills. Evacuation drills, which can be considered part of field-based disaster education, encourage participants to think about how to survive natural disasters. However, conventional evacuation drills are insufficient to represent disaster situations. Participants simply follow fixed evacuation routes under the usual conditions and cannot feel a sense of tension during evacuation (disaster response). During a real evacuation, evacuees may encounter serious situations and may have to make various decisions. Therefore, we believe that evacuation drills should be more realistic and interactive. As a result, we developed a game-based evacuation drill (GBED) system that focuses on situational and audio-visual realities and scenario-based interactivity [7].

The GBED system, which uses a tablet computer with a GPS receiver, presents digital materials (e.g., slideshows, videos and single-choice questions) based on a participant's location and a branched evacuation scenario (game storyline). Most participants will have difficulty in imagining disaster situations without any experience of a real disaster. Therefore, situational reality must be considered in the evacuation scenario. Furthermore, the digital materials must realistically represent disaster situations, i.e., audio-visual reality must be considered in the digital materials.

To improve situational reality, we have developed a web-based authoring system for the GBED [8]. This system helps evacuation drill designers (e.g., disaster educators) compose evacuation scenarios and create slideshows by visualization and non-programming techniques. To improve visual reality, we have extended the GBED system by using augmented reality (AR) techniques [9]. The extended system superimposes two-dimensional computer graphics (2DCG) onto the real-time vision captured by the tablet computer's camera. We experimented with the extended GBED system in a small-scale evacuation drill and found that visual reality was still insufficient, because the AR was not realistically presented and the tablet computer's screen was not large enough for the AR.

To improve visual reality, we adopted simple AR as a restricted but usable method for representing disaster situations and a binocular opaque head-mounted display (HMD) instead of the tablet computer. The simple AR does not need visual markers and represents vague extensive disaster situations (e.g., rain and fog) realistically.

II. GAME-BASED EVACUATION DRILL

During a GBED, participants experience pseudo-disaster situations in a race-against-time scenario that involves consecutive decision-making (i.e., the game elements).

The GBED system recognizes a participant's current location and presents corresponding digital materials based on the recognized location and the given evacuation scenario.

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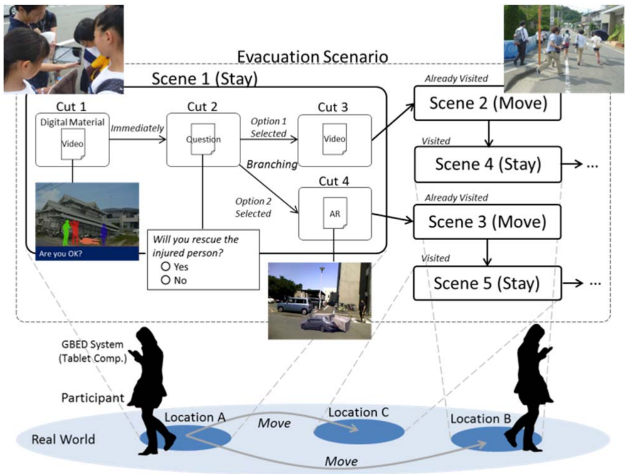

Figure 1. An example of an evacuation scenario.

A. Evacuation Scenario

The evacuation scenario, which begins at a certain location and ends at a designated evacuation site within a time limit (i.e., game rule), is composed of scenes categorized into “stay” (SS), “move” (MS), and “interrupt” (IS). Fig. 1 shows an example of the evacuation scenario. Each SS corresponds to a location and is composed of at least one “cut”. The “cut” is the smallest unit used to present digital material. MSs and ISs are independent of location and are conceptually located between SSs. Two types of branching conditions exist: “normal” and “timer interrupt” conditions. Table 1 shows examples of the normal conditions. The branched scenario allows participants to decide how they evacuate and provides them with multiple endings (e.g., safely arriving at an evacuation site has a “happy ending” and being injured has a “bad ending”).

To improve situational reality, the evacuation scenario should deal with moral dilemmas such as life-saving and safety-promoting actions that often consume time in a real evacuation. Difficult decisions must be made among multiple right choices. For example, when encountering an injured person escaping from a tsunami, an evacuee must make a difficult decision: whether to help the injured person. In the GBED system, therefore, participants should experience pseudo-disaster situations involving moral dilemmas.

TABLE I. EXAMPLES OF NORMAL BRANCHING CONDITIONS

Condition	Explanation
Option Selected	Relation: cut -> cut Every option in a single-choice question has a unique ID number. The next cut depends on which option a participant selects.
Already Visited	Relation: cut -> cut, cut -> MS The next cut/scene depends on which cut/scene a participant has visited in/till the current scene.
Visited	Relation: MS -> SS This condition is valid only for an MS where one or more SSs are the next scene candidates. When visiting one of the next scene locations—when entering a required area of the location, a participant moves to the next scene (SS).

B. AR as Digital Material

The extended GBED system recognizes an SS and presents AR as a digital material that corresponds to a cut in the SS. Fig.2 shows two examples of the AR. The AR is presented without visual markers according to the following procedure.

(i) Similarity calculation: To begin the AR, the GBED system calculates the brightness similarity between the real-time vision and a previously shot image using the sum of absolute differences.

(ii) Superimposing: The GBED system superimposes a designated 2DCG (background-transparent image) onto a designated position in the real-time vision as soon as the calculated similarity is less than a threshold.

(iii) Synchronization: To synchronize the superimposed image with the real-time vision, the GBED system adjusts the image’s position at millisecond intervals using Optical Flow, which extracts the motion vectors between two successive frames in the real-time vision.

An injured person   A crushed car

Figure 2. Examples of AR for GBED.

III. SIMPLE AUGMENTED REALITY FOR REPRESENTING DISASTER SITATIONS

In the extended GBED system, the markerless AR could eliminate visual interference (unnaturalness) caused by the presence of visual markers but it was unstable due to errors in the image processing; i.e., high geometric consistency (high accuracies of the similarity calculation and the synchronization) was not realized. Furthermore, the superimposed 2DCG was not adapted to illuminance in the real-time vision, i.e., photometric consistency was not considered. These weaknesses can decrease not only the visual reality but also the effectiveness of the GBED.

Nonetheless, since AR is a powerful method for representing disaster situations, we rethought how AR can be used to improve visual reality in the GBED.

A. Fundamental Idea

From our rethinking, we concluded that not all disaster situations have to be represented realistically. This is because during a real evacuation, evacuees may not have the time to examine disaster situations. That is, evacuees may see disaster situations subconsciously while escaping from danger. Strictly speaking, we do not have to consider geometric and photometric consistencies in the AR for the GBED system. On the other hand, we have to select disaster situations to be represented realistically by the AR.

In the GBED system, participants have to stop to view the AR at SSs (designated locations). In a real evacuation, evacuees may stop only when serious situations occur in front of their eyes (e.g., encounter an injured person or collapsed houses in their paths). In other words, the evacuees may spend most of the evacuation time moving (i.e., escaping). Such serious situations should be represented realistically by the AR with high geometric and photometric consistencies. In contrast, disaster situations that evacuees see while moving can be represented realistically by the AR without necessitating high consistencies. Note that disaster situations consisting of substantial objects (e.g., a crushed car) should be represented by the AR with a certain level of consistencies. However, technically it is still difficult to present such AR for participants who are moving.

Thus, we determined to implement AR presented during MSs, focusing on vague (insubstantial/intangible) extensive disaster situations, e.g., rain, fog, smoke, and fire. Such disaster situations shroud evacuees and make them feel a sense of tension during evacuation as a result of poor visibility. Therefore, we implement AR that covers a participant's view without necessitating high consistencies or visual markers. We refer to such AR as "simple AR" and it aims to maximize the visual reality of the vague extensive disaster situations.

Simple AR must make participants feel that they are shrouded in the specific disaster situation. In other words, the simple AR must provide high immersion, which is barely provided by tablet computers because of the small displays. Therefore, we adopt a binocular opaque HMD "Oculus Rift" instead. The HMD can provide high immersion with a 110-degree viewing angle and sensitive head motion tracking.

B. System Overview

The new GBED system, which works on high-performance mobile computers (Microsoft Windows computers) with Oculus Rift and a small stereo camera "Ovrvision", recognizes MSs according to a given evacuation scenario and presents simple AR. To represent vague extensive disaster situations realistically, the GBED system superimposes the disaster situations (dynamic three-dimensional computer graphics (3DCG) rendered by a game engine "Unity 3D" overall onto the real-time vision captured by Ovrvision. Fig. 3 shows the system overview.

The GBED system branches an evacuation scenario according to a participant's answers to single-choice questions. However, it was difficult for participants wearing Oculus Rift to answer the questions through conventional methods (e.g., keyboard, mouse and touch operations). However, the new Oculus Rift system provides a method using head motion tracking that enables the participants to answer by eye direction. In this method, they can answer by gazing at one of the designated directions associated with choices for several seconds.

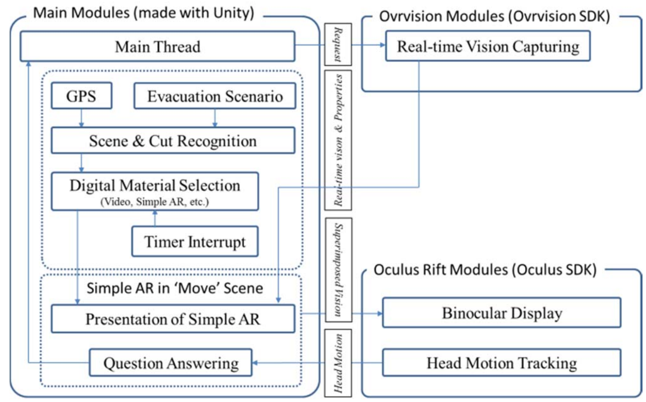

Figure 3. Overview of the GBED system with simple AR.

C. Implemented Simple AR

We have implemented the simple AR that represents four vague extensive disaster situations by superimposing semi-transparent dynamic 3DCG rendered by the particle system in Unity3D onto the real-time vison. Table 2 shows the implemented simple AR and other visual effects with examples of the disaster situations. The GBED system, which presents the simple AR in MSs according to a given evacuation scenario, described in XML, occupies a participant's view with the simple AR.

1) Rain: The GBED system can adjust representation of rain to a participant's eye direction. As soon as a participant (wearing Oculus Rift) looks up at the sky, the GBED system detects his/her eye direction using the head motion tracking and superimposes raindrops that fall to his/her view onto the real-time vision. The intensity of raining can be set in the evacuation scenario.

2) Fog: The GBED system superimposes white semi-transparent smoke at a constant change overall onto the real-time vision regardless of the participant's eye direction.

3) Smoke: The system superimposes white smoke at a constant change overall onto the real-time vision regardless of the participant's eye direction.

4) Fire: Fire is vague and extensive but relatively local. Therefore, the GBED system does not represent fire that shrouds a participant for a long time; otherwise, the participant will have nowhere to escape. The intensity and duration of a fire can be set in the evacuation scenario.

We have additionally implemented "darkness" and "shake". Darkness represents disaster situations (e.g., blackout) at night or when in a closed space (e.g. cooped up in an elevator) and shake represents an earthquake situation. These visual effects may not be regarded as AR because computer graphics (CG) are not superimposed onto the real-time vision, but are necessary to deal with various disaster situations.

An evacuation scenario (game storyline) example that includes the simple AR is shown as follows: *When a student is in a school building, a big earthquake occurs. He/she escapes from the building filled with smoke, encountering a* *fire on the way. It is raining heavily outside. Despite the rain, he/she runs to an evaluation site before a tsunami attacks.*

TABLE II. DISASTER SITUATIONS REPRESENTED BY SIMPLE AR

Disaster Situation	Imple- mentation	Example
Rain	Dynamic rendering by the Unity 3D's Particle System	
Fog	Particle System	
Smoke	Particle System	
Fire	Particle System	
Darkness	Contrast change of the real-time vision	Evacuation in dark situations (e.g., blackout and the inside of a collapsed building)
Shake	Shake of the real-time vision	Earthquake, impulsion, and giddiness

D. Related Works

Various educational AR systems are available [10], [11]. For field-based education, AR materials are often presented on mobile computers, such as PDAs [12] and smartphones [13]. A location-based educational AR system superimposes text adapted to each learner's profile and status onto the real-time vision [14]. In field-based education, the concept of AR presentation has been diversified. For example, some systems advocating AR recognize locations or real-world objects using GPS [15], quick response codes [16] or image recognition techniques [17], but do not have superimposing functions that are indispensable for effective disaster education.

The combination of AR and HMDs has also been introduced in education. For example, manipulatable 3DCGs of Earth–Sun relationships in geography [18] and curves in geometry [19] are superimposed onto real-time vision using video and optical see-through HMDs. These systems deal with subjects that do not require wearers (learners) of HMDs to make extensive movements, because they reduce awareness of surroundings and it is difficult to move around safely.

On the other hand, evacuation drills require that participants make extensive movements (widespread migration). HMDs may prevent participants from simulating a speedy escape. However, in a real evacuation, an evacuee may not accomplish a speedy escape when encountering difficulties (serious disaster situations). Therefore, we believe that evacuation drills should include various difficulties, and the combination of AR and HMDs can emphasize such difficulties by improving the situational and visual realities.

In the past, GBEDs have been realized primarily as simulation games in virtual worlds. For example, a simulation game about fire evacuation allows learners to evacuate from a virtual 3D building [20]. Other simulation games have realized virtual fire evacuation using a public 3D viewing space [21], HMDs, and other platforms [22]. Such GBEDs are sufficient for safer disaster education, but are insufficient for more realistic disaster education. In an evacuation drill in a virtual world, it is difficult for participants to realistically feel the surrounding environment, psychological pressures, and physical tiredness. Therefore, we think that a new GBED system (i.e., one having realistic evacuation drills by integrating virtual and real worlds) is necessary for disaster education.

IV. DISADVANTAGES

We interviewed participants (graduate and undergraduate students) who experimentally used the new GBED system having simple AR. Fig. 4 shows a snapshot of the experimental setup. As a result, we found the following disadvantages.

1) 3D sickness: Most participants suffered from 3D sickness to some extent due to viewing the real-time vision through the HMD. 3D sickness is primarily caused by the difference between information obtained by the eyes and other sensory organs. The mobile computer used in this experiment caused slight latency when capturing the real-time vision. We think that 3D sickness is not necessarily introduced by simple AR but it is brought about by the overall system performance. It can be reduced by higher-performance HMDs, cameras, and mobile computers in addition to our efforts to improve system implementation.

2) Difficulties in moving: Although the accompanying assistant successfully helped the participants to move around, they could not always move smoothly. We had assumed this would be true; however, difficulties in moving were more serious than expected. Some participants had to remove the HMD to move, in part due to 3D sickness. This situation must be avoided for the simple AR executed in MSs. Ideally, participants who wear the light-weight HMD with a built-in computer (e.g., Google Cardboard and a high-performance smartphone) should be able to perform the evacuation drill without an assistant.

Figure 4. Snapshot of GBED system (simple AR and HMD) in use.

V. CONCLUSIONS

In GBEDs, visual reality should be improved so that participants can feel a sense of tension in evacuation. We have focused on vague extensive disaster situations (e.g. rain and smoke) and developed a new GBED system that uses simple AR for representing the disaster situations realistically and a binocular opaque HMD (Oculus Rift). Through experimental use, we found that the GBED system may pose safety problems such as 3D sickness and causing difficulties in movement.

Our research depends heavily on devices. For example, new HMDs are being developed rapidly and wearers may soon be able to view presented AR safely while moving. We await new devices that satisfy the requirements as we continue our research. At the same time, we will further improve the visual reality and immersion in the GBED system and clarify the effectiveness of the GBED system through many large-scale practical experiments. Even though HMDs impede participant mobility, our research was shown to contribute considerably to effective disaster education.

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