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Expressing Disaster Situations for Evacuation Training Using Markerless Augmented Reality

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Abstract

Evacuation training is crucial for protecting human lives from natural and man-made disasters, but it should be more realistic to achieve training effects. In this study, we focused on expressing disaster situations using markerless augmented reality to achieve realistic evacuation training. We prototyped a scenario-based evacuation training system that superimposed three-dimensional computer graphics of disaster situations (e.g. fire and debris) onto real-time vision (captured by Android tablets or smartphones) using ARCore and Unity3D. Through preliminary experiments, we found that the prototype system can provide realistic expression and potentially be used for evacuation training, but we have not yet clarified the training results and how the expressions influenced participants' emotions.

Keywords: Augmented reality; disaster education; evacuation training; smartphone application

1. Introduction

Disaster occurrence is unpredictable; therefore, preparedness is important for protecting human lives from natural and man-made disasters. We should participate in evacuation training and learn how to evacuate to be prepared for disaster occurrences. However, traditional evacuation training is unrealistic. In such training, trainees simply follow a fixed evacuation route under normal situations; transforming normal situations into disaster situations is difficult for trainers even when a false alarm is given. Introducing virtual reality (VR) that expresses and simulates disaster situations is an approach to achieve realistic evacuation training. There have been several VR-based disaster training systems and practices. For example, Li et al. [1] developed a VR-based earthquake safety training system in which

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earthquake-hit indoor environments are precisely simulated, and trainees can acquire observation and self-protection skills for disaster survival by navigating and manipulating the simulated environments. Morélot et al. [2] reported that immersion in a VR for fire safety training promoted procedural but not conceptual learning, and these two types of learning were not affected by the sense of presence and the compositive interaction. VR-based disaster training systems are often fused with complex and high-quality games [3]. For example, Chittaro and Buttussi [4] developed a VR-based complex game for learning aircraft cabin safety and reported using a large-scale game-play analysis that improved players' safety knowledge and in-game behaviours. Feng et al. [5] developed a VR-based complex game for earthquake emergency training and reported that children acquired greater knowledge and improved self-efficacy through the game. Recent VR-based disaster training can provide not only high safety but also high audiovisual reality (immersiveness), enjoyment and training effects.

As mobile devices such as smartphones have become ubiquitous, augmented reality (AR), which can transform real-world situations into semi-virtual world experiences by superimposing computer graphics (CG) onto real-time vision, has attracted great attention and has been applied in various education training and learning programs [6]. Although not so much as VR, there are some mobile AR-based disaster training systems, for example, Sebillo et al. [7] developed an AR-based emergency responder training system that superimposes virtual information of earthquake-damaged buildings onto real-time vision, and Dong et al. [8] developed an AR-based first responder training system that superimposes 3DCG (three-dimensional CG) of disaster situations (e.g. fire and fire victims) based on disaster scenarios. These systems enable trainees to more effectively practice emergency management in real-world scenarios. Recently, AR-based evacuation training has attracted increasing attention [9]. For example, Catal et al. [10] developed an AR-based evacuation training game in which trainees can learn how to reach the nearest exit in a disaster-damaged building while observing and interacting with disaster situations (e.g. fire) superimposed onto real-time vision. There may be some challenges in AR-based evacuation training because ensuring safety and geometric registration (and tracking) in AR-based evacuation training is more difficult than in VR-based evacuation training. However, AR-based evacuation training can make trainees feel as if realistic disaster situations; therefore, in this study, we expect that AR-based evacuation training can provide a higher training effect than that provided by VR-based evacuation training.

Focusing on how AR's use for more realistic evacuation training, we developed scenario-based evacuation training systems that express disaster situations (e.g. fire, debris, wall cracks [11][12], smoke, fog and rain [13]) using marker-based and markerless AR technologies. In these systems, a trainee wears a head-mounted display and evacuates from a place in the real world while observing disaster situations. Nowadays, markerless AR has become popular with the advent of high-performance smartphones and convenient software libraries (e.g. ARCore and ARKit). In this study, we propose a scenario-based evacuation training system that expresses disaster situations using markerless AR; this system can be used in Android smartphones.

2. Realistic Evacuation Training

In a cyclic disaster management model [14], evacuation training corresponds to activities in the preparedness phase and contributes to successful evacuation (i.e. surviving disasters by oneself) in the response phase. Traditional evacuation training, which is regularly conducted in schools, companies and local communities, focuses on teaching a fundamental manner (e.g. 'evacuate calmly') and a fixed (safest) evacuation route.

We believe that evacuation training, which can be regarded as simulated disaster experiences, should be based on Kolb's experiential learning theory with four stages: concrete experience (CE), reflective observation (RO), abstract conceptualisation (AC), and active experiment (AE) [15]. Therefore, we propose an ideal evacuation training model, where trainees cyclically experience an evacuation situation (simulated disaster situations), reflect on their evacuation experiences, conceptualise better evacuation patterns and apply their concepts in the same or similar situations (Fig. 1). By following this cycle, trainees can successfully evacuate under several disaster situations, that is, they can survive different disaster types. Traditional evacuation training may focus only on CE and not necessarily lead to a successful evacuation.

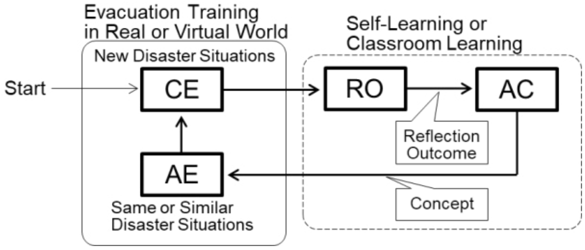

Fig. 1. Proposed ideal evacuation training model.

2.1. Scenario-based Evacuation Training

In a real evacuation, disaster situations will vary based on a combination of several factors, such as location, time and human. For example, if a recommended evacuation route is narrow, dark and crowded, another route must be found and used. Each decision will influence successful or failed evacuation. However, most traditional evacuation training does not consider decision making against unexpected and difficult situations; thus, its training effects may be insufficient. To improve training effects, we need realistic evacuation training that considers decision making, where trainees can learn how to evacuate through simulated disaster situations.

To achieve realistic evacuation training, we focus on scenario-based evacuation training. The scenario comprises designated locations and time and can be categorised on the basis of a trainee's decision making.

2.2. Situational and Audiovisual Realities

In this study, evacuation training reality is divided into situational and audiovisual realities.

- **Situational reality:** This reality depends on whether trainees perceive that virtual disaster situations are possible. To heighten this reality, evacuation training should simulate possible disaster situations (i.e. what happens when and where) in the training area. In other words, the scenario should deal with possible disaster situations and involve decision making.
- **Audiovisual reality:** This reality depends on whether trainees perceive virtual disaster situations as real-life situations. To heighten this reality, evacuation training should express virtual disaster situations with audiovisual effects.

2.3. System

To enhance the situational reality, we used geofencing that recognises whether tablet or smartphone users enter virtually designated locations (fences) in the real world and presents digital contents corresponding to the locations. This technology is suitable for evacuation training in which trainees must reach a real-world shelter while making decisions at locations.

We had previously developed a geofencing evacuation training system for GPS-enabled Android tablets or smartphones [16]. Based on a scenario written in XML, this system recognises whether trainees enter designated locations (rectangular areas designated by latitude and longitude) or time, and it presents digital contents (video and single-choice question) that express disaster situations corresponding to the locations or time (Fig. 2). In the evacuation training system, a trainee observes disaster situations and makes decisions using the presented digital contents.

Fig. 2. Scenario and digital contents.

2.4. Scenario

In this study, a scenario begins and ends at a designated location or time; a successful or failed evacuation will correspond to whether a trainee reaches a shelter within or over a time limit. The designated locations and time are referred to as scenes:

- **Stay scene (SS):** Each SS corresponds to a location and is used to express a disaster situation that may arise at the location.
- **Interrupt scene (IS):** Each IS, independent of locations, corresponds to an elapsed time or a designated time and is used to express a time-dependent disaster situation.
- **Move scene (MS):** Each MS, conceptually assigned between SSs, is prepared for trainees to reach the next SS.

Each scene has at least one cut, which corresponds to the presented digital content. A single-choice question is included in the digital content and frequently used to let trainees make a decision, i.e. to categorise a disaster scenario. The scenario is categorised according to the following conditions:

- **Option selected:** The next cut depends on which option a trainee chooses.
- **Already visited:** The next cut/scene depends on which cut/scene the trainee has visited in/till the current scene.
- **Visited:** This condition is valid only for an MS linked with multiple SSs as the next scene. The trainee visits one of the SSs from the MS.
- **Elapsed time:** Because visiting a scene exceeds a threshold, when time elapses, the trainee compulsorily visits (enters) an IS.
- **Designated time:** At a designated time, the trainee compulsorily visits an IS.

2.5. Digital Content

In a real evacuation situation, for example, we anticipate to see fire, debris, collapsed houses, injured people and other disaster-related situations. Imagining what kind of disaster situations could happen and expressing disaster situations in words is difficult for trainees; thus, disaster situations should be expressed with digital content focusing on audiovisual effects. A prefabricated video that expresses disaster situations is relatively easy to create, but its audiovisual reality is insufficient because trainees cannot feel as if disaster situations are happening in real time.

To enhance audiovisual reality, we extended the evacuation training system using AR that enables trainees to view a semi-virtual disaster situation via tablets or smartphones (Fig. 2). In other words, the system can superimpose 3DCG of disaster situations onto real-time vision. Marker-based AR can facilitate geometric registration of superimposed 3DCG; a marker must be put on in the real world, but the corresponding 3DCG only has to be superimposed onto the marker's position in real-time vision. On the contrary, markerless AR does not need a marker, but the system needs accurate geometric registration.

3. Prototype System Using Markerless AR

We prototyped a scenario-based evacuation training system that expressed disaster situations with markerless AR. We believe that disaster situations, including evacuees, should be expressed [17] because evacuees can influence trainees' cognitive biases and evacuation behaviours. For example, when heading to a shelter, people witnessing evacuees standing or walking on streets may mitigate their negative emotions (e.g. urgency, fear and anxiousness) and underestimate disaster-related dangers, whereas people witnessing evacuees sprinting on the streets may intensify their negative emotions and evacuate quickly but in panic.

We used ARCore and Unity3D to express disaster situations with markerless AR. A disaster situation expressed with markerless AR corresponds to a cut in an SS (location) and has the location (latitude and longitude) as in-scenario data (Fig. 3). The prototype system detects whether the trainee visits an SS from a trainee's current location (latitude and longitude) and then executes the following processing:

i. Checks whether a disaster situation (the current cut) is expressed with markerless AR.
ii. (If yes) Calculates the distance and relative angle between the disaster situation and trainee using spherical trigonometry. The direction of trainee's smartphone's acquired while visiting the SS serves as a baseline for the angle calculation (0, 90, 180 and 270 degrees for east, north, west and south, respectively).
iii. Transforms the calculated distance and angle to Unity, a left-hand coordinate system. In the coordinate system, a distance unit corresponds to 1 m in the real world, and the trainee's (smartphone's) location and direction are set to the origin and Z-axis, respectively.
iv. Activates the smartphone's rear camera to capture real-time vision.
v. Prompts the trainee to shoot horizontally and vertically with the camera.
vi. Detects a plane using the ARCore's plane detection.
vii. Superimposes 3DCG corresponding to the disaster situation onto the real-time vision, while fitting to the detected plane.
viii. Renders the 3DCG in consideration of environmental light (sunlight and illumination) using the ARCore's light estimation.

Expressing movable evacuees is more complicated than expressing immovable disaster situations (e.g. debris). Currently, evacuees are not included in the scenario, and the prototype system reads independent data about evacuees. For each evacuee, some ordered positions are designated beforehand, and the prototype system superimposes animated 3DCG of evacuees that move in a straight line between two positions (current and next positions) onto real-time vision. We intend to implement the superimposition based on past trainees' evacuation trajectory data (time and position). Fig. 4 shows examples of disaster situations expressed with markerless AR.

```
<flow>
  <scene no="1" type="move" id="207">
    <name>Moving</name>
    <cut no="1" id="208">
      <bgm loop="true">test.mp3</bgm><content name="" type="map"/>
      <next condition="end"/>
    </cut>
    <next condition="visited">2</next><next condition="visited">3</next>
  </scene>
  <scene no="2" type="stay" id="425">
    <name>Fire</name>
     <condition sensor="gps">34.07840648462173,134.5623296704996,34.07831873147802,134.56242488891695</condition>
     <cut no="1" id="231">
      <content type="ar_markerless" name="fire">34.07825097265929,134.56237124473816</content>
      <next condition="end"/>
    </cut>
    <next condition="button_pressed">1</next>
  </scene>
  <scene no="3" type="stay" id="436">
    <name>Debris</name>
```

Fig. 3. Settings for expressing virtual disaster situations using markerless AR.

Fig. 4. Examples of virtual disaster situations that are expressed with markerless AR.

4. Preliminary Experiments

We conducted two preliminary experiments focusing on participants' emotions to evaluate the usability of the prototype system (i.e. expressing disaster situations using markerless AR) for evacuation training. In these experiments, approximately 6-inch smartphones were used, and disaster situations were expressed without sound effects; therefore, when we asked participants about reality, it meant visual reality on a small display.

4.1. Experiment 1

This experiment, conducted as simple earthquake evacuation training with the prototype system, examined the influence of disaster situations (fire and debris) on participants' emotions and evacuation behaviours.

Settings: Participants (trainees) included ten university students studying computer science. Individually, the participants answered a question regarding their preparedness for disasters and then evacuated from the designated building (entrance) to the designated shelter in their campus. Virtual fire and debris were set to prevent the participants from evacuating through shorter routes (Fig. 5). After reaching the shelter, the participants answered 5-degree Likert scale questions regarding their emotions in the evacuation training.

Fig. 5. Disaster situations expressed in Experiment 1.

Results: Table 1 shows mean values and standard deviations of the participants' answers to the questions. Concerning participants' preparedness for disasters (Q1), the mean value was 2.8 and participants tended to have medium preparedness. Concerning their sensed reality (visual reality), the mean value of the entire reality (Q2) was 4.1 and mean values of the reality for each disaster situation (Q2-1–Q2-4) were 3.9–4.3. Concerning their sensed urgency (Q3), fear (Q4), anxiousness (Q5) and enjoyment (Q6), the mean values were 3.6, 3.2, 3.7 and 4.2, respectively. Table 2 shows the participants' evacuation times and route patterns. All the participants first saw fire at Spot A on the shortest route to the shelter and chose another route. In other words, they did not go through Spot A. Five participants saw fire and debris at Spot B but went through the spot and reached the shelter (Pattern 1). Two participants chose another route when they saw debris at Spots B and D; the two participants did not go through these spots (Pattern 2). Three participants chose another route after observing fire at Spot C and debris at Spots B and D; the three participants did not go through any of the spots (Pattern 3). The mean, shortest and longest evacuation times were 281.3, 134 and 563 s, respectively. Participants spent more time in the order of Pattern 1, 2 and 3. Unsurprisingly, this result depended on their evacuating distances. Clear relations were not found between their answers and evacuation time.

Table 1. Mean values and standard deviations of participants' answers to questions in Experiment 1.

Question	Mean	SD
Q1. How do you evaluate your current preparedness for disasters?	2.8	1.13
Options: 1 = Very low; 2 = Low; 3 = Medium; 4 = High; 5 = Very high		
Q2. Did you sense reality for the evacuation training?	4.1	0.73
Q2-1. Did you sense reality for fire at Spot A?	4.3 (n = 10)	0.67
Q2-2. Did you sense reality for fire and debris at Spot B?	3.9 (n = 10)	1.44
Q2-3. Did you sense reality for fire at Spot C?	4.33 (n = 3)	0.57
Q2-4. Did you sense reality for debris at Spot D?	4.2 (n = 5)	1.30
Q3. Did you sense urgency during the evacuation training?	3.6	1.42
Q4. Did you sense fear during the evacuation training?	3.2	1.31
Q5. Did you sense anxiousness during the evacuation training?	3.7	0.94
Q6. Did you sense enjoyment during the evacuation training?	4.1	0.99

Options for Q2–Q6: 1 = Strongly disagree; 2 = Disagree; 3 = Neither; 4 = Agree; 5 = Strongly agree

Table 2. Evacuation times and route patterns.

	Part. A	Part. B	Part. C	Part. D	Part. E	Part. F	Part. G	Part. I	Part. J	Part. K
Time (s)	169	163	277	152	151	563	134	250	440	514
Route	Pattern 1	Pattern 1	Pattern 2	Pattern 1	Pattern 1	Pattern 3	Pattern 1	Pattern 2	Pattern 3	Pattern 3

Pattern.1: Start -> Spot A (fire) -> Spot B (debris) -> The participants went through the debris. -> Goal (shelter)

Pattern 2: Start -> Spot A (fire) -> Spot B (debris) -> Spot D (debris) -> Goal (shelter)

Pattern 3: Start -> Spot A (fire) -> Spot B (debris) -> Spot C (fire) -> Spot D (debris) -> Goal (shelter)

Considerations: The mean values of Q2 and Q2-1–Q2-4 were favourable and indicated that the disaster situations were visually realistic. The mean value for Spot B (fire and debris) was slightly lower than those for Spots A (fire), C (fire) and D (debris). At Spot B, the prototype system expressed that the fire was sparse and the debris was low enough to leap over. These expressions may have prompted five participants to underestimate the danger and go through the spot. The more dangerous situations are expressed, the higher visual reality the participants may sense. The mean values of Q3, Q4 and Q5 were not highly favourable. These results may indicate that the high visual reality was not reflected in their sensed urgency, fear and anxiousness (i.e. negative emotions). The mean value of Q6 was favourable and their sensed enjoyment (i.e. positive emotion) may indicate that the participants expected further evacuation training. We need to discuss whether negative emotions should be evoked in evacuation training, how realistic disaster situations should be expressed and how positive and negative emotions should be balanced in designing evacuation training; this is because if negative emotions are extremely evoked, participants may lose self-efficacy and refuse further evacuation training. In other words, our ideal evacuation training model may not work as intended. On the contrary, if the focus is on enjoyment, participants may superficially follow the model but pay no attention to RO and AC. Although these discussions are essential for providing effective evacuation training, we have not yet considered concluding them.

4.2. Experiment 2

This experiment examined how evacuees influenced participants' emotions.

Settings: Participants were 18 university students studying computer science, who were different from those in Experiment 1. The participants answered a question regarding their preparedness for disasters and were homogeneously divided into three groups based on their answers to the question. In this experiment, the participants observed earthquake-caused disaster situations at a fixed spot through the prototype system (Fig. 6). Five participants of Group A saw fire and debris. Seven participants of Group B saw not only fire and debris but also evacuees walking on the street. Six participants of Group C saw not only fire and debris but also evacuees sprinting on the street. After observing the disaster situations, the participants answered 5-degree Likert scale questions regarding their emotions towards the disaster situations.

Fig. 6. Disaster situations expressed in Experiment 2.

Results: Table 3 shows the mean values and standard deviations of the participants' answers to the questions. We adopted ANOVA to test differences in the mean values among the three groups, assuming a normal population and homoscedasticity. Concerning the participants' preparedness for disasters (Q1), the mean values of Groups A, B and C ranged between 2.0–2.33 with insignificant differences. This indicates that the participants were homogenised among the groups. Concerning their sensed reality (Q2), urgency (Q3), fear (Q4), anxiousness (Q5) and enjoyment (Q6), the mean values were 4.0–4.33, 3.0–3.80, 2.83–3.20, 2.57–3.20 and 3.66–4.14, respectively and had no significant differences in each question.

Considerations: The mean values of Q2 were favourable and indicated that the virtual disaster situations were visually realistic for all the groups. However, no significant differences revealed that the evacuees did not remarkably influence the participants' visual reality. This may be caused by the superimposed 3D evacuees (e.g. appearances, animations and accuracy of geometric registration). The mean values of Q3 were not highly favourable and indicated that Group B did not sense the most urgency. The mean values of Q4 were unfavourable and indicated that Group C did not sense the most fear. The mean values of Q5 were unfavourable and indicated that Group B did not sense the most anxiousness. The mean values of Q6 were relatively favourable and indicated that Group C did not sense the most enjoyment. We had expected that the sprinting evacuees could increase the negative emotions (i.e. urgency, fear and anxiousness), but Group A sensed negative emotions more than Groups B and C. In Group B, the walking evacuees may have made the participants to underestimate the danger and mitigated their urgency and anxiousness by conformity bias. From the above results, we found that the walking evacuees can decrease the negative emotions of participants, but the sprinting evacuees cannot necessarily increase the negative emotions.

Table 3. Mean values and standard deviations of participants' answers to questions in Experiment 2.

Question	Group A	Group B	Group C	ANOVA
Q1. How do you evaluate your current preparedness for disasters?	2.0 (0.70)	2.28 (0.48)	2.33 (0.51)	n.s.
Options: 1 = Very low; 2 = Low; 3: = Medium; 4: = High; 5 = Very high.				
Q2. Did you sense reality towards your viewed disaster situation?	4 (0)	4.14 (0.37)	4.33 (0.51)	n.s.
Q3. Did you sense urgency towards your viewed disaster situation?	3.80 (0.44)	3.0 (1.15)	3.66 (0.51)	n.s.
Q4. Did you sense fear towards your viewed disaster situation?	3.20 (1.09)	3.0 (0.81)	2.83 (0.75)	n.s.
Q5. Did you sense anxiousness towards your viewed disaster situation?	3.20 (1.09)	2.57 (1.13)	2.83 (0.75)	n.s.
Q6. Did you sense enjoyment towards your viewed disaster situation?	4.0 (1.0)	4.14 (0.69)	3.66 (1.50)	n.s

Options for Q2–Q6: 1 = Strongly disagree; 2 = Disagree; 3 = Neither; 4 = Agree; 5 = Strongly agree.

4.3. Limitations

In these experiments, the participants were limited to university students. Disaster-vulnerable people (e.g. school children and elderly) can react differently. The expressed disaster situations were also limited. Other disaster situations can differently influence participants' emotions and evacuation behaviours. We should conduct further experiments with a wider range of people and various disaster situations to address these limitations. In addition, we should build models that explain relations between emotions and reality, including an exploration of how to evaluate reality.

5. Conclusions

This paper described a scenario-based evacuation training system expressing disaster situations using markerless AR. The results of the preliminary experiments indicated that the prototype system can provide realistic expression and be potentially used for evacuation training. However, the experiments were insufficient to clarify the influence of the expression on participants' emotions and training effects. In addition, the experiments did not focus on auditory reality (e.g. sound effects and voices) possible to evoke their emotions and enhance linguistic thinking. We must clarify training influence through large-scale experiments. To complete the system for practical use, we must increase the number of disaster situations to be expressed and improve the accuracy of geometric registration. In the experiments, a few participants reported that the expressed disaster situations were improbable and unrealistic. In addition, examining how we should design practical evacuation training using the completed system is very important to maximise the training effects.

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