A radiation learning support system by tri-sensory augmented reality using a mobile phone

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Abstract: A radiation learning support system has been developed to support learning basic knowledge of radiation and its strength of human body impact by using tri-sensory Augmented Reality (AR) technology with presenting information to visual, auditory and haptic sensation. The system consists of a knowledge learning mode in which learners can learn basic knowledge of radiation and an experience learning mode in which they can virtually experience its strength of human body impact under various conditions. As the result of a simple evaluation, it was suggested that the system improves the learners' intuitive understanding, and information presentation of the radiation strength to auditory and haptic sensation is more comprehensive than that to visual sensation.

Keyword: radiation learning; augmented reality; mobile phone; experience learning; multimodal learning

1 Introduction

Nuclear energy is being expected as a measure against global warming problem and a stable energy source in the world. However, people tend to feel uneasy about nuclear facilities including nuclear power plants (NPPs) and therefore it is tough works for nuclear companies to get public acceptance to build new NPPs and to continue plant operation when they commit accident. Especially after Fukushima Daiichi NPPs accident, not only neighbors but also people living even more than 100km far from Fukushima Daiichi NPPs are unnecessarily afraid of radioactive harm to their health. Slovic indicated that our risk perception has mainly two factors which are "unknown" and "dread"[1], and the radiation has high risk perception because of its high "unknown factor". On the other hand, many workers have been engaged in dangerous decontamination maneuver to recover the heavily damaged Fukushima Daiichi NPPs at present. They should be properly protected from radioactive dosage to prevent their occupational harm. This is similar situation in maintenance and decommissioning works in other NPPs. From these viewpoints, it is important for not only field workers of NPPs but also general public to have enough knowledge of radiation and understand its characters, especially radioactive harm to human body.

The strength of human body impact caused by radiation varies depending on such as the type of the radiation, distance from radiation source and radiation shield. It is however difficult to understand it intuitively because they can not see, hear nor feel its existence like electric field and magnetic field. In addition, it is troublesome in reality to conduct an experiment for radiation education because we should prepare not only radioactive materials and its detectors but also appropriate protective wear in advance.

On the other hand, recent improvement of information and communication technologies has created new information presentation methods like augmented reality (AR). The AR is a technology which expands real world by merging additional information. Concretely, it can expand the users' perception by superimposing computer-generated information into their surrounding world. Utilizing this feature, research activities have been promoted in various fields such as medical, architectural, industrial, educational and entertainment fields[2,3].

From these backgrounds, the purpose of this study is to develop a radiation learning support system to improve learners' intuitive understanding of radiation by AR technology. Although conventional AR mainly superimposes computer-generated visual information such as text message and computer graphics onto users' surrounding view in order to expand their perception[2,4,5], the proposed system utilizes an

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imaginary radiation source and presents its strength of human body impact as not only visual information but also auditory and haptic information. This method does not use a real radiation source and a radiation detector however the learners can virtually experience the strength of human body impact by perceiving it via their visual, auditory and haptic sensations. Because of this new learning method by the virtual experience, it is expected that learners can not only understand character of radiation and its strength of human body impact as knowledge but also understand them intuitively. “Intuitive understanding” in this study means that they can understand the knowledge without their conscious thought.

Related to this study, various studies of multimodal interaction have been made in various fields using visual, auditory and haptic information[6,7]. For example in a rehabilitation field, virtual reality environments have been developed presenting not only visual information but also auditory and haptic information[8-10]. As an AR environment using the multimodal interaction, IMSS has been developed to design portable digital devices[11]. Especially in the field of education, various application studies have been made by utilizing the learning effect that the multimodal interaction improves learners’ understanding and memorization[12-14]. In this study, the radiation learning support system has been proposed in which not only radiation distribution is visualized but also its strength at the learners’ position is presented as both auditory and haptic information in order to realize the learning effect.

The structure of this paper is as follows; the design and development of the proposed system are described in chapter 2, then the method and the results of evaluation experiment are followed in chapter 3. Chapter 4 describes the conclusion of this paper.

2 Development of a radiation learning support system

2.1 Purpose of system

The purpose of the system is to improve learners’ intuitive understanding of character of radiation and its strength of human body impact by utilizing tri-sensory AR technology which presents information not only to visual sensation but also to auditory and haptic sensations. The target learners of the system are field workers of NPPs and general public who have basic knowledge of mathematics, physics, chemistry and biology learned in high school. The learning contents are basic knowledge of radiation characters and the strength of human body impact under various conditions which are useful to prevent themselves from radioactive harm.

2.2 System outline

This system mainly deals with character of radiation regarding the strength of human body impact. They are varied by type of radiation, distance from radiation source, amount of radioactivity, radiation shield and attenuation by time. The system therefore enables learners to virtually experience the difference of the impact strength by changing radiation sources, distance, radioactivity, shields and attenuation by time. In order to learn these impacts effectively, it is to be desired that they learn the basic knowledge of radiation in advance of the virtual experience. This system therefore consists of “knowledge learning mode” and “experience learning mode”, which are to learn basic knowledge of radiation and to experience the strength of human body impact by AR with tri-sensory information, respectively.

This system employs iPhone 3GS as a learning device which has both a display and a backside camera in its small and light body. In addition, it offers a touch sensitive display for comprehensive user interface. Table 1 shows the concrete specification of iPhone 3GS.

Table 1 Specification of iPhone 3GS[15]

Item	Specification
Size	115.5 x 62.1 x 12.3 mm
Weight	135g
CPU / GPU	600 MHz ARM Cortex A8 processor, PowerVR SGX535 GPU
OS	iPhone OS 3
Display	TFT capacitive touchscreen, 16M colors, 320 x 480 pixels, 3.5 inches
Sound speaker	Frequency: 20Hz to 20,000Hz
Camera	3.15 MP, 2048x1536 pixels, autofocus, Video:VGA@30fps

2.2.1 Knowledge learning mode

The knowledge learning mode offers basic information of radiation to the learners before they learn in the experience learning mode. In this mode, the following specifications are required to realize effective knowledge learning.

1. Basic knowledge of radiation is provided comprehensively,
2. Learning contents can be perused in order,
3. They can be easily reviewed and
4. Learning progress can be easily confirmed.

2.2.2 Experience learning mode

The experience learning mode improves the learners' understanding especially about the radiation impact on the human body by virtually experiencing the strength of radiation from a virtual radiation source under various conditions. As mentioned above, the impact is related to the five factors such as type of radiation, distance from source, amount of radioactivity, material and thickness of radiation shield and attenuation by time. This mode is therefore required the following specifications.

1. Type of radiation can be easily changed by changing radiation source,
2. Distance from the radiation source can be easily changed,
3. Amount of radioactivity can be easily changed,
4. A radiation shield can be easily placed in any position,
5. Material and thickness of the shield can be easily changed and
6. Attenuation time of the radiation sources and elapsed time can be virtually changed.

In order that learners can virtually feel and experience the strength of human body impact, the system utilizes tri-sensory information presentation. For visual and auditory sensation, a display and a speaker of iPhone are employed. On the other hand, for haptic sensation, the authors have developed a new clicking sensation presentation device which presents the strength of the human body impact as a frequency that virtual radiations hit the body. In order to realize the above, the following specifications are also required;

7. Radiation distribution can be seen via a display of iPhone,
8. The strength of radiation can be heard as the sound volume via a speaker of iPhone and
9. It can be also experienced as the frequency of clicking feeling in haptic sensation.

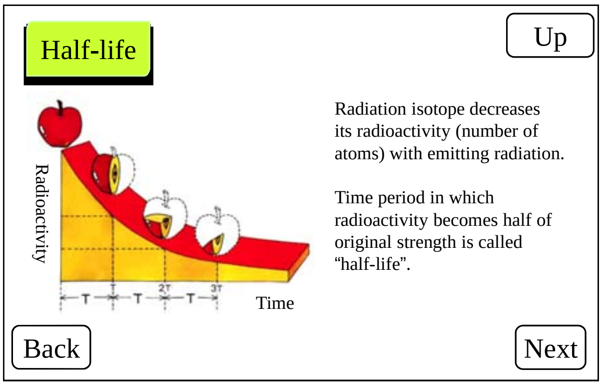
2.3 System design

2.3.1 Design of knowledge learning mode

Table 2 shows the learning contents of the knowledge learning mode. In order to learn these contents effectively, pictures and figures are often used as shown in Fig. 1 to improve learners' comprehension and memorization. The learning contents are classified into 7 chapters as shown in Fig. 2. And when they touch one of the chapter title buttons, the first page of the chapter contents is displayed. In each content page, there are [Next], [Back] and [Up] buttons to move to next, previous and the chapter title pages respectively. After learning all the contents pages of the chapter, the text color of the title button will turn red and "(Done)" mark will be added to show users' learning progress. This mark can be erased by touching [RESET] button on the title page for reviewing the contents again.

Table 2 Learning contents of knowledge learning mode

Chapter	Contents
Radiation and radioactivity	Radiation, radioactivity, definition of half-life
Types of radiation	Category of radiation, radiation sources of each radiation, characteristics of radiation
Unit	Definition of Bq, Gy and Sv
Utilization of radiation	Examples of radiation utilizations
Influence on human body	Deterministic influence, probabilistic influence, influence by high and low dose
Radiation protection	Basic knowledge to reduce radiation exposure, dose limitation by law
Natural radiation	From aerosphere, from ground, radiation in daily life, *etc*.



Radiation isotope decreases its radioactivity (number of atoms) with emitting radiation.

Time period in which radioactivity becomes half of original strength is called "half-life".

Fig. 1 Design of learning content page.

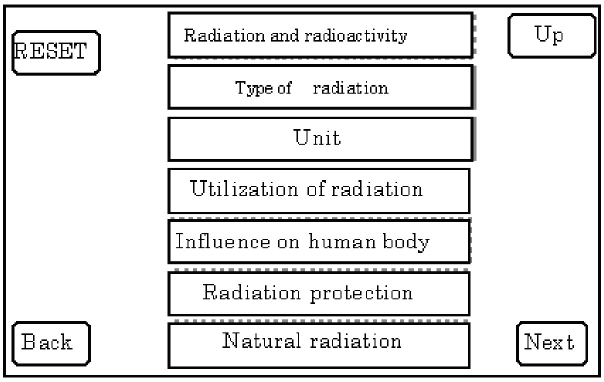


Fig.2 Design of chapter title page.

2.3.2 Design of experience learning mode

In order to realize the virtual experience of human body impact from a virtual radiation source, artificial AR markers are utilized as a radiation source and a radiation shield. Figure 3 shows a dice-shaped marker as the virtual radiation source and a marker panel attached on a tripod as the virtual radiation shield. By preparing various markers which expresses various type of radiation source, radioactivity and radiation shields, the learners can easily change them by changing and placing the corresponding markers. Other AR markers are also pasted on the walls of a learning room in advance as shown in Fig. 3 in order to track the positions and the orientations of virtual radiation sources and the virtual shields[16].

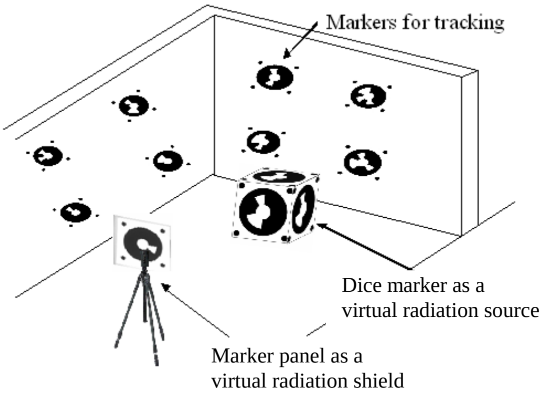


Fig. 3 Artificial markers for AR.

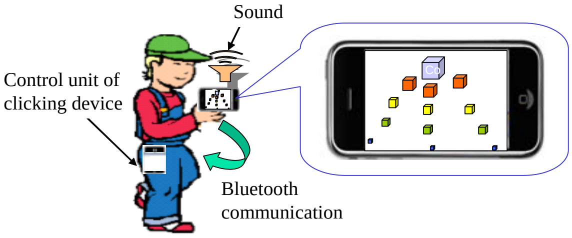


Fig. 4 System hardware of experience learning mode.

In order that the learner can feel the radiation impact on the body, radiation distribution is presented on the display of iPhone and its strength at the learner's position is presented as a sound volume from the speaker. At the same time, clicking sensation is presented by driving 10 small flapper type solenoids wearing on the learner's upper body according to the strength of impact by the virtual radiation. The hardware of the system consists of iPhone and a clicking device as shown in Fig. 4 in order to realize these functions.

When capturing a dice marker as a virtual radiation source by a camera of iPhone, the position, the type and the radioactivity of the source are identified by the marker information and the radiation distribution is calculated in real time. When a marker panel as a virtual radiation shield is placed in front of the radiation source, its effect is also calculated. 3DCG which expresses virtual radiation distribution is superimposed on the captured image according to the calculation results and presented to the learner via the display. At the same time, the sound volume is changed to express the degree of impact at the learner's position.

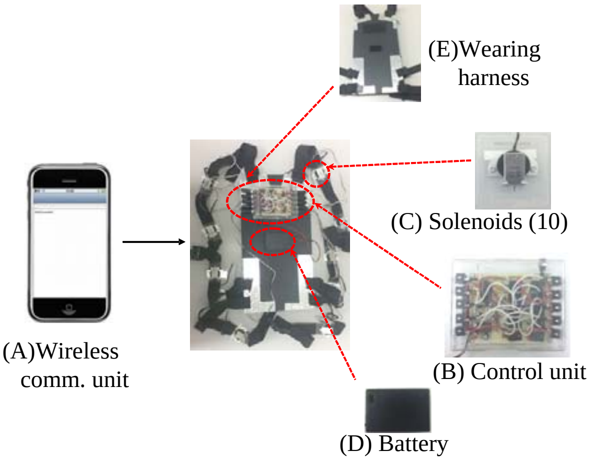


Fig. 5 Modules of clicking device.

On the other hand, the clicking device consists of the following five modules as shown in Fig.5 to realize clicking sensation to express hitting feeling of the virtual radiation.

(A) Wireless communication unit,
(B) Control unit,
(C) Solenoids for clicking sensation presentation,
(D) Battery and

(E) Wearing harness.

(A)Wireless communication unit receives the strength of the radiation impact from the iPhone via Bluetooth communication in real time and send it to (B)control unit. (B)Control unit changes the driving frequency of (C)solenoids attached on the learner's upper body according to the strength of the impact. (D)Battery provides electric energy for (B)control unit and (C)solenoids. (E)Wearing harness supports the learner to easily attach (A)-(D) devices on the upper body.

2.3.3 Experience contents

In the experience learning mode, the learner experiences the change of radiation impact under changing the following five condition factors.

(1) Type of radiation (source)

The learner experiences the difference of the impact depending on the type of radiation using three dice markers as radiation sources which virtually radiate alpha, beta and gamma radiations.

(2) Attenuation by distance

He/She places a dice marker as a gamma radiation source, walks around it to change the distance from it and experiences the attenuation by distance.

(3) Radioactivity

He/She places two dice markers which express gamma radiation sources of 1.0GBq and 0.2GBq radioactivity and experience the difference of the impact depending on the difference of radioactivity.

(4) Radiation shield

Using dice markers of alpha, beta and gamma radiation source and marker panels which expresses radiation shields of paper, thin plastic, 150mm iron plate, 30mm lead plate and 50mm lead plate, he/she experiences the effect of various radiation shields.

(5) Attenuation by time

He/She first places two dice markers as radiation sources of different half life. Then he/she virtually changes elapsed time by touching one of time elapse buttons on the display and experiences the effect of attenuation by time.

2.4 System implementation

The software of iPhone has been developed in Xcode 3.0 provided by Apple and its language is Objetive-C. 3DCG is displayed utilizing OpenGL ES library.

2.4.1 Implementation of knowledge learning mode

Figure 6 shows a top page of the knowledge learning mode. There are chapter title buttons to learn the contents of each chapter and the learners can move there by touching one of the buttons. The total number of learning contents pages is 35 as shown in Table 2.

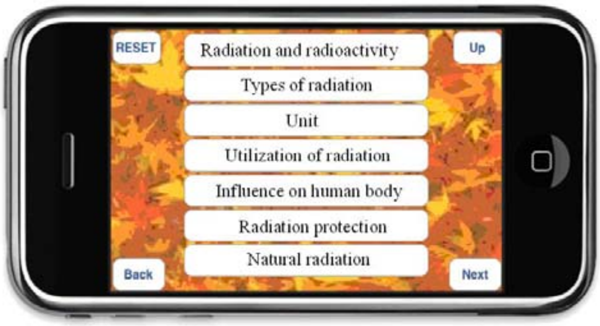


Fig. 6 Top page of knowledge learning mode.

2.4.2 Implementation of experience learning mode

Figure 7 shows a top page of the experience learning mode. They can experience each learning contents as mentioned in 2.3.3 by touching one of the corresponding buttons. After touching it, an explanation page of the content is displayed, then the virtual experience starts by touching [Next] button. Figure 8 shows an example display when a dice marker is placed as a virtual beta radiation source. When a marker panel is placed as a virtual radiation shield, it is displayed as shown in Fig. 9.

As mentioned in 2.3.2, the radiation distribution is calculated in real time when a radiation source and a shield is placed. The calculation employs radiation calculation library developed by Institute for Energy Technology, Norway[17]. As shown in Fig. 8, the calculated radiation distribution is visually displayed by superimposing colored cubes on the image captured by a backside camera of iPhone. The degree of the impact at the learner's position is presented to the auditory sensation as a sound volume from the speaker. The volume varies as an exponential function in order that the strength of auditory sensation is consistent with the strength of the impact according to Weber-Fechner's law[18]. The impact is also presented to haptic sensation by using a newly developed clicking device as mentioned in 2.3.2. Figure 10 shows a picture when a learner wears the device. There are 10 flapper type solenoids as shown in Fig. 11 attached on the upper body and their driving frequency varies according to the calculated the strength of human body impact.

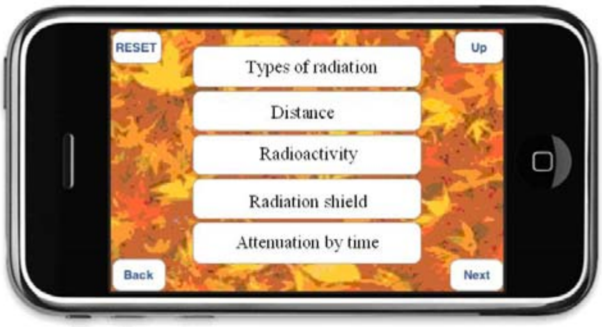


Fig. 7 Top page of experience learning mode.

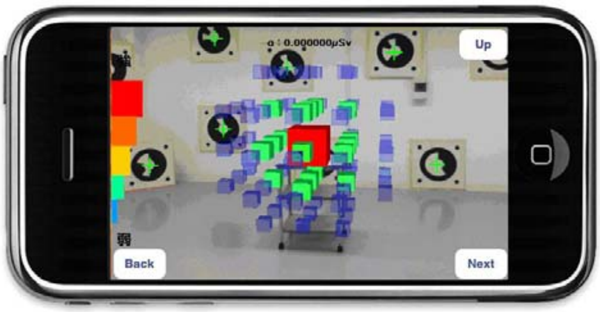


Fig. 8 An example of radiation distribution.

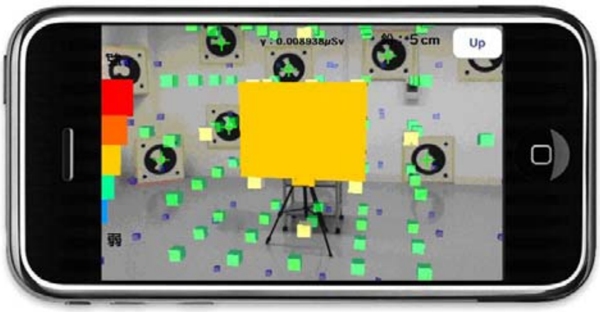
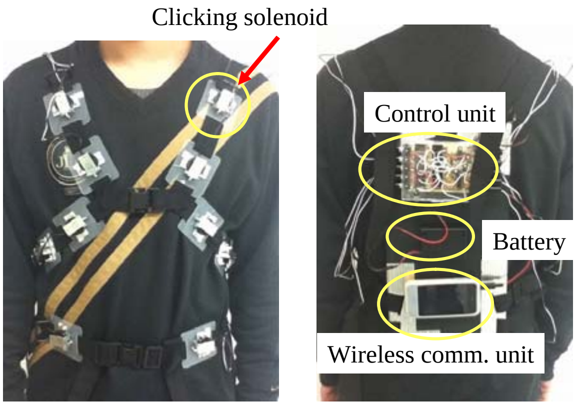


Fig. 9 An example display when a shield is placed.



Front side Back side

Fig. 10 Clicking device worn on upper body.

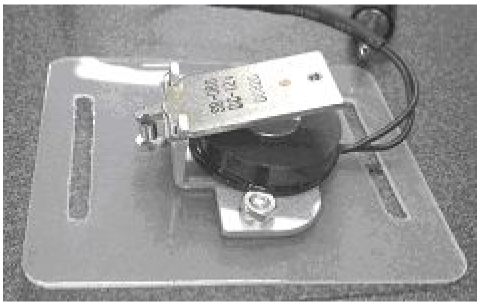


Fig.11 A flapper type solenoid.

3 System evaluation

3.1 Purpose of evaluation

A radiation learning support system has been developed according to the system designs as mentioned in chapter 2. By using the system, a simple evaluation was conducted to confirm whether it properly realizes the specifications, functions and whether it is effective to improve learners' intuitive understanding of radiation characters.

3.2 Evaluation method

3.2.1 Evaluation environment

Figure 12 shows the top view of learning room. 16 circular markers of 200mm radius were pasted on the walls as tracking markers and their positions and orientations were automatically measured by Marker Automatic Measurement System (MAMS) [19]. Several dice markers with sides 230mm long were prepared as virtual radiation sources and circular markers with 80mm radius were pasted on every plane as shown in Fig. 13(a).

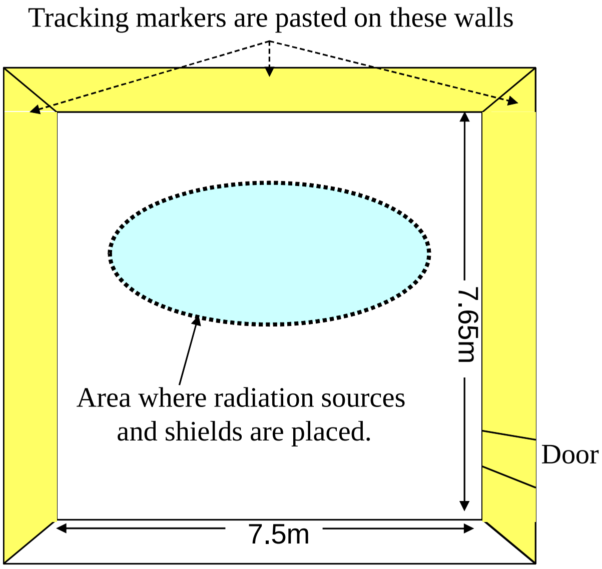


Fig.12 Top view of learning room.

Several square marker panels with sides 225mm long were also prepared as virtual radiation shields attached on tripods and circular markers with 80mm radius were pasted on the panels as shown in Fig. 13(b).

(a) Dice-shaped marker (radiation source)

(b) Marker panel (radiation shield)

Fig. 13 Dice-shaped marker and marker panel.

3.2.2 Evaluator

The evaluators were 8 university students who had never taken special radiation education.

3.2.3 Evaluation procedure

Table 3 shows the evaluation procedure and its outline is described below.

(1) Explanation of the evaluation procedure to the evaluators,

(2) Use of the system along with the learning scenario described below and

(3) Questionnaire and interview.

Table 3 Evaluation procedure

Time (Approx.)	Procedure
10 min.	Explanation of evaluation procedure. Signature on letter of consent.
20 min.	Learning basic knowledge of radiation in the knowledge learning mode.
5 min.	Break.
10 min.	Explanation and preparation of the experience learning mode.
40 min.	Experience learning in the experience learning mode.
5 min.	Questionnaire and interview.

3.2.4 Learning scenario

The evaluators first study basic knowledge of radiation in the knowledge learning mode, then they virtually experience the variation of the impact under various conditions by using the experience learning mode. The concrete learning contents in the experience learning mode are as follows;

(1) Type of radiation

They first place three dice markers on the floor which express alpha, beta and gamma radiation source of 1.0GBq radioactivity, then experience the difference of the impact by the different types of radiation.

(2) Distance from radiation source

They first place a dice marker which expresses a gamma radiation source of 1.0GBq radioactivity on the floor, then virtually experience the attenuation of the impact strength while walking around it and changing the distance from the virtual radiation source.

(3) Radioactivity

They first place two dice markers on the floor which express gamma radiation sources of 1.0GBq and 0.2GBq radioactivity, then virtually experience the difference of the impact by the difference of the radioactivity.

(4) Radiation shield

They first place a virtual gamma radiation source on a small table, and also place one of the marker panels which express paper, plastic, iron and lead of 30mm and 50mm thickness as radiation shields in front of the radiation source. Then they virtually experience the difference of the impact by the different shields. They also experience placing alpha and beta radiation source in the same manner.

(5) Attenuation by time

They first place two virtual gamma radiation sources of 250 days and 5.26 years half life on the floor, then they virtually change elapsed time by touching one of the buttons which proceed virtual elapsed time and experience the attenuation by time.

Fig.14 shows a scene when an evaluator learned in the experience learning mode.

3.2.5 Questionnaire and interview

In order to examine whether the specifications and the functions of the system as mentioned in chapter 2 are properly realized or not, they answered a questionnaire. Each questions were answered in the format of five grade Likert scale from 1:disagree to 5:agree. They also answered good points and the point to be improved as free description at the bottom of the questionnaire. After the questionnaire, they had an interview for the details based on their questionnaire answers

Fig. 14 A scene of experience learning mode.

3.3 Evaluation result and discussion

3.3.1 Knowledge learning mode

Table 4 shows the questionnaire results of the knowledge learning mode. The average of the results from Q1 to Q4 is larger than 4, while that of Q5 is below 3. The [RESET] button is used to reset the learning progress record when they want to study the contents again. In this evaluation however they didn't use the button and they could not confirm the function of the [RESET] button.

3.3.2 Experience learning mode

Table 5 shows the evaluation results of the experience learning mode. Most of the results are more than 4, while the result of Q8 is 3.25 because of the same reason as Q5 above.

As the expression method of radiation, this system employs three sensory information presentations. The average results of Q14 and Q15 which evaluate visual expression of radiation are less than 4. It is necessary to reconsider the visual expression method of radiation distribution more comprehensively. On the other hand, evaluator D answered that the radiation strength expression by color was comprehensive in his free description.

The results of Q16 and Q17 which evaluate auditory and haptic sensation expressions are 4.00 and 4.75

Table 4 Results of questionnaire for knowledge learning mode

Questions	Average
Q1. I could learn basic knowledge of radiation easily with explanation text and figures.	4.38
Q2. I learned the contents in order.	5.00
Q3. I could choose the content which I wanted to review by touching one of the title buttons.	4.38
Q4. It was easy to confirm the progress of my learning.	4.00
Q5. [RESET] button was useful when I wanted to learn them again.	2.88

Table 5 Results of questionnaire for experience learning mode

Questions	Average
Q6. I could choose the experience content to learn by touching one of the title button.	4.88
Q7. It was easy to confirm the progress of my experience learning.	4.25
Q8. [RESET] button was useful when I wanted to learn them again.	3.25
Q9. I could easily change the kind of radiation source by changing dice-shaped markers.	5.00
Q10. I could easily change the distance from the source by walking around with iPhone.	4.88
Q11. I could place a virtual shield freely by placing a marker panel.	4.00
Q12. I could easily change the material and thickness of the virtual shields by changing the kinds of marker panels.	4.63
Q13. I could change the virtual time by touching one of the elapsed time buttons.	4.75
Q14. I could easily see the camera image and 3DCGs on the iPhone display.	3.63
Q15. The radiation distribution expressed as 3DCG was intuitively comprehensive.	3.75
Q16. I could intuitively understand the strength of radiation from the sound volume change.	4.00
Q17. I could intuitively understand the strength of radiation from the click frequency change.	4.75
Q18. The clicking device did not prevent from my body motion.	4.63
Q19. I could intuitively understand the character of radiation by learning with this system	4.63

respectively, while those of Q14 and Q15 which evaluate visual sensation expression were below 4 as mentioned above. This result suggests that auditory and haptic sensation expressions are more effective for intuitive understanding.

The result of Q19 is positive by all the evaluators and this indicated that they could intuitively understand the character of radiation and its impact by using this system.

On the other hand, the following opinions were obtained from free descriptions of questionnaire and interviews.

(1)Auditory sensation expression from iPhone speaker was hard to be heard because of click sound of clicking device (evaluator A,E,G),

(2)Radiation distribution expression was hard to be seen because of a small display of iPhone (evaluator D), and

(3)Learning contents were hard to be read because of a small display in the knowledge learning mode (evaluator F,H).

4 Conclusion

In this study, a radiation learning support system has been developed in which learners can not only learn basic knowledge but also experience virtual radiation in their visual, auditory and haptic sensations by tri-sensory augmented reality to improve intuitive understanding of the character and human body impact of radiation.

As the result of the simple evaluation experiment, it was suggested that tri-sensory information presentation is effective for intuitive understanding, and especially auditory and haptic information presentation is more comprehensive than visual one. It was also found that clicking sound of the haptic information presentation may prevent auditory information presentation, so that the conflict between these two modalities should be considered.

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