Development of scattered radiation distribution visualization system using WebAR

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Abstract. Radiation protection education is difficult for some radiological workers to taking because they are busy with medical work. In radiation protection, understanding the behaviour of scattered radiation is important for reducing exposure. Although applications that visualize the behaviour of scattered radiation using augmented reality or virtual reality have been developed, such applications are limited by the need to download the application and the performance of the device. We have developed a system that can be used in a web browser to visualize the behaviour of scattered radiation more easily. Monte Carlo method was used to simulate the behaviour of scattered radiation during radiography using a portable X-ray machine. An augmented reality (AR) system was developed using A-Frame, an open-source web framework, and AR.js, which adds the AR function. Finally, the behaviour of scattered radiation was observed using various devices. With AR, the behaviour of scattered radiation was visualized in three dimensions. The newly developed AR system can be used with web browsers to easily learn the behaviour of scattered rays without the need for special devices.

1. Introduction

Radiological workers may have little opportunity to receive proper education on radiation protection because of their busy work schedules [1] [2]. Good knowledge of radiation protection is necessary for these workers to be able to perform their duties safely, and thus methods that help workers acquire this knowledge quickly and easily are being developed. In radiation protection, one of the important factors to understand is the behaviour of scattered radiation, which helps in reducing one’s exposure to radiation [2]. However, visualization of the behaviour of scattered radiation is difficult because scattered radiation is invisible.

In the past, the spread of scattered rays was displayed in two-dimensional (2D) isolines and colour images [3]. However, the behaviour of scattered radiation is 3D, and understanding how scattered radiation actually spreads in an examination room can be difficult if only the conventional 2D methods are used. Research using technologies such as virtual reality (VR) and augmented reality (AR) has thus made it possible to observe the spread of radiation in 3D and to visualize the behaviour of scattered radiation. In a study by Matthias et al., VR was used to visualize the behaviour of scattered radiation during intraoperative imaging and fluoroscopy using a C-arm [4]. The study demonstrated how VR allowed the operator to confirm the captured image and observe the behaviour of scattered radiation.
from the C-arm operation, which is effective for education on radiation protection. On the other hand, in a study by Nicolas et al., AR was used to visualize the behaviour of scattered radiation during angiography [5]. In that study, the behaviour of scattered radiation was simulated from the position of the C-arm and displayed using AR.

Conventional research that uses AR or VR technology for visualization [4, 5] required dedicated cameras and controllers, which makes it difficult to apply the proposed methods to practical use in radiation protection education. To counteract these problems, the use of WebAR, a method that enables the use of AR in a web browser, in the visualisation of the behaviour of scattered radiation is proposed. Compared to conventional AR/VR methods, WebAR has fewer OS-related limitations, does not need to be downloaded, and shows little dependence on the performance of the device. WebAR allows the behaviour of scattered radiation to be easily observed via the AR function on a wide variety of devices.

The purpose of this study is the development of a system for radiation protection education that visualizes the behaviour of scattered radiation during portable imaging using WebAR and can be used easily even without a special device.

2. Materials and methods

2.1. Simulation of scattered radiation behaviour in portable imaging

A typical example of radiation work that medical personnel perform is imaging using a portable X-ray imaging machine. Therefore, in this study, the behaviour of scattered radiation when using a portable X-ray imaging machine was simulated. To simulate this behaviour, the Monte Carlo simulation code Particle and Heavy Ion Transport code System (PHITS) version 3.17 [6] was applied. The simulation assumed a recumbent chest X-ray. An X-ray tube, X-ray source, bed (height 60 cm, length 240 cm, width 120 cm), portable X-ray equipment, and patient, in the form of a human body voxel phantom patient in accordance with the International Commission on Radiological Protection (ICRP) [7], were prepared. The geometric arrangement is shown in Figure 1. X-ray spectrum by Tucker’s formula version 4 (X-Tucker-4) [8], a diagnostic region X-ray spectrum calculation software, was used to calculate the continuous energy spectrum, given a tube voltage of 80 kV and intrinsic filtration of 2.5 mmAl, at 0.5 keV intervals. The data obtained were used to simulate the radiation source. The irradiation field was irradiated such that the distance between the focus and the detector was 120 cm and that the irradiation field was $35.4 \times 43\text{cm}^2$ [9]. The tube current could not be set via PHITS. The quotient of the ambient dose equivalent [10] and the incident surface dose of 0.2 mGy per irradiation under the simulation conditions was then assigned to be the value of relative dose; the displayed value is the relative dose. For the resolution, the imaging room was divided into cubes of side 2 cm. The result of the simulation of the behaviour of scattered radiation was confirmed in 2D, on the front and side of the patient, as shown in Figure 2.

![Figure 1. Geometrical positional relationship during simulation.](image-url)
Figure 2. Behaviour of scattered radiation in 2D: (a) side of patient, (b) front of patient.

2.2. 3D display of simulation data
The 3D visualization software ParaView version 5.6.0 [11] was used to display the spread of scattered radiation for each specified dose value range. The 3D images were rendered on VR, as shown in Figure 3. In addition, colour was assigned to each dose value and was used to distinguish the corresponding spread of scattered radiation.

The 3D volume data from the PHITS simulation were converted into polygon data. The surface of the 3D geometry data output rendered by ParaView was rough, and thus, the 3D data processing software Blender version 2.79 [12] was used to smoothen the surface (Figure 4). The extension of the Blender file was (.obj), whereas the extension of the PHITS volume data was (.vtk). Meanwhile, the data file converted to use the data extension (.obj) represents the 3D geometry only rendered in ParaView.

| Displayed relative dose Range [μSv/0.2mGy] |
|------------------------------------------|
| (a) 100-1000                             |
| (b) 10-100                                |
| (c) 1-10                                 |
| (d) 0.5-1                                 |
| (e) 0.1-0.5                               |

Figure 3. 3D display of spread of scattered radiation.
2.3. WebAR system development

Based on the smoothed data, the WebAR system was created using Glitch [13], a service used to create and publish web applications for free. To add AR functions, an AR system was developed using A-Frame version 1.02 [14], which is an open source web framework, and AR.js version 3.0 [15], which is a JavaScript library for adding AR functions. These added functions included 3D data arrangement of marker type AR and X-ray tube, and display of cross-sectional image of the scattered radiation distribution.

A user can start up the system via its URL or its QR code connected to the URL. When the system boots, the camera boots first. When the AR marker (Figure 5) is recognized by the camera, a 3D object is displayed. The device can be moved to allow observations to be made from any direction.

![Figure 5. AR marker.](image)

2.4. Operation verification on multiple devices

The differences in the operation of the WebAR system, when used in different devices, were investigated. Table 1 lists the devices used in this study. Each of these devices, which are all owned by the laboratory, has a camera facing outward. The AR.js library, which enables WebGL and WebRTC to be used, should be operated in either Google Chrome for Android 5.1 or later, or Safari for iOS 11 or later [15]. The amount of time for the WebAR system to load and for the camera to start up, and the degree of tracking to recognize the marker were examined.

| OS        | Device                     | Browser         |
|-----------|----------------------------|-----------------|
| iOS 13.6.1| iPhone XR A2106            | Safari 13.1.2   |
| iOS 13.2  | iPad Pro (12.9 inch) A1584 | Safari 13.0.3   |
| Android 7.1.1 | Nexus 9                 | Google Chrome 75.0.3770.101 |
3. Results

3.1. Display in WebAR
Figure 6 shows the actual behaviour of scattered radiation observed at the terminal. When the marker was captured by the camera, the spread of scattered radiation could be observed from any direction. In addition, the spread of scattered radiation, which varies depending on the dose value, could be observed (Figure 7).

Figure 6. View on WebAR (a) from top, (b) from feet, (c) from side.

Figure 7. Behaviour of scattered radiation displayed for each range of dose values: (a) 100–1000 [μSv / 0.2 mGy], (b) 10–100 [μSv / 0.2 mGy], (c) 1–10 [μSv / 0.2 mGy], (d) 0.5–1 [μSv / 0.2 mGy], (e) 0.1–0.5 [μSv / 0.2 mGy].
### 3.2. Operation verification for each device

The operation was tested on all devices listed in Table 1. The system started up on iPhone XR, iPad Pro, Nexus 9, and Arrows Tab QH30/W, but not on iPad mini and ZenFone2 Laser_Z00ED. Meanwhile, Table 2 outlines the results of camera start-up time measurements.

| Display device       | Data size              |                              |
|----------------------|------------------------|------------------------------|
|                      | Small (453 KB)         | Large (83436 KB)             |
| iPhone XR A2106      | 1.81                   | 11.41                        |
| iPad Pro (12.9 inch) A1584 | 1.44                   | 10.55                        |
| Nexus 9              | 4.39                   | 13.06                        |
| Arrows Tab QH30/W Edge | 11.73                   | 20.37                        |
| Arrows Tab QH30/W Chrome | 12.23                   | 20.74                        |

When the data size of the display was small, the camera start-up times on iPhone XR and iPad Pro were the shortest, which were then followed by the camera start-up time on Nexus 9. Arrows Tab QH30/W was the only device where the boot time exceeded 10 s. There was little difference in the start-up times between Microsoft Edge and Google Chrome. For all devices, the larger the data size of the displayed object, the longer the time required to start the camera. As shown in Table 2, the start-up time was the shortest for iPad Pro and the longest for Arrows Tab QH30/W. On Nexus 9 and on Arrows Tab QH30/W, the display became unstable when the data size increased. When Nexus 9 was used, the display position of the 3D display object when the device orientation was landscape was different from when the device orientation was the portrait.

Regarding the tracking of the marker, the range in which the device can be moved relative to the marker was large, in the order of iPhone XR, iPad Pro, Nexus 9, and Arrows Tab QH30/W. Meanwhile, recognizing the markers is difficult for Arrows Tab QH30/W even with the same markers.

### 4. Discussion

#### 4.1. About displayed WebAR functions

Because the system can be used with a web browser, the system can be used more easily than other applications that require downloading of AR or VR. The 3D display via AR allows the behaviour of scattered radiation to be observed in 3D, which can help the user to understand the exposure of scattered radiation during the examination. In addition, because the dose values are displayed in colour, visually understanding the rough exposure dose during examination is made easy.

#### 4.2. About display devices

When the data size of the display object becomes larger, the start-up time of the camera naturally becomes longer because the data reading time becomes longer. Because the load increases as the data size increases, that the display becomes unstable when the data size increases is conjectured. The data size problem can be solved via reduction of the data size through reduction of the number of polygons, or through the use of a higher-performance GPU. However, a high-performance GPU may either be
difficult to use or unavailable for workers who need education on radiation protection, and thus reducing the data size through reduction of the number of polygons is more desirable. The reason why the display position is shifted depending on the device orientation of the Nexus 9 is probably because the origin of the WebAR system differs between iOS and Android. In troubleshooting the tracking and recognition of the marker, the performance of the camera installed in the device and the origin of the marker itself are considered. The difference in the ability to recognise the AR marker is due to the AR marker being recognisable based on its white-and-black contrast; the ability to recognise this contrast differs from one camera to another. The contrast of the marker also differs depending on whether the marker is displayed on a paper medium or on an electronic medium, resulting in a difference in the degree of recognition.

4.3. Usefulness and issues with proposed AR system for scattered radiation visualisation

Compared to other AR and VR systems [4, 5] that require special devices or downloading of special apps, the AR system developed in this study is considered to be widely usable as a teaching material for radiation protection education because the system can be used on a web browser, allowing the behaviour of scattered radiation to be easily observed without downloading an app. The system can be used in devices equipped with a web browser and a terminal equipped with a camera, and thus dissemination in educational settings would likely be easy.

The challenge is on using it effectively in radiation protection education. WebAR can display and observe the behaviour of scattered radiation in three dimensions, but the system does not have a function to measure the degree of understanding of the observer. Therefore, it will be necessary either to add a function for measuring the degree of comprehension of the user to the system itself or to prepare another evaluation method. In addition, because the degree of comfort with using AR differs depending on the terminal performance and OS, another method or device for adapting to these differences in usability, such as a spare terminal, may be necessary.

5. Conclusion

A download-free WebAR system for radiation protection education that can be used in a web browser and that visualises the behaviour of scattered radiation during portable imaging was developed. With this system, the behaviour of scattered radiation could be observed more easily from any angle. For more effective use in radiation protection education, a method for measuring the degree of understanding of users will have to be created. In addition, reducing the differences in usability due to differences in OS and devices will have to be considered.

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