Markerless augmented reality: Display Compton scattering model

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Abstract. Simulations were performed using markerless augmented reality on the concept of Compton scattering. Compton scattering identifies that photons can not only behave as waves but also behave like particles. The process of colliding photons with electrons causes dispersion which shows that the photon has momentum. This article will explain a photon collision simulation to prove the state of light dualism by utilizing augmented reality technology. The development of this simulation was tested using the black-box testing method. Interactive media using augmented reality for Compton scattering simulations can display the concept of collisions between photons and electrons. Our simulation successfully simulates the mechanism of energy release and momentum changes before and after the contact.

1. Introduction

Increased interest in Compton simulations has increased the requirement for models that describe the behavior of properly scattered radiation [1]. In general, Compton simulations rely on Monte Carlo-based methods, which can analyze ionization energies accurately [2], and express scattering behavior well in high probability regions of the spectrum [1].

Through Compton scattering simulation, there will be confirmed the presence or absence of frequency shifts in a photon, such as confirmation of the lack of redshifts in x-rays [3] in the study of Compton scattering anomalies [4], and identify the polarization of gamma-ray beams produced by Compton scattering of an electron beam and a laser beam [5]. This simulation is useful for understanding the wave-particle duality process of electrons in the context of the Compton effect. Compton effect is expressed in terms of wavelength and frequency of incidents, where electrons are initially at rest, and rotation is ignored [6].

The variety of simulations that can demonstrate the real visuals for users, one of which is augmented reality (AR) [7]. The advantages of the AR system in education are learning demonstration [8] and motivation in learning [9], and time effectiveness [10]. Research in augmented reality is a massive one. It is like an application in the potency of augmented reality [8], the development of Lorentz forces [11], and the generator application to produce electricity [12]. Furthermore, preliminary research on the radioactive concept has been developed in various media, such as using the electronic book to stimulate user [13], and the development of 3D animations on radiation material [14].

This article will present a simulation of Compton scattering by utilizing augmented reality technology. The simulation of this effect begins with the collision between the photon and the electron.
The results of this simulation will be used to regulate the parameters of Compton scattering simulation in learning media.

2. Methods
The primary purpose of this simulation is to visualize Compton scattering through collisions between electrons and photons. The visualization of concepts in Compton simulations is illustrated in Figure 1.

![Figure 1](image1.png)

**Figure 1.** Principle of Compton scattering [15].

The incoming photons (Fig. 2) in this simulation are illustrated as waves that propagate in the cartesian axis in the form of transverse waves in the blue spectrum ($\lambda = 495$ nm). Over the time, the waves will deliver and hit the electrons that are at rest (Fig. 4), causing the photons to lose some energy and change the color spectrum to shift towards the red range, in this simulation it turns to the green spectrum ($\lambda > 495$ nm) in Figure 3.

![Figure 2](image2.png) ![Figure 3](image3.png)

**Figure 2.** The blue spectrum of photon. **Figure 3.** The blue spectrum of photon.

![Figure 4](image4.png)

**Figure 4.** The electron.

This media was tested using black-box testing, which type is Boundary Value Analysis (BPA). Software examination is a commonly implemented procedure to verify and validate the quality of software [16, 17]. The input conditions in this study are limited by the values $a$ (Failed) and $b$ (Success) [18]. Black-box testing is used to develop software research and analyze the functioning of the software, such as the development of augmented reality systems on smartphones [19], and virtual reality on android applications [20]. The stages of this study are shown in Figure 5.
3. Results and discussion

3.1. Development results

The results of the simulation development using markerless augmented reality (MAR) on the Compton effect have been carried out by simulating a collision that causes a redshift in the wave spectrum. The color spectrum has different numerical ranges among many references, such as the blue spectrum, which starts from 430-480 nm [21], 455-492 nm [22], and 450-495 nm [23]. This simulation uses the last one. The spectrum table is shown in Table 1 below.

| No | Wavelength range (nm) | Color  |
|----|-----------------------|--------|
| 1  | 450-495               | Blue   |
| 2  | 495-570               | Green  |
| 3  | 570-590               | Yellow |
| 4  | 590-620               | Orange |
| 5  | 620-750               | Red    |

The simulation successfully displayed the difference between the collisions of electrons and photons at certain angles. The process of using this simulation begins by scanning the surrounding environment with a smartphone camera. Then you will see a 3D electron object around the user. The display, when scanning the surrounding environment, is shown in Figure 6. Meanwhile, the application is allowed to download using QR code and install it into the smartphone (Fig. 7).

Figure 5. Research flow.

Figure 6. Display of smartphone camera.

Figure 7. QR code to download the application.

The user will be guided to direct the camera screen to the surrounding electron objects, then shoot them with photons with a wavelength of 495 nm (blue spectrum). When shotting using a photon, the simulation displays the collision process between electrons and photons. The simulation results before
collision are shown in Figure 8 and after the event in Figure 9. At the time before the crash, the electromagnetic spectrum is illustrated in the blue range (Fig. 8). After that, the electromagnetic wave turns to green (shifts towards the red spectrum (Fig. 9).

![Figure 8. Origin photon reach the electron.](image)

![Figure 9. Photon collide the electron in 30°.](image)

The markerless augmented reality media displays the concept of collisions of electrons in the electrons resulting in the reflection and release of energy. This release of energy causes a shift in the color spectrum of the photon towards the red spectrum. The change of the spectrum in this simulation only shifts to green shown in Table 2.

| No | λ (nm) | Spectrum | Φ (°) | λ’ (nm) | Spectrum | ΔE (joule) |
|----|--------|----------|-------|--------|----------|------------|
| 1  | 495    | Blue     | 30    | 495,000,325 | Green    | 2.635 x 10^{-25} |
| 2  | 495    | Blue     | 45    | 495,000,710  | Green    | 5.761 x 10^{-25} |
| 3  | 495    | Blue     | 60    | 495,001,212  | Green    | 9.834 x 10^{-25} |
| 4  | 495    | Blue     | 90    | 495,002,424  | Green    | 1.967 x 10^{-24} |

Then in this simulation also displayed the momentum and release of energy from photons. Before the collision, the photon has a wavelength λ of 495 nm (blue spectrum) with the energy of 4.0157 x 10^{-19} joule. After the crash occurs, which causes the release of energy from the photons shown in Table 3.

| Φ (°) | E | p | E’ | p’ | E_e |
|-------|---|---|----|----|-----|
| 30    | 4.0158 x 10^{-19} | 1.33859 x 10^{-27} | 4.0157549 x 10^{-19} | 1.3385849 x 10^{-27} | 2.635 x 10^{-25} |
| 45    | 4.0158 x 10^{-19} | 1.33859 x 10^{-27} | 4.0157518 x 10^{-19} | 1.3385839 x 10^{-27} | 5.761 x 10^{-25} |
| 60    | 4.0158 x 10^{-19} | 1.33859 x 10^{-27} | 4.0157477 x 10^{-19} | 1.3385825 x 10^{-27} | 9.834 x 10^{-25} |
| 90    | 4.0158 x 10^{-19} | 1.33859 x 10^{-27} | 4.0157379 x 10^{-19} | 1.3385793 x 10^{-27} | 1.967 x 10^{-24} |

From the Table 3. After the collision occurs, the energy and momentum of the photon decrease, photons also transfer their energy to electrons, so that it has the energy $E_e$ to move away from the collision point.

3.2. Test result

Testing is done on simulation software using BPA type black-box testing. Flowchart of the developed application is shown in Figure 10.
Tests performed in the augmented reality application response process are shown in Table 4. Testing is done using an android smartphone with an android system that has been equipped with a gyroscope. The test results show that of several test items. Obtained test results are displayed in the following table.

| No | Field                          | Success rate (%) | Interpretation |
|----|--------------------------------|------------------|----------------|
| 1  | Installation                   | 100              | Valid          |
| 2  | Starting                       | 100              | Valid          |
| 3  | Initiating the environment     | 100              | Valid          |
| 4  | Colliding the electron         | 100              | Valid          |
| 5  | Displaying the properties of photon | 100          | Valid          |

Average of all Field 100 Valid

The test results obtained that the percentage of the success of the function in the developed application system is 100% valid. The progress of the system was reviewed from 31 items from 5 aspects that successfully passed the test. Testing the markerless augmented reality device in Table 4 results in the conclusion that the application can run well on an android smartphone that has been equipped with a gyroscope. The display generated from this application is made interactive so that it can be played by students. The development of interactive AR needs to be developed to improve the quality of simulations in the world of education.

4. Conclusion
As a result, we succeeded in simulating the mechanism of energy release and changes in wavelength before and after the collision through the concept of Compton scattering. This system can be used to analyze differences in the visualization of photon collisions in material conditions (dualism of waves). After testing with the black-box testing method, the test results are obtained that this application is valid and functioning properly.

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