

Development of a Learning Material for Light Interference Phenomena Using Tablet Devices and Augmented Reality

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ABSTRACT

To use augmented reality (AR) technology requires the use of specialised device. We focused on the fact that many Japanese educational institutions have tablet computers. We developed a teaching material that allows users to experience light interference phenomena using tablet terminal and AR markers.

1 INTRODUCTION

For many years in Japan, young people's lack of interest in science has been a challenge. It can be confirmed that physics is less attractive, especially when compared to other subjects, according to the 'Report on Survey of High School Students' Attitudes toward Science and Other Subjects: Comparison of Japan, the United States, China and South Korea' [1] published by the National Institution for Youth Education in 2014. Thus, the same report confirms that Japanese high school students prefer to learn by conducting their experiments. Furthermore, the Japanese Ministry of Education, Culture, Sports, Science and Technology's Guidelines for the Course of Study for High Schools suggest that observation and experiments are required for a better understanding of natural processes [2].

Due to a variety of constraints such as class hours and equipment setup, doing many experiments in class is difficult. Furthermore, performing such experiments in a real-world setting is not always simple. As a result, our research team has been working on developing educational materials [3-5] that employ VR (Virtual Reality) and HMD (Head Mounted Display) technologies to enhance users' learning. In the aforementioned study, we confirmed that we could arouse the interest and concern of the users. However, because these systems are expensive and require specific equipment, preparing them one by one for each user is difficult. As a result, it is expected that practical application will be challenging.

Therefore, focusing on the fact that the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) has stated that as part of its GIGA school initiative, it is creating an environment in which students can learn using one tablet terminal per student [6], we will create an environment where students can experience learning using tablet terminals and AR

(Augmented Reality) technology.

Light interference in the field of waves is the subject of this research. According to GÜREL et al., understanding optics principles just from a textbook is challenging [7]. Therefore, using experiments and advanced technology in learning optics can help students understand the subject better. Muliya et al. described a system that scans the markers and presents a learning video to help students learn [8]. The video, on the other hand, is a complement to the textbook and does not allow students to interact with physical events. Albert et al. proposed an AR experiment that showed notions like force and rays while also extending real-world physics experiments [9]. However, it is expected that the experimental setting is ready to enhance physical experiments. In practice, the above AR experiment is not suited if it is difficult to construct the experimental environment for each person or to conduct the experiment. As a result, the purpose of this study is to develop a teaching material that allows students to interact with light interference by creating an experimental setting using a tablet terminal and AR technology. The teaching materials will include wave synthesis, which is necessary for understanding interference, Young's experiment, which is carried out in Japanese high schools, and recording process of CGH (Computer-Generated Hologram), which allows learner to experience light interference in three dimensions.

2 PROPOSED SYSTEM

In this section, we describe an overview of the proposed system, the development environment, the hardware used and the AR technology.

2.1 OVERVIEW

In this study, the experimental environment is built by recognising AR markers with a camera incorporated into the tablet device and the appropriate equipment is created onto the AR markers. In addition, the experiment is conducted while modifying the settings by moving the installed AR markers and adjusting the parameters connected to the experiment and the learner can interactively experience light interference.

2.2 DEVELOPMENT ENVIRONMENT

The AR project will be developed using Unity and Vuforia as the development environment. Unity is a gaming engine developed by Unity Technologies, Inc. that can construct virtual environments and Vuforia is a PTC-developed AR application development platform. Vuforia is a PTC AR application development platform that allows users to set markers to recognise the location of virtual items to be presented in AR using image registrations. We will use a Galaxy Tab S4 as the tablet device. Table 1 shows the specifications of the tablet device.

Table 1 Performance details of tablet device.

Model	Galaxy Tab S4
OS	Android 10
CPU	Snapdragon 835 2.35GHz Octa core
GPU	Adreno 540
Memory	4GB
Resolution	2560 × 1600
Size	249.3 × 164.3 × 7.1mm
Weight	482g

2.3 AR MARKER

Figure 1 shows the AR markers. Touching the AR markers on the screen can change the parameters (amplitude, period, initial phase speed, etc.) to perform the experiment intuitively for learners. The size of the AR markers in the proposed system is a square of about 4 cm per side.

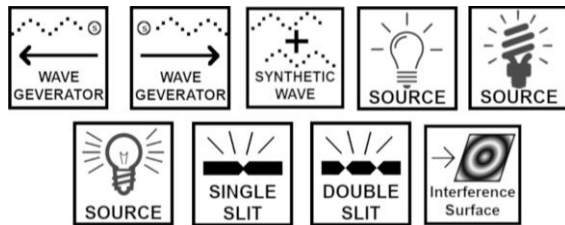


Fig. 1 AR markers to be used.

3 DEVELOPMENT METHODOLOGY

In this section, we describe the technology used in the proposed system.

3.1 WAVE SYNTHESIS

In the proposed system, the sine wave and the synthetic wave are represented by spheres. The height y_0 of the synthetic wave is calculated by detecting n spheres in the same x -coordinate and their respective heights y_k .

$$y_0 = \sum_{k=1}^n y_k \quad (1)$$

However, if multiple spheres generated from a single AR marker are detected, there is a risk that we will not confirm the correct composite wave. Therefore, when various spheres that determine the height of the synthetic wave are detected, the average height of the spheres is calculated before as shown in Fig. 2.

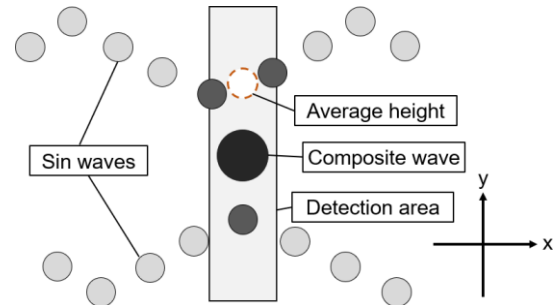


Fig. 2 Calculating a composite wave with two sine waves.

3.2 VISUALISATION OF LIGHT WAVES

In the proposed system, light waves are represented by torus- and sphere-shaped objects to make the process of developing interference fringes easier to check. Furthermore, the phase and spread of the light waves are depicted by expanding the objects while changing their colour every unit of time.

In addition, Young's experiment and holographic recording utilise the nature of light interference to create interference fringes. In the proposed system, we prepare an interference fringe plane consisting of a set of small rectangular units shown in Fig. 3. When a rectangular unit collides with an object that represents a light wave, the object's colour information is reflected in the rectangular unit's colour, resulting in an interference fringe.

3.3 CREATING A SUB CAMERA

When viewing the interference fringes generated on the interference fringe surface, the user may try to look into the interference fringes by altering the angle of the mobile device. In such a case, the AR marker on the screen changes, making it difficult to continue the experiment. Therefore, for teaching materials that require the interference fringe checking, a sub-camera for observation should be installed on the screen to make it easier to check the interference fringes while recognising the AR marker allowing learners to review the interference fringes without adjusting the orientation of the device.

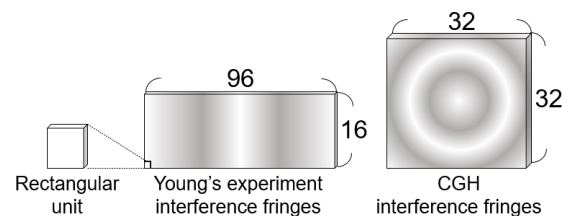


Fig. 3 Overview of the interfering surface and the rectangular units that make up the interfering surface.

4 RESULT AND DISCUSSION

In this section, we describe the development results and discussion of the proposed system.

4.1 OBSERVATION OF SYNTHETIC WAVES

Figure 4 shows the running screen, with the two AR markers generating the identical waveform sine wave and the yellow composite waves created by the interference of the two waves. it was confirmed that as the parameters of the sine wave, such as amplitude and frequency, were adjusted, the appearance of the synthesised wave changed.

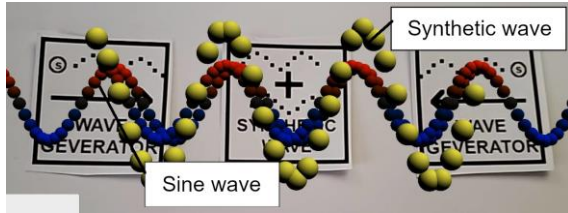


Fig. 4 Observation of synthetic waves by the proposed system.

4.2 YOUNG'S EXPERIMENT

Figure 5 shows the running screen. Figure 5(a) shows the placement of the AR markers and the object during execution, and Fig. 5(b) shows the created interference fringes. From the results, we confirmed that the visualized light waves generate the interference fringes.

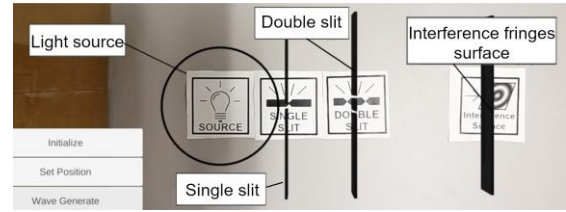
Suppose the distance between the slits of the double slits is d , from the double slits to the interference fringe plane is L , the bright spot and the centre on the interference fringe plane is x . The wavelength of the light source is λ . the post-following equation can express the position of the bright point by first-order approximation.

$$x = \frac{mL\lambda}{d} \quad (m = 0, 1, 2, \dots) \quad (2)$$

Therefore, we changed the conditions of d and L , executed and confirmed that they changed the positions which intervals of the bright spots. Figure 6 shows the execution results.

A problem arose while we confirmed the generation of interference fringes with the proposed system under various conditions. It is not easy to implement the system with numerical settings similar to the experiments conducted in the real world. The reasons are as follows:

1. The wavelength is longer than the actual light due to the visualisation of light waves.
2. There is a limit to where we can place AR markers due to the camera's angle of view and the recognition accuracy of the AR markers.
3. The distance from the double-slit to the interference fringe surface does not correspond to the value obtained from the camera and the space in the real world.



(a) AR markers placement diagram and execution process.



(b) View of the created interference fringes.

Fig. 5 Young's experiment with AR markers.



(a) Interference fringes are obtained by halving the distance between the slits of a double slit.



(b) Interference fringes are obtained by doubling the distance from the double slit to the interference fringes plane.

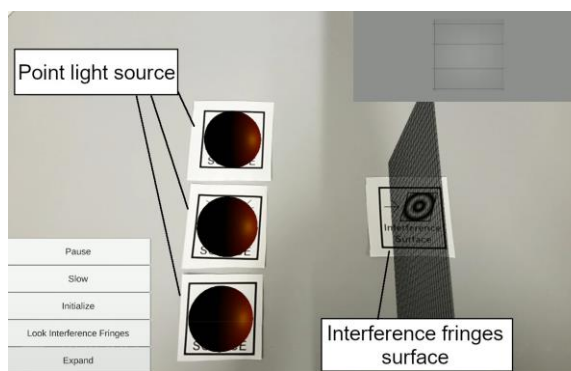
Fig. 6 Interference fringes of Young's experiment obtained with different parameters.

As a result, as a future effort, we will evaluate the learning effect by conducting experiments under the proposed system's conditions and comparing the findings to numerical settings that are similar to those used in real-world studies. In addition, we will conduct a questionnaire survey on the subjects to verify whether the system can sufficiently arouse their interest and concern.

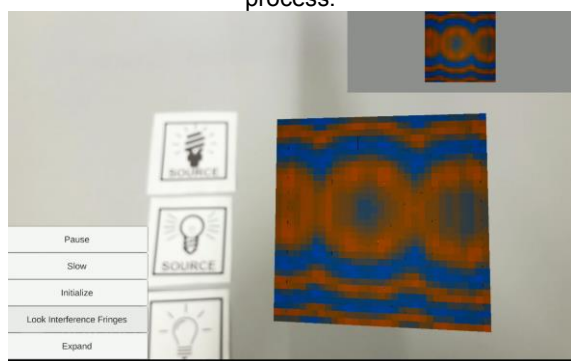
4.3 RECORDING CGH WITH POINT LIGHT SOURCE

The proposed system is an inline hologram, which visualises creating with a point light source. Figures 7(a) and (b) show the execution with three points light sources and the created interference fringes. From these results, we confirmed that the point light sources make the interference fringes.

However, since the proposed system requires one AR marker per light source, it is vital to register as many AR markers as possible in Vuforia as feasible to accommodate a large number of light sources. Another challenge is that the resolution of the hologram is low, and increasing the number of light sources does not result in the correct interference fringes. Therefore, handling several light sources based on a single AR marker's position and increasing the number of rectangular units that make up the hologram can help solve the problem. However, increasing the number of light sources and the resolution of the hologram is



(a) AR markers placement diagram and execution process.



(b) View of the created interference fringes from the front.

Fig. 7 Visualisation of the recording process of CGH with point light source.

expected to affect the processing speed. As a result, we believe that further research into this subject is required in the future.

5 CONCLUSIONS AND FUTURE WORK

Some research has suggested that extended reality technology can be used to learn physics, but there are some practical challenges, such as equipment setup and use in the educational field. This study focused on equipping tablet terminals for learning at educational institutions in Japan and developed a teaching material that enables users to experience light interference interactively by constructing an experimental environment using tablet terminals and AR markers. We have developed a teaching material that allows users to experience light interference interactively by visualising light and changing various conditions in the processes of wave synthesis, Young's experiment, and holographic recording.

As future tasks, we will investigate the learning effects of the proposed system and develop more effective teaching materials based on the results.

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