International Journal of Advanced Culture Technology Vol.10 No.4 478-486 (2022)
DOI https://doi.org/10.17703/IJACT.2022.10.4.478

IJACT 22-12-57

A Study on the Implementation of a Portable Hologram Recording System for Optical Education

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Abstract

Holography is a human-friendly technology that can express 3D stereoscopic information without eye fatigue. You can experience the mysterious features of light directly and indirectly, and you can also experience the principles of 3D imaging, which makes it a very good curriculum. As such, although holography is very effective in teaching students optics and 3D imaging technology, it has not yet been systematically established. The reason is the cost burden such as expensive equipment and laboratories, and the lack of easily accessible educational equipment. We implemented a portable holographic recording system to solve this problem. In addition, since silver halides, which use harmful chemicals, are not used in the process of developing the recording medium, and photopolymers are used, it is possible to educate not only the general public but also young students. In order to improve the completeness of the recorded result, the mechanism part, light source, and recording medium part of the production system were newly constructed to complement all the existing problems. The proposed system will make holography easily accessible to many people in a variety of fields, not just education. Through the interesting experience of various features and principles of light and the production of holograms with high satisfaction, we hope to popularize them in various fields such as education.

Keywords: *Holography, 3D Images, Diffraction, Interference, Photopolymer, Reflection Hologram*

1. INTRODUCTION

Around the world, IT-based information society is striving for informatization education, including domestically. In the past, education was limited to the confined space of the school. Recently, due to the development of the IT industry and the social environment in all countries, students are now being educated through the Internet easily at home or in other places other than school without time and space restrictions. There was also a study on maker activity-based optical education using artificial intelligence technology for science gifted education programs [1]. Except for the 2007 revised curriculum, the education in the field of optics in elementary schools in Korea accounted for a large proportion in the field of physics, with three units

Manuscript received: November 24, 2022 / revised: November 30, 2022 / accepted: December 9, 2022
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each time. Each revision of the curriculum has undergone changes such as reduced content, removal of difficult concepts, or movement to higher grades. These changes are due to a decrease in the number of hours in science classes and societal changes and demands on curricula, and the main points of the optical curriculum vary slightly from country to country [2-4]. Education using holography is gradually increasing. In order to confirm the learning and efficiency of holography, research results related to holograms were collected and comprehensively analyzed. The results showed that holography applied training had a positive effect on learning efficiency. In convergence education using holography, learners had a greater learning effect in the cognitive domain than in the emotional domain. The effective size of learning varied by subject, with math and science being the most effective. The magnitude of effectiveness was then calculated in the order of language, engineering, and medicine [5]. Hologram technology is a technology that uses the characteristics of light, such as interference, diffraction, and scattering. Since learning using various characteristics of light, it is expected to have a great effect in optical education. Although holography is optimized for various convergence education, including optical education for students, the reality is that it cannot be popularized at present due to limitations in terms of learning environment and cost. Holographic technology is used comprehensively for math, science, light phenomena, and technical content essential in today's fast-paced society. It helps to develop students' STEAM (science, technology, engineering, arts, mathematics) educational competencies. STEAM is a convergent talent education, and many educational communities around the world are currently researching its effectiveness and how to use education [6]. Although convergence education through holography has a very efficient learning effect, it has not been popularized by the general public or students due to various environmental problems. In this study, students as well as the general public can have a safe and interesting experience regardless of time and place. In order to be able to experience the high-quality hologram technology without being burdensome, we researched a portable hologram recording system.

2. THEORETICAL BACKGROUND

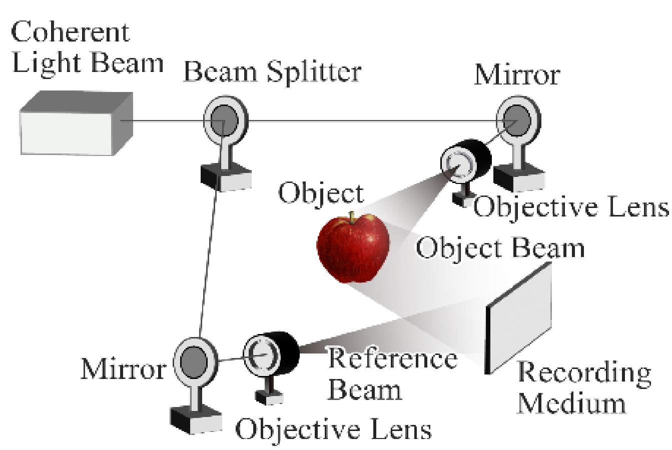


Figure 1. Holographic recording method

Light accompanies cutting-edge technologies in various fields such as information, communication, energy, medicine, industry, and art, including holograms, and plays a very important role in creating new technologies of the future. Much research on the properties of light has continued around the world. Until the 19th century, the wave theory of light and the particle theory were of interest to many scientists. The wave nature of light refers to the characteristic of propagating while changing periodically in time and space. Particularity refers to the property that light is a matter and has kinetic energy that moves while colliding with other nearby substances. In 1690, Christiaan Huygens (1629-1695) advocated the wave theory of light, and in 1704, Isaac Newton (1642-1727) argued for the particle theory in his book ‘Opticks’. In the early 1800s, Thomas Young's (1773-1829) ‘double-slit experiment’ discovered the Interference and diffraction of light, reviving Huygens' wave theory. Huygens said that if you know the current location of the wavefront, you can determine the location of the wavefront after a certain period of time. When all elements on the wavefront are called wavelet source point, and the commonly tangent surface of the waves emanating from all wavelet source point is called the envelope, the newly created envelope becomes the new wavefront [7]. Figure 1 is a transmission hologram recording method that records using interference phenomena and diffraction phenomena, which are wave phenomena of light. The Interference and diffraction of light are important factors in the wave characteristics of light.

Holography is a technique that uses Interference and diffraction, which are wave forms of light. Light Interference refers to the phenomenon that when light from the same light source is divided into two or more parts, the matching waves meet and overlap, and the waves become stronger or weaker. There is constructive interference, in which the wave becomes stronger due to the phase difference of the matching waves, and destructive interference, which is weakened by canceling out. The reason why a thin film of soap bubbles or oil mixed with water looks like a rainbow is also an interference phenomenon caused by the principle of superposition where two or more waves meet. Thomas Young figuratively explained the Interference of light through the waves of the water waves, saying that the interference phenomenon of two identical water waves can be observed by water waves of the same magnitude. [8]. Figure 2 shows the formation of interference fringes in transmission hologram and reflection hologram. The difference between these two recording methods depends on the direction of irradiation of the reference beam and the object beam relative to the recording medium.

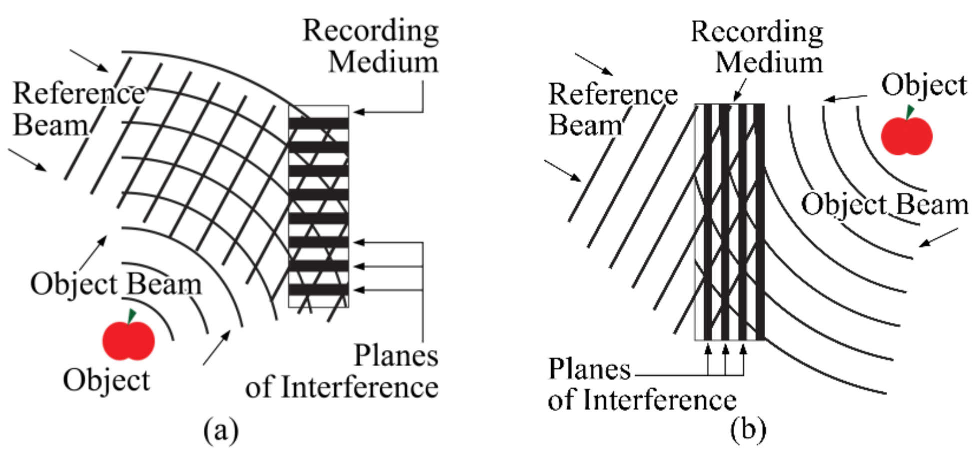


Figure 2. (a) The formation of interference fringes in transmission hologram (b) The formation of interference fringes in reflection hologram

Diffraction of light refers to the phenomenon in which waves bend or spread due to interference with objects and deviating from straightness. If you zoom in on the shadow of a thin razor blade, you can see that the interface of the corner shadow is unclear, and the light is also reaching the inside of the border. This phenomenon, which cannot be explained geometric optical, is called diffraction [9]. Diffraction patterns can be seen in Joseph von Fraunhofer's (1787-1826) diffraction pattern in Figure 3.

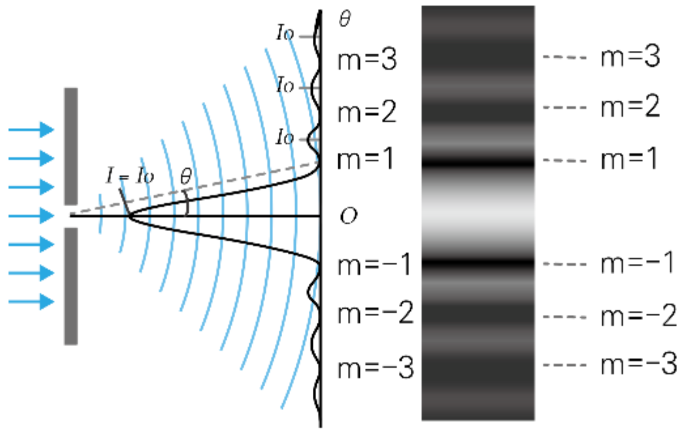


Figure 3. Distribution of diffraction pattern strength of Fraunhofer

The luminosity I can be calculated and equation (1) is established.

$$I = I_o \left[\frac{\sin(\beta/2)}{\beta/2}\right]^2 , \ \beta = \frac{2\pi a}{\lambda}\sin\theta \quad (1)$$

In equation (1), the wavelength is λ, the width of the slit is a, and the angle is θ. The width a of the slit and the first dark pattern are related to $\sin\theta \propto \lambda/a$, and the spacing between a and the pattern is inversely proportional, resulting in a wide spread of the light pattern [10]. Hologram is a combination of the ancient Greek words 'holos' meaning perfect and 'gramma' meaning message, which can be interpreted as 'complete message'. Holograms are created using the principles of light interference and diffraction. Based on Thomas Young's law of light interference in 1802, the theory of holography was first proposed by Dennis Gabor (1900-1979) in 1948. The results obtained at that time were not very complete and did not attract much attention from the public. In the 1960s, the invention of a recording light source with excellent coherence led to the active research of holography. Juris Upatnieks (1936) and Emmett Leith (1927-2005) of the United States investigated object beam and reference beam in the same direction and succeeded in recording transmission holograms with higher completion than conventional results [11,12]. In the late 1960s, Yuri Denisyuk (1927-2006) proposed the successful recording of reflection holograms using high-resolution photoresist emulsions [13,14]. In 1968, S.A. Benton (1941-2003) succeeded in recording rainbow holograms, color holograms that can be reproduced with normal natural or white light [15]. In the 1980s, there were many developments in holography and applied in various fields. It can be seen as the time when the foundation for 3D reproduction technology that can reproduce recorded objects as they are was laid [16]. In recent years, research on digital holograms has also been actively carried out due to the development of IT technology [17]. Holography is an image technology that can record 3D phase information and amplitude information of a recording object and reproduce it three-dimensionally. It uses the non-deforming interference phenomenon caused by light and the diffraction phenomenon of waves that cannot be expressed by particles. The hologram records a recording light source in the recording medium using the interference that appears due to different phase differences when the reference light directly irradiating the recording medium and the object light reflected from the object.

3. SYSTEM DESIGN

When recording holograms, in order to obtain a high-quality recording result, the optimal light source, the optimal recording medium, and the optimal recording method are important issues. In this study, the system was implemented by the 'reflection hologram' method that can be reproduced with natural light or general light source after recording. The system configuration is shown in Figure 4.

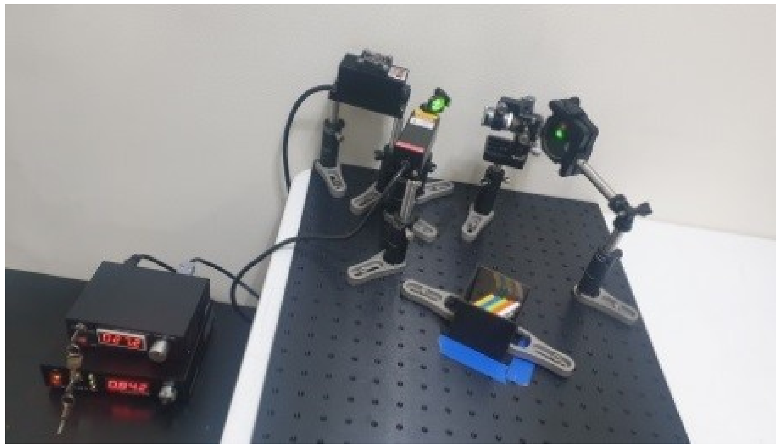


Figure 4. The recording system used in this study

Two recording light sources, a red laser and a green laser, were concentrated through a beam splitter. It diffused with the objective lens and focused using a pinhole plate to remove the miscellaneous signals. The optimal light source thus adjusted was adjusted using a light mirror to investigate the recording object. After recording, the light source was irradiated from top to bottom for more natural reproduction.

3.1 The Light Source Part

In the existing hologram recording, gas lasers such as He-Ne lasers with strong light source strength were used, which was economically burdensome and dangerous for educational use. In this study, safer and more economical semiconductor lasers were used [18]. Even holograms recorded at the wavelengths of the three light sources, red, green, and blue, efforts are needed to find the optimal light intensity ratio, and in this study, two lasers were used [19]. The advantage of semiconductor lasers is that they can be easily controlled through the power supply without the need for a separate ND filter to adjust the intensity of the light source to find the optimal recording conditions.

3.2 The Recording Medium Part

There are various types of recording medium, but photopolymers that do not require separate bleaching and development treatment and are not harmful were used. The photopolymer has high diffraction efficiency and has relatively few miscellaneous signals. Unlike other recording medium, it is also resistant to moisture and can be stored at room temperature of 12°C~26°C without the need for refrigeration. As shown in Figure 5, a recording medium holder was made and used using 3D printing technology.

Because holograms use a recording medium with excellent light sensitivity, they must be recorded in the darkroom with all external light blocked. In addition, since the recording person is adapted to the dark and the pupil is dilated, safety should be paid attention to when using a laser light source. For safety, reflective metals and unnecessary items around them should be removed and experimented. The recording method was recorded under various conditions according to the intensity of the recording light source, the exposure time of the recording light source, and the distance between the recording light source and the recording object.

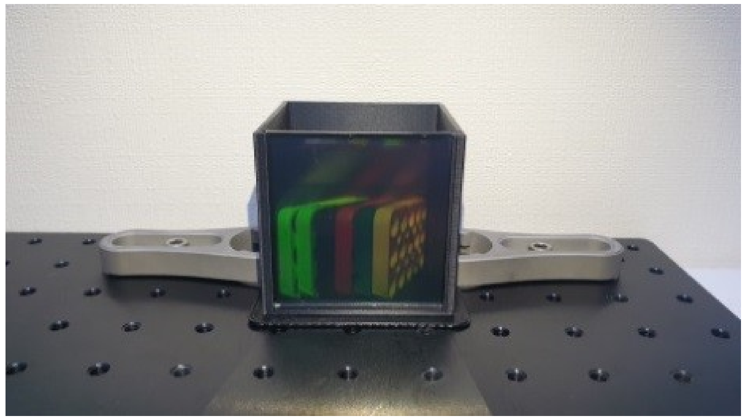


Figure 5. Recording medium stand used in the system

4. RESEARCH METHOD

4.1 Recording Experiment According to the Intensity of the Light Source

The completeness of the recording results was compared according to the strength of the recording light source, which is the most important part. In order to obtain the result of reproducing colors as close to reality as possible, it is necessary to coordinate the intensity of the red laser and the green laser. As shown in Table 1, the recording experiment was performed according to the output intensity.

Table 1. Output intensity of red and green laser for recording according to light source

	Red laser power	Green laser power
The output of a light source	25mW	25mW
		50mW
	50mW	25mW
		50mW

4.2 Recording Experiment According to the Exposure Time of the Light Source

Using the concentrated light source of the red laser and the green laser, the recording time irradiated on the recording medium was recorded according to the following standards.

① 60seconds ② 180seconds ③ 360seconds ④ 600seconds

4.3 Recording Experiment According to the Distance between Light Source and the Recording Object

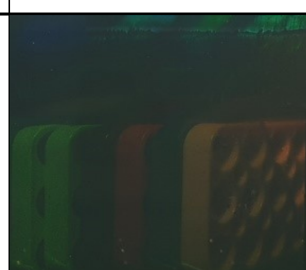
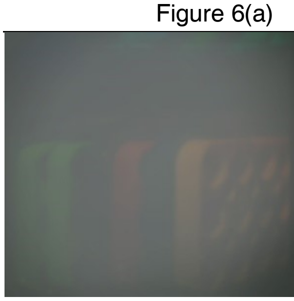
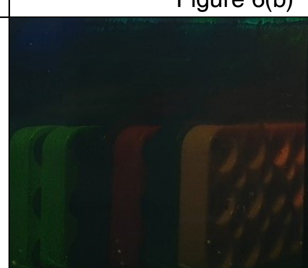
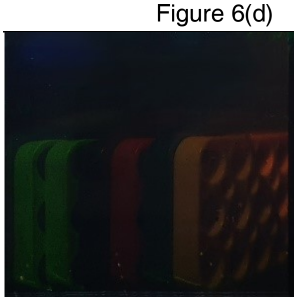
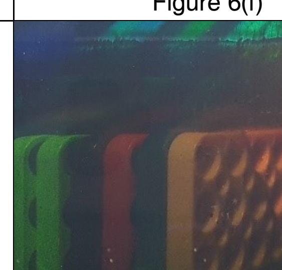
As with other conditions, the optimum recording distance must be set to achieve a high-quality result. The recording experiment was performed based on the two distances as shown below.

① 25cm ② 45 cm

5. RESULTS

Comparative analysis of recording results shows that the intensity of the recording light source, the exposure time of the recording light source, and the recording distance have a great influence on completeness. In addition, the flow of surrounding air, such as the operation of the air conditioner and the operation of the ventilator, also had a great influence on the completeness of the recorded results. Table 2 shows the results recorded under various conditions. (R: Red laser intensity (%), G: Green laser intensity (%), D: Recording distance (cm), M: Recording time (min)). Figure 6(a) and 6(b) recorded several times with the intensity of the red laser and green laser set to 100%, the recording distance to 45cm, and different recording times. The result was a lot of green. Figure 6(c) and 6(d) recorded several times with the intensity of the red laser set to 100%, the intensity of the green laser to 50%, the recording distance to 25cm, and different recording times. All the results were recorded as murky because the recording distance was too close, and the center part was altered and muddy. Figure 6(e) and 6(f) recorded several times with the intensity of the red laser set to 100%, the intensity of the green laser to 50%, the recording distance to 45cm, and different recording times. The results were darker than Figures 1 and 2, but relatively good. Figure 6(g), 6(h), and 6(i) recorded several times with the intensity of the red laser set to 100%, the intensity of the green laser to 25%, the recording distance to 45cm, and different recording times. The recording result with the longest recording time had the best resolution.

Table 2. Results recorded under various conditions

Recorded results	Recording conditions	Recorded results	Recording conditions	Recorded results	Recording conditions
	R 100 G 100 D 45 M 3		R 100 G 100 D 45 M 6		R 100 G 50 D 25 M 3
Figure 6(a)		Figure 6(b)		Figure 6(c)	
	R 100 G 50 D 25 M 6		R 100 G 50 D 45 M 3		R 100 G 50 D 45 M 6
Figure 6(d)		Figure 6(e)		Figure 6(f)	
	R 100 G 25 D 45 M 3		R 100 G 25 D 45 M 6		R 100 G 25 D 45 M 10
Figure 6(g)		Figure 6(h)		Figure 6(i)	

6. CONCLUSION

Recently, due to various factors, the amount of time spent indoors and the development of digital technology have increased the number of opportunities to come into contact with visual media, and the level of video required has increased a lot. Young students are also familiar with visual media as the penetration rate of smart devices increases. Among these various visual media, holographic images are being studied because they can experience perfect 3D stereoscopic images unlike other images. We proposed a workflow for the system so that you can experience hologram creation in a simple and risk-free way, rather than the existing burdensome and cumbersome system. It will also be educationally effective and creative activities. Furthermore, we hope that an environment where holograms can be accessed up close at any time in daily life will be created, so that our portable hologram recording system can contribute to the small development of holography.

ACKNOWLEDGEMENT

This research is supported by Ministry of Culture, Sports and Tourism and Korea Creative Content Agency (Project Number: R2021040083), The present research has been conducted by the Excellent researcher support project of Kwangwoon University in 2022.

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