The Full Color See-through Head Mounted Display Based on Transmission-type Holographic Optical Elements and Parallel Plane Mirrors

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ABSTRACT

The full color see-through head mounted display (HMD) which consists of two transmission-type HOEs, two parallel plane mirrors and a single image source is proposed. The red, green and blue incident light will overlap at the output HOE. Then the dispersion of transmission hologram will be compensated.

1 INTRODUCTION

Recently, with the development of technology, see-through display is becoming more and more important in the life. In order to accomplish the see-through system, prisms or half-mirror need to combine with display. However, it caused the systems are always too bulky and heavy to ware. To overcome this problem, reflection-type holographic optical element (HOE) and waveguide are often used in the systems [1-4]. The reflection-type HOEs has the wavelength selectivity, thus it can achieve monochrome display when the backlight is with broadband wavelengths. However, it is necessary to overlay multiple reflection-type HOEs [2] or use wavelength-multiplexing technology [3, 4] to achieve full color display. These two methods would cause the low diffraction efficiency and will complicate the fabrication processes.

In the previse publication, the use of four transmission-type HOEs can achieve full color display. However, this system has small FOV on account of the size of the HOE. Furthermore, because of the light sources, the system is too bulky to be portable [5]. Comparing with prior publication, we use two parallel plane mirrors to let the three input HOEs become one input HOE for reducing the input volume. Furthermore, we increase the size of HOEs and use LED light sources which combined with pattern or panel to increase FOV and reduce the system volume.

In this study, a pair of transmission-type HOEs which have symmetry linear gratings and two parallel plane mirrors are used to achieve full color display. When the full color image is inputted on transmission-type HOE, the red, green and blue (RGB) images can reflect back and forth in different diffraction angles by two parallel plane mirrors. And by calculation, the RGB images can overlap on the output HOE again. Then the full color image locating at infinity can be observed.

2 THE FULL COLOR HMD SYSTEM

The goal of our study are to reduce the input volume and achieve the full color display. Therefore, a pair of transmission-type HOEs and parallel mirrors are used. Two parallel mirror can compensate the dispersion to let the output image be full-color.

Fig. 1 shows the full color HMD system. The distance of two parallel mirrors is 1.5 cm. The size of both HOEs are 1.66 cm. In addition, the distance between two HOE is 8.27 cm. Two HOEs have a pair of linear grating to combine the RGB input image to achieve the full color display. The small LCD panel and the RGB LED light sources which are integrated by X-cube are used to provide the image source. The lens has 5 cm focal length, and the panel locates at the focal position of the lens to let the output image can be observed with background at infinity.

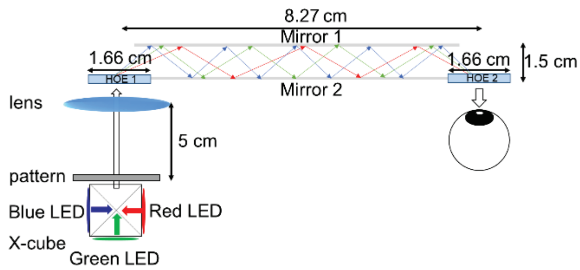

Fig. 1. The proposed system of the full color HMD based on transmission-type HOEs.

3 EXPERIMENT

3.1 Parameters of The HMD

For our system, the RGB LED which have the wavelength peaks of 625 nm, 530 nm and 450 nm were chose as the light sources. In order to determine the parameters of the HMD, the grating equation was used to find the diffraction angles of RGB light.

We know the wavelength of the incident light is λ, and d is the grating spacing. For the linear grating, when the

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light is normally incident, it will have diffractive angle θ_d. So the grating equation can be wrote as

$$d \sin \theta_d = m\lambda \quad (1)$$

Where m=1 because we only use first order of diffracted wave.

Then we use LabVIEW to calculate the most suitable parameters of two mirrors distance and the output HOE location.

After calculation, the diffraction angle for 532 nm green light which we choose is 35 degrees. And because of the dispersion of transmission-type HOE, the diffraction angles of the 625 nm red light is 42 degrees and the diffraction angles of the 450 nm blue light is 29 degrees. The distance of two parallel mirrors is 1.5 cm.

3.2 The recording of the HOE

The Holography is a stereoscopic technique that uses photosensitive material elements to record the interference fringe of light and reconstruct it by using diffraction. In our experiment, we use the 532 nm Diode-Pumped-Solid-State (DPSS) laser beams as the light source. The Fig. 2 shows the recording system in this study. The object wave and reference wave was separated by polarization beam splitter (PBS). Half-wave plate 1 (HWP1) and PBS used to regulate the intensity ratio between two waves. We use s-polarization to record HOE, hence, HWP2 is used to let the p-polarization become s-polarization. Additionally, the spatial filtering (SF), which includes an objective lens and a pinhole, used to let the laser beam become the special wave and clean up the laser. The collimated lens (CL) used to change the special wave into plane wave, as shown in Fig. 2. The interference fringe of two plane waves were recorded by the HOE.

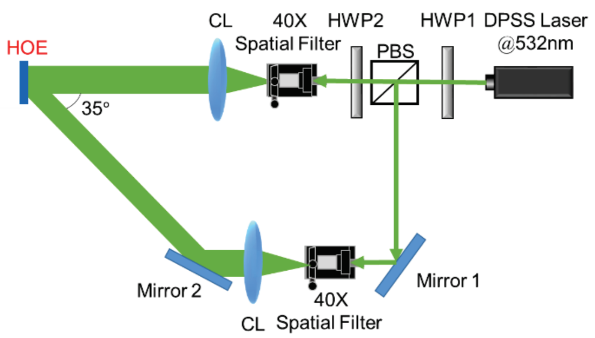

Fig. 2. The system of recording input and output HOE.

In this study, the material of HOE is VRP-M and the recording systems of two transmission-type HOEs were the same. The recording angles of HOEs were both 35 degrees. Nevertheless, for this study, the object wave and reference wave for output HOE are opposite to input HOE. Therefore, two HOE have the symmetry linear period to combine RGB lights to eliminate the dispersion of the diffraction images by transmission-type HOE.

3.3 The HMD System

In order to offset dispersion and achieve full color display, two HOEs have the same recording system but have opposite placement direction in the HMD. Consequently, two transmission-type HOEs are a symmetry linear grating. In this system, two HOEs and mirrors are all correct by RGB laser beams to achieve full color display.

4 RESULTS AND DISCUSSIONS

4.1 Experiment Results

In the study, two transmission-type HOEs, which were generated by VRP-M, was proposed to accomplish a see-through full color HMD in free space. A pair of HOEs have a symmetry linear grating to eliminate deformation and achieve full color display. The output image can be captured with background simultaneously at infinity. The experimental results verified the output efficiencies of input and output HOE are 28% and 32%, respectively.

Furthermore, the HMD can display any static or motion full color images by LCD panel or pattern with RGB LED light sources. The final image which can be observed at infinity are shown in Fig. 3. The image of Fig.3 (a) shows the input image by pattern and white LED light source which combined by RGB LED. The viewing angle in horizontal and vertical of Fig. 3 are 2.3 and 0.6 degrees. The output image of each color with background in bright room are shown in Fig. 3 (b) to (d). The full color output image in bright room is shown in Fig. 3 (e).

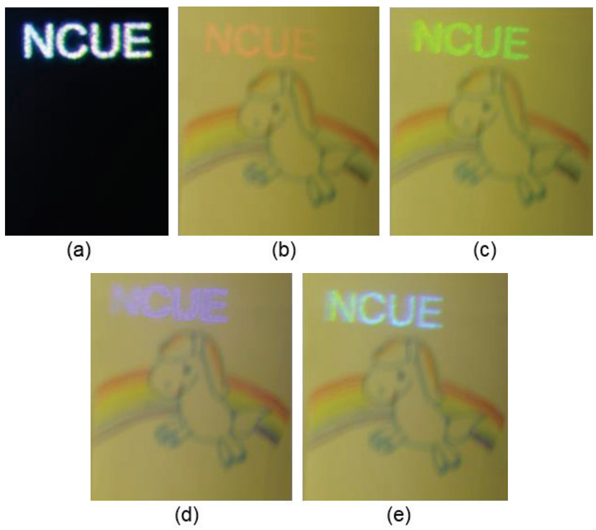

Fig. 3. The figure shows (a) the input image by white LED light source which combined by RGB LED , the (b) red; (c) green; (d) blue output image and the (e) full color output image in bright room.

In this case, LCD panel also allowed to use to input the image or video that people need as showed in Fig. 4. In that way, the instant information can be couple into the human eye to make it easy for users to access information.

Figure 4 presents the experimental results by using LCD panel for HMD system. The viewing angle in horizontal and vertical of Fig. 4 are 3.0 and 3.5 degrees. Fig. 4 (a) shows the input information. The pictures of Fig. 4 (b) to (d) show the R, G and B monochrome output image quality. Additionally, the full color image was captured with background in Fig. 4 (e).

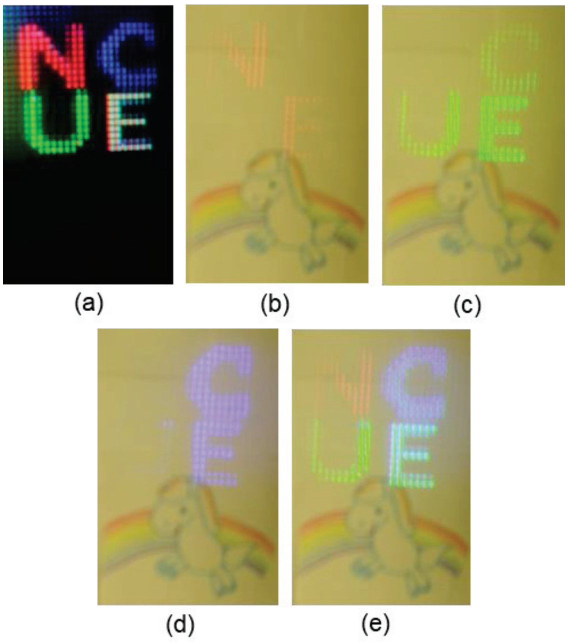

Fig. 4. The figure shows (a) the input image by panel and white LED light source which combined by RGB LED, the (b) red; (c) green; (d) blue output image and the (e) full color output image in bright room.

4.2 Digital Correction

For the reason of the non-uniformity of R, G and B efficiencies, the output image have dispersion as shown in Fig. 3. Thus, we can discover that the efficiency of red image is lower than green and blue one. In order to solve this problem, the red LED light power is increased to get a uniform white output image as shown in Fig. 5 (e). Finally, we can obtain the output image which same as the input information.

Since the red LED light power is increased, the input image after digital correction in Fig.5 (a) looks a bit red. Fig. 5 (b) to (d) show the output image by monochrome input image. Nevertheless, the full color output image which the same as input pattern is shown in the Fig. 5 (e).

In addition, digital correction can also use in panel input image. We also only need to increase the red LED power to avoid the dispersion as shown in Fig. 6. Fig. 6 (a) shows the input image which is illuminated by LCD panel and RGB LED light sources after digital correction. The monochrome output image of R, G and B are shown in Fig. 5 (b) to (d), respectively. And Fig. 5 (e) shows the full color output image.

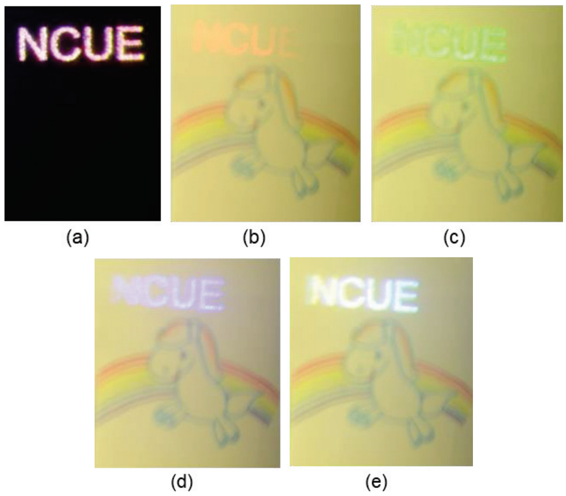

Fig. 5. The figure shows (a) the input image after digital correction, the (b) red; (c) green; (d) blue output image and the (e) full color output image in bright room.

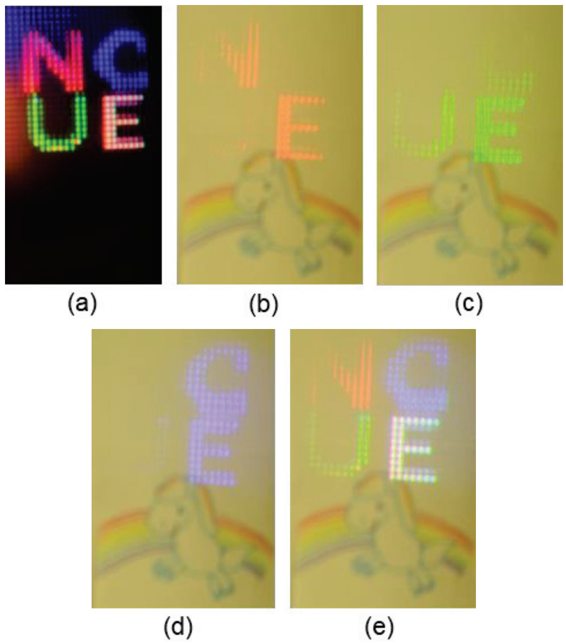

Fig. 6. The figure shows (a) the input image after digital correction, the (b) red; (c) green; (d) blue output image and the (e) full color output image in bright room.

4.3 Limit of the Field of View (FOV)

One of the most important point of this system is that it can offer the full color image at infinity. The extreme horizontal FOV of the system is 4.35 degrees, and the extreme vertical FOV of the system is 6.30 degrees. It is thus clear that the FOV of system is not big. The angle tolerance and exit pupil are the affecting factors of FOV. As a result, the angular sensitivity of the HOE with 35 degrees diffraction angle was measured as shown in Fig. 7.

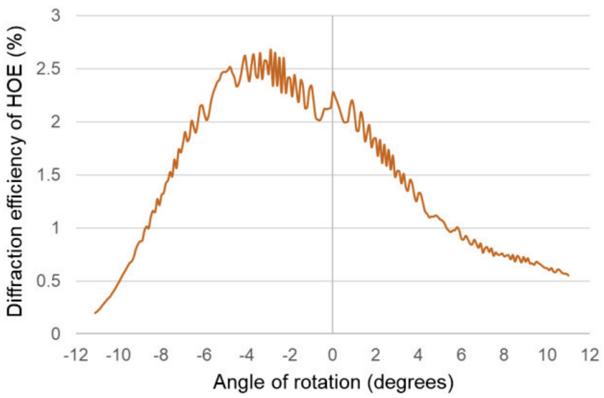

Fig. 7. The angular sensitivity of the system.

Because the angular sensitivity of the HOE is larger than the FOV of the system, we can evaluate that the main limitation of FOV is the exit pupil of the system. In the future, we can test how to expand the exit pupil to improve this full color HMD.

5 CONCLUSIONS

The two symmetric transmission-type HOEs with low wavelength selectivity are used to simplify the fabrication process of full color HMD. The use of two parallel plane mirrors let the RGB images overlap at the output HOE to compensate the dispersion of the diffraction images. This see-through HMD can get the full color image at infinity.

The LCD panel was utilized to input any information whatever we need. Since the efficiency of red image is lower than green and blue one, the red LED light power is increased to get a uniform full color output image. The extreme horizontal and vertical FOV of the system is 4.35 degrees and 6.30 degrees, respectively. By the measure of the angular sensitivity of the system, we recognize that exit pupil are the main factors to affect the FOV of this system.

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