Improved Fabrication Process of Holographic Waveguide Combiner in a Head Mounted Display System

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Keywords: Holography, Waveguide, Head Mounted Display

ABSTRACT

In this research, we propose a simplified way to expand the exit pupil of a holographic Head Mounted Display (HMD). The divergent spherical wave is transmitted in the waveguide, and a large diffraction area is formed to make an output Holographic Optical Element (HOE).

1 INTRODUCTION

In recent years, the development of Augmented Reality (AR) has attracted much attention. The digital information is projected into the user's eyes through the visual display without shielding the external scene so that the user can simultaneously receive the external real scene and digital information. This concept is often used in the form of HMD and Head-Up Display (HUD).

At first, the prototype of these devices was heavy and large. To improve this problem, a single-reflection HOE as a light guide for HUD or HMD has been proposed, and the output of the display can be combined with the external reality [1, 2]. The field curvature, astigmatism, distortion and other aberrations that may be caused by such this architecture are analyzed [3].

In addition, some literature proposed to reduce the weight and size by using waveguide elements, and successfully achieve a lightweight wearable display. For example, Tapani Levola has proposed to use gratings and a waveguide as a light guiding element, and use the gratings which were recorded total reflected light to splicing them to extend output coupling [4]. This technology has also been applied to HUD [3, 5].

However, the popular issue is that the image is coupled to the input and output through two symmetric HOEs, the architecture is as shown in Fig.1. The research also analyzed the aberrations of such architectures and proved that they can be eliminated by image sources with opposite aberrations [6].

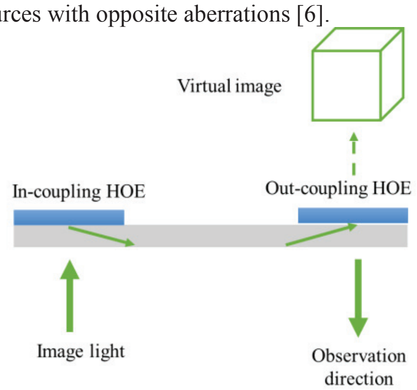


Fig.1 Schematic diagram of the coupling waveguide.

The way to precisely splicing into a large-sized out-coupling HOE with gratings is successful for expanding exit pupil and viewing blocks [4]. However, the disadvantage of this method is that the process is complex and the diffraction at each different location on the HOE must be precisely controlled to achieve a uniform exit image.

According to previous studies on the waveguide element, most of them use the plane wave to transmit in the waveguide. In this study, we tried to expand the exit pupil by using the divergent spherical wave as the medium in the waveguide, and using its own divergence angle to achieve a large-area output coupling element. This way can avoid difficulties in splicing, and the output HOE should be easily recorded. It is expected that the procedure can be simplified. Furthermore, to avoid the visual fatigue caused by the user's eyes focusing at different positions, the image is presented at infinity. For this reason, we used the input HOE which is with the spherical wave phase to make the image at infinity. Therefore, the HMD didn't use the lens in the system.

The result of this paper is that coupling the light emitted by the projection system into the waveguide through the HOE. After coupling to the output HOE, the light is coupled out and transmitted to the user's eyes by another HOE. Finally, the user can obtain the monochromatic visual information at infinity by the device.

2 EXPERIMENT

2.1 The HMD System

In HMD design, the experimental waveguide size is a 50 mm × 70 mm × 5 mm beveled glass waveguide, and the angle of the bevel is 40 degrees. The input HOE is designed with lens function and two couplings are reflection-type gratings as shown in Fig.2. Both HOEs are separated by 5mm. According to the holographic principle, the reflection-type HOEs are with wavelength selectivity so that a low coherence white light can be used as a backlight for the HMD.

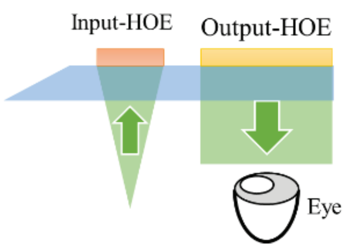


Fig.2 Design diagram of the HMD.

2.2 Record The HOE

In the experiment, the HOEs are recorded by 532 nm wavelength, and the material of the HOE is photopolymer. First, the s-polarized spherical wave is incident on the beveled side of the waveguide, so that part of the light which meets the conditions of total reflection can transmit in the form of the divergence. And then, the output HOE is recorded by the divergent spherical wave and the s-polarized plane wave, so that the transmitted light can reconstruct a uniform plane wave, as shown in Fig.3.

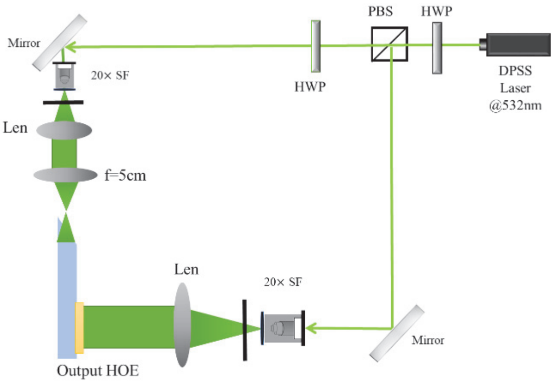


Fig.3 The output HOE recording system.

After that, the output HOE is illuminated by a conjugate plane wave to reconstruct the convergent spherical wave in the waveguide. Then, the input HOE is recorded by the convergent spherical wave and the reconstructed light, as shown in Fig.4.

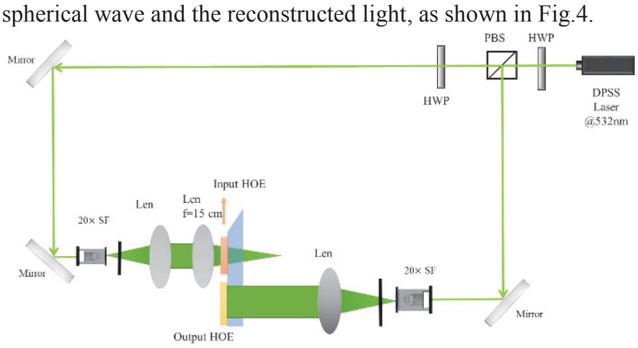


Fig.4 The input HOE recording system.

Finally, the diameter of the input HOE is 17 mm and the output HOE is 33 by 30 mm. The focal distance of the input HOE is 75 mm. The eye relief of this HMD is 27 mm.

3 IMAGE RESULTS

In Fig.5(a), due to the size of the camera, the input light is turned by the beam splitter (BS). The 3 by 4 cm LCD panel at the focus of the input HOE is used as the image source. When it inputs the 3 by 3 mm/ grid image as shown in Fig.5(b), the HMD is separately used the 532 nm laser and the white light LED as the backlight. The output image is shown in Fig.5(c), (d). The field of view (FOV) are extremely different, because the bandwidth is related to the diffraction distribution in the two-reflection HOEs architecture. From the Fig.5(d), the image stretch left and right with slanted and trapezoidal aberration. The horizontal and vertical FOV of Fig.5(d) is 13.3 degrees and16.5 degrees.

In this HMD, the exit pupil is confined by the size of the input HOE and its shape is an ellipse. The size of the exit pupil is 30 mm in length, 24 mm in width, and approximately 53 mm away from the output HOE.

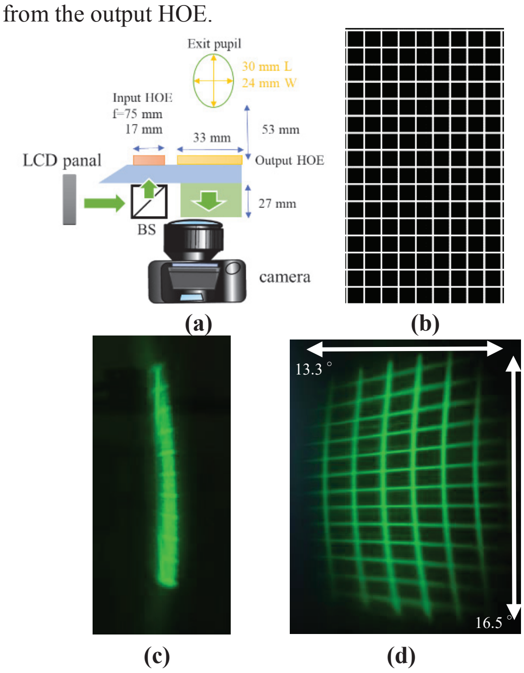


Fig.5 (a)The parameter of the HMD; (b) input the 3 by 3 mm/grid image of the LCD panel; (c) the image by 532 nm at infinity; (d)the image by white light LED at infinity.

3.1 MTF Measure

To realize the spatial resolution of this system, the pattern as shown in Fig.6 is a resolution test target. It consists of six groups and each group consists of six elements. From Fig.7, the best resolution is the group 1 of the 6 elements. According to Table.1, the best resolution is 3.56 lp/mm.

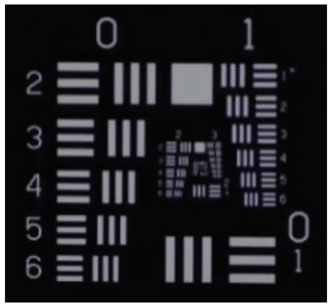


Fig.6 The 1951 USAF resolution test chart.

Fig.7 The image result of the resolution test chart.

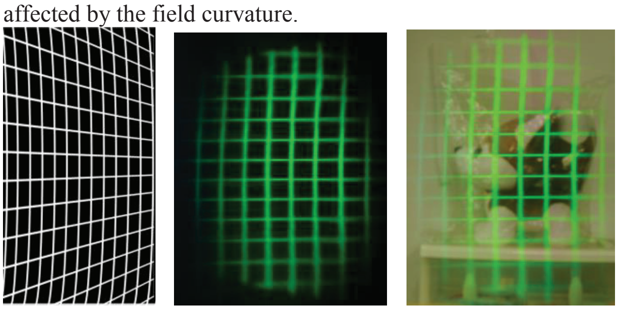
Table.1 Number of line pairs / mm in USAF resolving power test target 1951.

	Group Number		
Element	0	1	2
1	1.00	2.00	4.00
2	1.12	2.24	4.49
3	1.26	2.52	5.04
4	1.41	2.83	5.66
5	1.59	3.17	6.35
6	1.78	3.56	7.13

3.2 Image Quality and Digital Correction

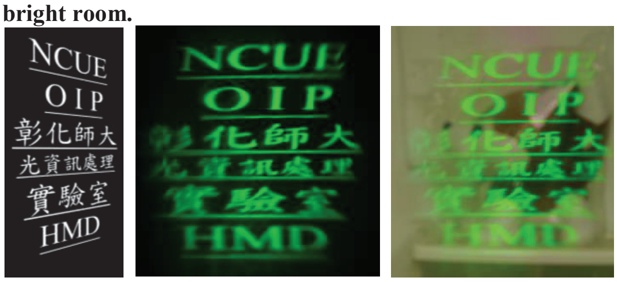
From the image results, the monochrome image is with the distortion which causes the straight line curved and the grid slanted. Fortunately, inputting an image with opposite aberration by LCD panel could revise the aberration as shown in Fig.8(a), (b). We can simultaneously see the real scene and the information at bright room as shown in Fig.8(c).

According to the previous revise, we try to input other revised information to see its image quality, and separately observe in bright and dark situations as shown in Fig.9. In addition to the surrounding intensity is weaker for the image, the surrounding image is some blurred than its center. Since the image is also affected by the field curvature.



(a) (b) (c)

Fig.8 (a) Input the revised grid image; (b)the revised image result at dark room; (c)the revised image result at bright room.



(a) (b) (c)

Fig. 9(a) Input the revised image; (b)the revised image result at dark room. (c)the revised image result at bright room.

4 DISCUSSION

Using the divergence wave as the transmitted light in the waveguide can simplify the process of the output HOE. The exit pupil is restricted by the input HOE in the system. This factor and the eye relief would decide the FOV of the HMD.

From the image results, we find the distortion and field curvature causing the image curved and surrounding blurred. Currently, we can improve the distortion by digital correction. In order to analyze the generation of aberrations, the system would be simulated with ZEMAX to find whether the transmitted light or the recorded HOE cause the aberration happened. Moreover, the ZEMAX can also find the position and size of the exit pupil.

5 CONCLUSIONS

In this study, we proved that using the divergent light in the waveguide to record the output HOE is successful to avoid the difficulty in splicing, but the image result would be with some aberrations such as distortion and field curvature. The deformation couldn't be avoided. However, the distortion can be improved by inputting the opposite aberration to observe the correct image. In this system, the input HOE is recorded by the spherical wave phase, so it can make the monochrome image appear at infinity. Let users see the informaton and scene at the same time. The horizontal and vertical FOV is 13.3 degrees and16.5 degrees, when the eye relief is 27 mm. The MTF of this HMD is 3.56 lp/mm.

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