Lens-less Monochromatic Head Mounted Display Based on Holographic Optical Element

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ABSTRACT

In this study, the lens-less monochromatic HMD based on HOE was proposed. This device composed of two HOEs and the input HOE is with the lens phase. This device can provide infinite AR images for the observer without geometric lens. Finally, the FOV of this device is 9.4°×14.6°(H×V).

1. INTRODUCTION

In the past, there have been many studies on the head up display (HUD) for car driving. The driver can't clearly grasp the road conditions while looking down at the dashboard, and increase driving risk. By presenting the dashboard information in the distance, the dashboard information and the real image will be displayed at the same time. There is no need to look down at the dashboard during driving, which can reduce the risk and increase the safety of driving [1-3]. Motorcycle driving also has this problem. Therefore, the Head Mounted Display (HMD) device for motorcycles is proposed. But traditional HMD is bulky, so we use the HOE technology to make the system become compact [4-5]. It can be combined with the helmet to achieve the HMD installed on the helmet.

In this study, the lens-less HUD based on HOE composed of the holographic waveguide element and the liquid-crystal display (LCD) panel. The holographic waveguide element constitutes by two reflective-type HOE. The input HOE is with spherical wave information. The information of LCD panel will be imaged at infinitely and be coupled into the waveguide, and meet the condition of totally internal reflection (TIR). The image is coupled out of the waveguide through Output HOE which another pair of linear gratings and guided into the observer's eyes. Finally, the device can display an infinite image with a Field of View (FOV) of 9.4°×14.6°(H×V). without any lens.

2. EXPERIMENT

The functional schematic diagram of the system is shown as Fig. 1. The size of the waveguide is 122mm × 49mm × 1.15mm. Input HOE is a reflective hologram which contains information of spherical wave. When a point light source was located at 60mm in front of Input HOE, Input HOE collimated the divergence spherical wave and coupled the reconstructed collimated wave into the waveguide at the angle of 55°. Then the collimated wave is coupled out by Output HOE along the normal direction. Finally, the observer can obtain an image of the point at infinity. Furthermore, the device can provide 2D images when the point source is replaced by a 2D display panel.

The proposed monochromatic HMD which consists of the holographic waveguide element, backlight system and an LCD panel was designed to install on the helmet. The schematic diagram of this device is shown as Fig. 2. The LCD panel was located at 60mm in front of the Input HOE, and the image can be obtained by the observer at infinity.

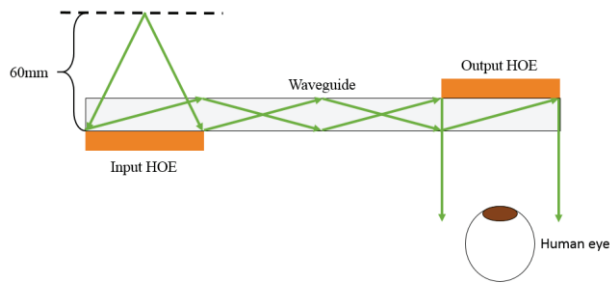


Fig. 1 The schematic diagram of the system

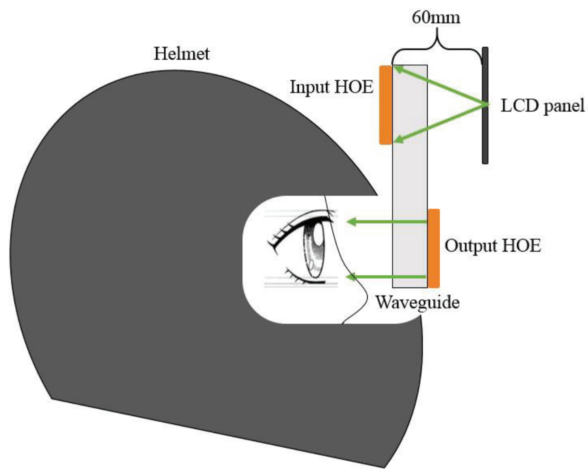


Fig. 2 The schematic diagram of this device.

The recording system for generating the Input HOE is shown as Fig. 3. In the system, Diode-Pumped Solid-State Laser (DPSS laser) which wavelength is 532nm was employed. The polarization beam splitter (PBS) and the first half-wave plate (HWP) were utilized to modulate the ratio of the reference beam and the signal beam. The second HWP was utilized to rotate the polarization of the reference beam as the s-wave. The two beams are converted into collimated waves by spatial filter (SF) and collimating lens (CL), then the collimated waves of the reference beam was converted into a convergent wave by a positive lens. The incident angle of the convergence beam and the collimated beam was 0° and 55° separately. After the exposure, the HOE records the interference fringes, and the diffraction efficiency of Input HOE is 58%.

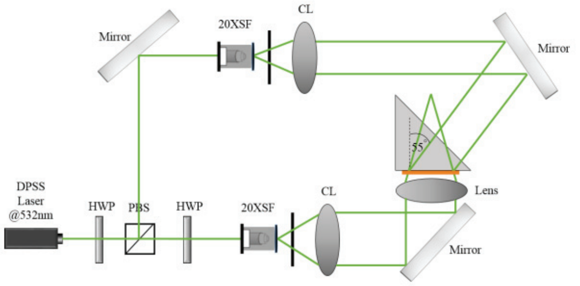


Fig. 3 The system for generating the Input HOE device. HWP: half-wave plate, PBS: polarized beam splitter, SF: spatial filter, CL: collimating lens

The recording system for generating the Output HOE device is shown as Fig. 4. The system is similar to the former one as shown in Fig. 3. A collimated wave is normal incident to the prism, and the other collimated wave is incident to the prism at an angle of 55°. After exposure, the HOE records the interference fringes, and the diffraction efficiency of Output HOE is 42%.

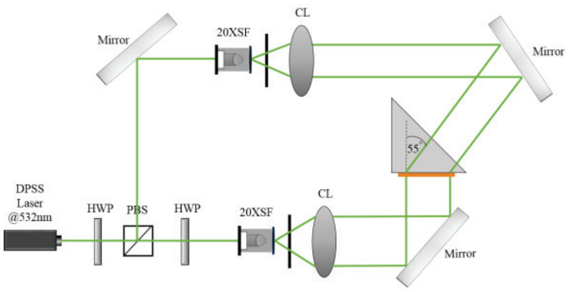


Fig. 4 The system for generating the Input HOE device.

In this study, 2D patterns which printed on transmission diffusers were employed to measure the maximum field of view (FOV) and the resolution of the holographic element. The pattern was placed at the focal point 60mm in front of the Input HOE. The camera is placed in front of the Output HOE and focus at infinity. The observation system is shown as Fig. 5.

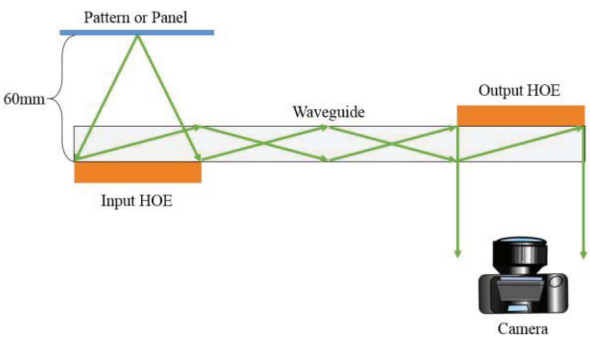


Fig. 5 The observation system. The pattern placed at 60 mm in front of the Input HOE

3. RESULTS

3.1 Field of View

In order to measure the vertical and horizontal FOV, a screen was arranged at 400mm in front of the camera, and the area on the screen which FOV was equal to the virtual image at infinity was marked. Then the half FOV can be described as

$$\theta = \tan^{-1}(w/l), \quad (1)$$

where w represents the half-height or half-width of the marked area, l represents the position from the camera to the screen. The pattern is shown as Fig. 6, and the size of each small rectangle is 3.5mm by 2mm. The black part of the mask is opaque, and the white part of the mask is transparent.

In this part, green lasers and green LED were utilized as the backlight respectively for observation. The results are shown as Fig. 7. We can observe that the FOV of resulting image with green LED have is larger than the other one. This is because of that the spectrum of green LED is much larger than that of green laser.

The final measured FOV is 3.7°×1.8° (H × V) per grid. According to the resulting image as shown in Fig 7, we can determine that the maximum FOV with laser backlight is 5.6° × 14.4° (H × V), and the maximum FOV with the green LED backlight is 27.7° × 14.4°(H × V).

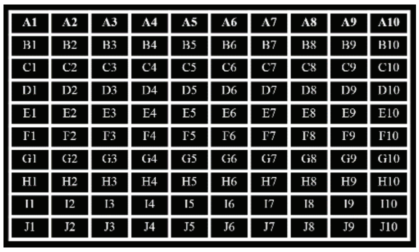
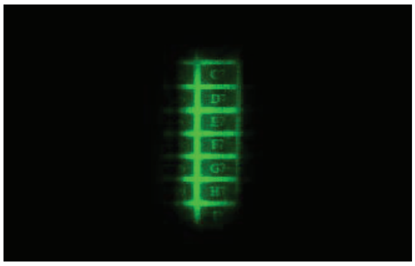
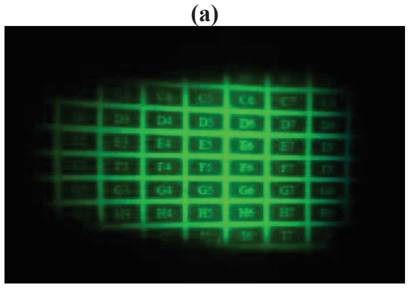


Fig. 6 The information of the pattern, the size of each small rectangle is 3.5mm by 2mm



(a)



(b)

Fig. 7 The images generated by HMD with (a) green laser, (b) green LED backlight

3.2 The MTF of lens-less system based on HOE

The MTF of the proposed lens-less system was measured using the USAF test target. The observation system is shown as Fig. 4. The pattern is replaced to the USAF-1951 test target. The information of the USAF test target is shown as Fig. 8. The resulting image is shown in Fig. 9 The maximum resolution is the lines in group 2 element 3. The corresponding spatial frequency in Table 1 is 5.04 lp/mm.

It means that the most meticulous linewidth of the final image can achieve 0.095° when the effective focal length of Input HOE is 60mm if the pixel size of the LCD panel is smaller than 0.1mm.

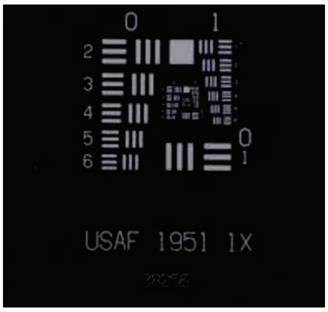


Fig. 8 The information of the USAF test target

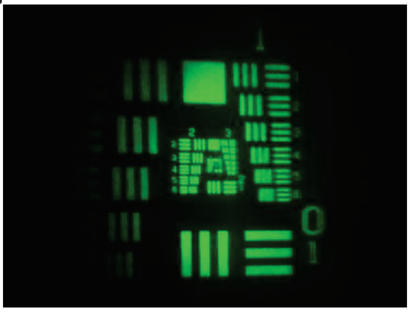


Fig. 9 The USAF test target generated by HMD

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

Number of line pairs/mm in USAF Resolving Power Test Target 1951					
Group Number					
Element	0	1	2	3	4
1	1.00	2.00	4.00	8.00	16.00
2	1.12	2.24	4.49	8.98	17.95
3	1.26	2.52	5.04	10.10	20.16
4	1.41	2.83	5.66	11.30	22.62
5	1.59	3.17	6.35	12.70	25.39
6	1.78	3.56	7.13	14.30	28.50

3.3 Image of system with LCD panel

The prototype HMD of the proposed device is shown as Fig. 10. The HMD with helmet is shown as Fig. 11. The holographic waveguide element is rotated 90 ° when it is installed on the helmet. The size of the LCD panel is 30mm × 40mm. According to the results of the above FOV measurement, in order to avoid dispersion and the low uniformity, only the smaller display area was employed. The pattern of the LCD panel is shown in Fig. 12, and the resulting images are shown in Fig. 13. The FOV of Fig .12(a) is 9.4° × 14.6°(H×V), and the FOV of Fig .12(b) is 14.0° × 16.9°(H×V).

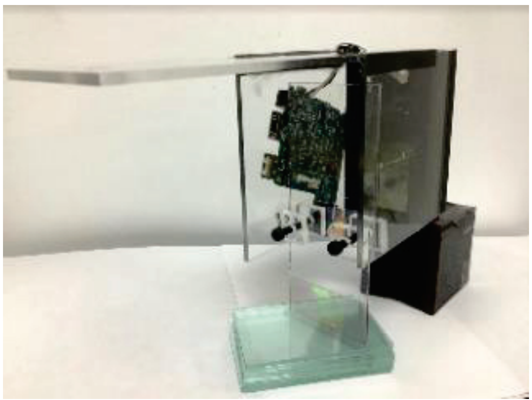


Fig. 10 The prototype HMD of the proposed device

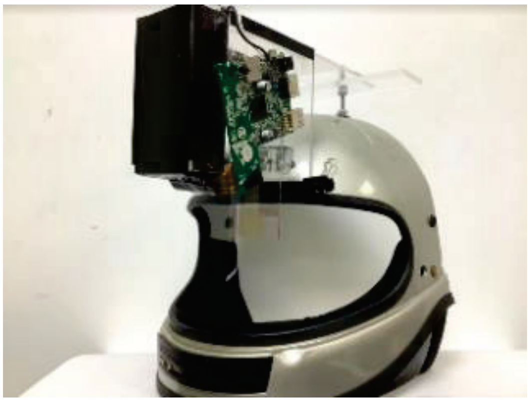
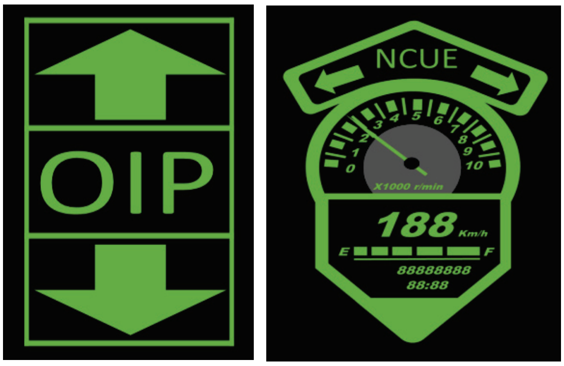
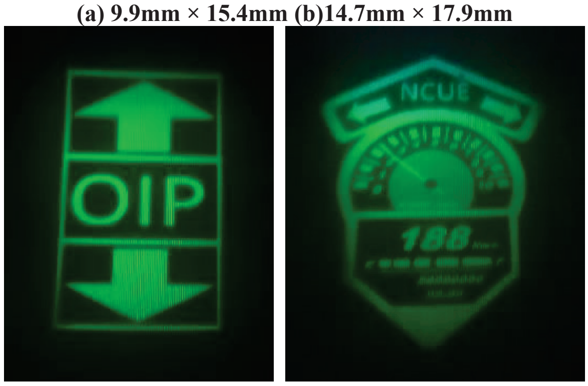


Fig. 11 The prototype HMD with helmet



(a) (b)

Fig. 12 The information of the pattern, the size is (a) 9.9mm × 15.4mm (b)14.7mm × 17.9mm



(a) (b)

Fig. 13 The image generated by HMD with LCD panel

4. DISCUSSION

In this study, this monochromatic holographic waveguide element was successfully employed in HMD. However, because of the limitation of the instrument, the exposure area of the Input HOE is small. The FOV is not having the expected size in the vertical direction. In order to solve the above problems, increasing the exposure area of the HOE should be improved effectively. When viewing the image pass through the Output HOE. The distance between the eyes and the holographic waveguide element will also cause the FOV to become smaller in horizontal and vertical direction. This is unavoidable, so we can increase FOV by angular multiplexing. In the future, full color HMD will be studied. The full color HOE is recorded by wavelength multiplexing. The HOE is reattached on waveguide element to achieve the full color HMD.

5. CONCLUSIONS

In this study, the lens-less monochromatic HMD based on HOE was proposed. The holographic waveguide element was tested with FOV and the MTF of this system. In the case of the reflective HOE with spherical wave information was employed without imaging lens. The information of the LCD panel can be directly imaged at infinity and coupled out waveguide. The purpose was achieved of compact optical system. The aberration of the system can be compensated by symmetrical grating structure. At present, using a wide-spectrum green LED as the backlight source of this system. The result of the FOV is 9.4° × 14.6°(H×V), and the MTF of this system is 5.04 lp/mm.

Acknowledgement

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