The Design of Head-up Display Based on Symmetric Holographic Optical Elements

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Keywords: head-up display (HUD), holographic optical element (HOE), symmetric structure HOE, holographic lens.

ABSTRACT

The study proposes HOE based on symmetric structure and exit pupil imagery of the HUD system. The symmetric structure of the system helps eliminate aberration. The exit pupil is imaged by the HOEs in front of human eyes and provides sufficient FOV.

1 Introduction

Head-up display (HUD) uses principles of geometric optics and sends system images through optical elements to the human eye. In this way, drivers can simultaneously observe system images and reality views which reach Augmented Reality (AR). This technique is widely applied in the automotive market, in order to avoid dangerous driving from being distracted by messages on the dashboard [1]. Traditional geometry automotive HUDs must use many lenses, aspherical lens, and freeform surfaces lens for reducing optical aberration and distortion of display effects [2]. Similarly, to refrain lens size from limiting the FOV, lens sets are characterized in large sizes. As a result, HUD has both problems of high cost and oversize volume [2-3].

In the previous research, a HUD system designed with a holographic lens could image an exit pupil by the system and place it in front of both human eyes [4]. At the same time, the HUD system combines a projection system to show the input image before the observer's eyes. HUD designed with single HOE causes anamorphic and serious aberration [4]. The projection lens in the HUD system or the location that input HOE limits FOV.

In this paper, the HUD is designed based on the symmetric structure HOE for compensating the anamorphic form of single linear grating, thus decreasing the aberration of the output image. In this system, the imaging lens is put at twice the focal length of the HOE set, then imaged in the identical size before the observer's eyes through the HOE set. In this way, the observer can obtain lens cases that accommodate eyes without being affected by the imaging lens and get imagery information that system input from infinity.

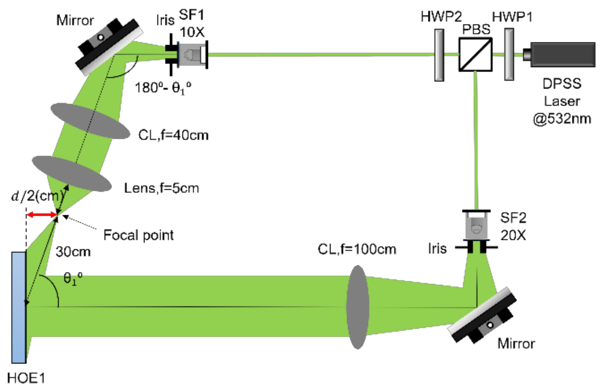
To provide automobile drivers a comfortable observing distance and suitable volume, the distance between observer and HOE output is 60 cm, spacing of HOE set is less than 20 cm.

2 Experiment

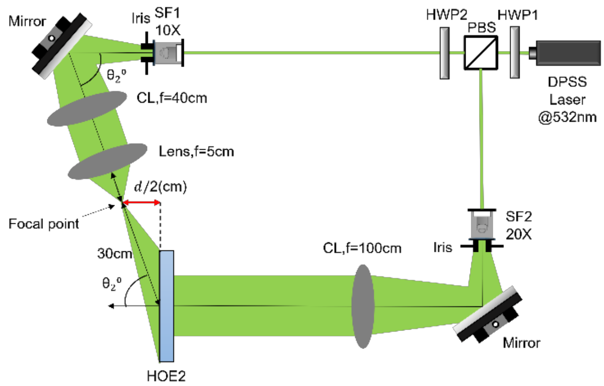
2.1 The recording of HOEs

The architecture diagram of this experiment is presented in Fig1. The 532 nm Diode-Pumped Solid-State Laser (DPSS) is used as a light source to record HOE1 and HOE2. First, a polarizing beam splitter (PBS) divides a laser into two orthogonal light beams. Then adds HWP (Half-wave plate): HWP1 is used to adjust the proportion of luminous intensity between S wave and P wave, HWP2 converts P wave into S wave. Next, using a mirror to decide the degree of angle when recording two beams of lights. HOE1 and HOE2 are recorded as incident light beams respectively, one in $\theta_1 = \theta_2 = 75^{\circ}$ and the other is perpendicular to HOEs. Two gaussian beams generate collimating waves through Spatial Filter (SF) and Collimating Lens (CL). The 75° incident wave is focused 30 cm in front of HOEs by a 5cm-focal-length convex lens. The other incident wave through a 100cm-focal-length convex lens generates a collimated beam and is perpendicular to HOEs. Last, the transmission HOE1 has the same side interference, and the reflection HOE2 has opposite side interference. Conduct exposure also records the interference fringes of two waves.

Complete record HOEs could be viewed as a 30cm-focal-length holographic lens, with the exposure zone being a circle of radius 4.5 cm.



(a)



(b)

Fig 1. The optical system configurations were employed to record (a) HOE1 and (b) HOE2.

2.2 The automotive HUD

The architecture of the automotive HUD is shown in Fig2. We set LED as a back light, and put pattern at once the focal length of the projection lens. Through the projection lens focus on infinity to HOE1, diffraction focal length is 30cm converging spherical waves, then enter the HOE2 by diverging spherical waves in 30cm focal length, diffract to one collimated light. Similarly, the distance between projection lens and HOE2 is 60 cm, eye box is imaged in 60 cm back of the HOE2. This design lets the distance from the projection lens to HOE2 equals the one from the observer to HOE2, both are 60 cm, realizing 1:1 imaging.

When observers put their eyes in front of the eye box, they could see the combination of output image and reality view, simultaneously. FOV in the optical system is not affected by the projection lens, it is only limited by the interference region of HOE2. The larger the interference region of HOE2, the bigger the FOV is available.

The group spacing is d=15.41cm, it was obtained after adjustment HOE1 and HOE2. Distance is less than 20cm which fits the initial setting.

The projection lens kit consists of three identity convex lenses. The specification of a single lens is shown in Table 1.

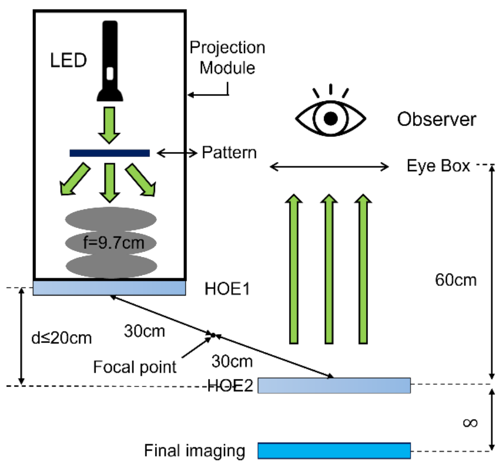


Fig 2. The automotive HUD observation architecture is made with HOE1 and HOE2.

Table1. The specification sheet of a single unit lens which composes the projection lens.

Radius1	Radius2	Width	Height	Thickness	Material
290mm	-290mm	50mm	100mm	11mm	BK7

2.3 The eye box measurement

Figure 3 exhibits the measurement system which was employed to determine the dimension of the eye box. The diffuser was arranged between the projection lens and HOE1. The dimension of the projection lens and the diffuser is the same. The image of the eye box will be imaged by HOE2 60 cm behind it, which will be the observer's observation position.

The specification of the projection lens is 100mm*50mm, offers an eye box enough space to accommodate both eyes.

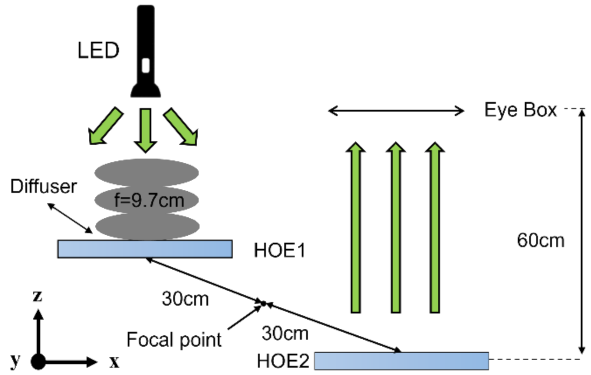
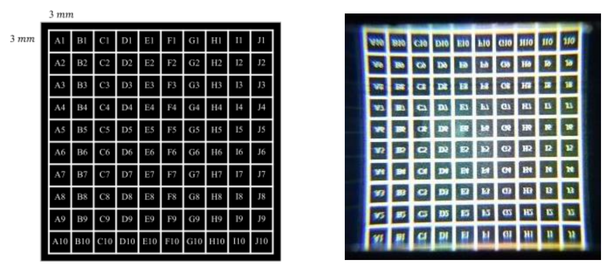


Fig 3. The dimension of the eye box was determined by measuring the image size of the aperture stop.

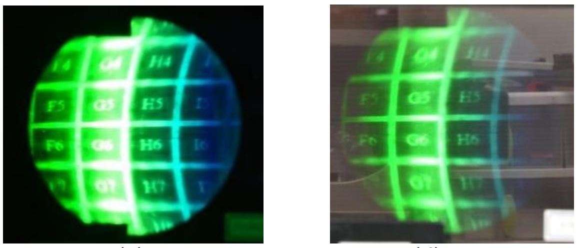
3 Result

3-1 Image of the automotive HUD

The diffraction efficiency of HOE1 and HOE2 of the system are 8% and 14.8%, separately. Input pattern is shown in Fig4 (a)., size of each grid is 3mm by 3mm. The input information is the image at infinity that was provided by the projection lens, as shown in Fig. 4(b). The final images in dark room and bright room are shown in Fig4 (c) and (d)respectively. Image has a more serious aberration also the light intensity attenuates from the middle to both sides. Only the right side of the center of the grid is displayed.



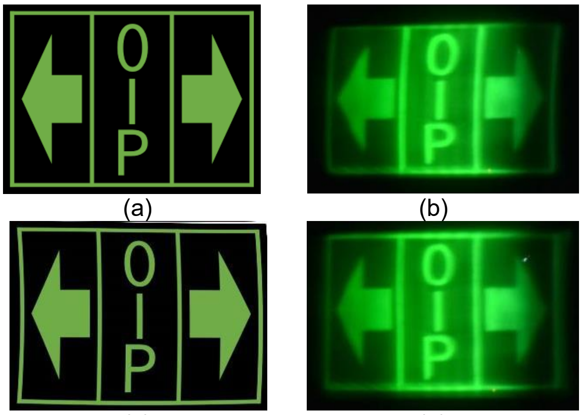
(a) (b)



(c) (d)

Fig4. The resulting image was performed with the green LED as the backlight. (a) the original pattern (3mm*3mm per grid); (b) from the projected image at infinity; (c) Final image in the dark room; (d) Final image in the bright room.

To solve the problem of image anamorphic, getting distortion-free image. A LC panel is used for digital correction, the LC panel is the place where pattern is changed. The size of a LC panel is 5.2mm*4.8mm. The contrast of the output image after digital correction is shown in Fig5. In comparison, the image after digital correction is closer to the original input image.



(a) (b)

(c) (d)

Fig5. The result of digital distortion correction was performed with an LC panel as the image source. (a) input image without correction; (b) final image without correction; (c) input image correction; (d) final image with correction.

3-2 size of the automotive HUD

The eye box size in this system is shown in Fig6 . The eye box is 8.5cm * 4.8cm. Owing to the off-axis design of HOEs, the eye box has a little bit of distortion. When putting both eyes in the eye box people can observe the export image from the system. FOV is not affected by the projection lens, only changed by the HOE2 interference region.

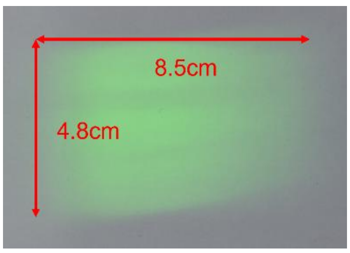


Fig6. The specification of the structure of HUD eye box.

Finally, use equation (1) to calculate the horizontal and vertical FOV of HUD when using LC panel or pattern as image source. Here, L is the projection distance, x is image size.

$$\theta_{\mathrm{FOV}} = 2\tan^{-1}\left(\frac{x/2}{L}\right) \tag{1}$$

The vertical FOV is 9.14°, the horizontal FOV is 9.05°, when pattern as image source. Under the constraint of the LC panel size, horizontal and vertical FOV can only reach 3°.

4 Discussion

FOV of this system is limited by the HOE2 interference region. FOV of the system can be increased through increasing HOE interference region. Under the constraint of LC panel size, only one third of the horizontal and vertical FOV is provided. Adding lens and diffuser in the projection system to amplify the input image. Theoretically, this is capable of offering horizontal and vertical FOV in full print.

The shape of the eye box is not imaged 1-to-1 scale, since affected by the HOEs aberration which makes the eye box a little bit smaller than the projection lens size. Whereas this does not affect putting both eyes in the eye box to observe the output image. The eye box after distortion is large enough to accommodate both eyes.

The projection lens is composed of three double converging lenses. The further to the optical axis center, the more serious the aberration would be. Therefore, the projection lens may not be the most suitable, the correction lens could be applied later to improve the aberration.

Images entered from the center of the grid end up with only the right part observed, not left and right symmetry. The generation of this phenomenon will be analyzed later through Zemax.

5 Conclusion

The study proposes HOE based on symmetric structure, can successfully be imaged from infinity, and possess FOV at horizontal 9.05° and vertical 9.14°. The exit pupil of the projection lens is imaged in front of the observer and provides sufficient FOV. The final image is not affected by the projection lens, only changed by the interference region. Through digital correction, an output image that is similar to the input image is provided, FOV at horizontal 3.1° and vertical 2.9°.

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