The Design of Head-up Display Based on Holographic Optical Element

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Keywords: Head-up display, Holograph, HOE

ABSTRACT

This study designed a HUD based on HOE and a projection system. In this system, the exit pupil is placed on the eyes of the observer and provides an image. The system has a larger FOV due to the placement of the exit pupil on the eyes of the observer.

1 INTRODUCTION

The head-up display (HUD) was first applied to fighters [1]. In order to prevent pilots from looking down at the dashboard frequently, the important information is displayed on a transparent glass in front of the line of sight. With advances in technology, this technique has also been widely used in the automotive market in recent years [2]. By using the HUD to provide the necessary information to the driver and present it on the outside of the window, the danger caused by bowing can be avoided [3]. In addition, the design of the HUD must provide an imaging distance that is far enough away. This long-distance imaging avoids the danger and fatigue caused by the human eye switching when it is close to the focus [4].

In the traditional design of the HUD optical system, in order to reduce the size of the entire device, each research team hopes to use a small panel image source combined with a lens kit to enlarge the output image and provide images with a wide angle of view. Such a design necessarily requires large optical components, but brings serious aberrations. To eliminate the aberrations, researchers have to add more optical components, which leads to excessive volume [5].

In order to avoid occupying too much space for the vehicle, a component such as a geometric lens, a mirror or a half-mirror is replaced by a holographic optical element (HOE). It can replace the lens or half-mirror and other components by recording the light wave front by a thin photosensitive material such as photopolymer. However, HOE still has many hard-to-solve problems, such as image distortion, HOE aberration as a convex lens, and mass production, which has made it difficult to produce such devices.

The purpose of this study is to design a HUD device for vehicles based on a reflective-type HOE. The size of eye box is the imaging result of the lens in the projection module with one to one imaging effect through the HOE.

2 HEAD-UP DISPLAY SYSTEM

The optical system architecture of this study is shown in Fig.1. Once the image source is applied by the projection module, it becomes a magnified intermediate image and, after the reflective-type HOE, the enlarged final image is imaged at infinity.

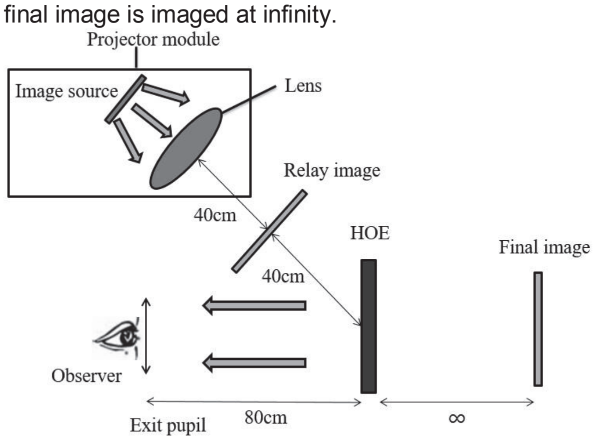


Fig. 1 The schematic side elevation view of HUD.

In Fig. 1, the projection module is placed above the observer and the source image is projected through the lens into an intermediate image located 40 cm behind the lens. The intermediate image is 40 cm ahead of the HOE and crosses the HOE to form a final image to infinity, allowing the driver to see the output image combined with the live view.

This reflective HOE is designed as a holographic lens with a focal length of 40 cm. The image of the intermediate image on the focal length of this HOE will produce a virtual image to infinity.

The lens of the projection module is placed 80 cm in front of the HOE and the lens of the projection module is imaged one by one after the action of the HOE. Simultaneously, the imaging of this lens is the exit pupil and the eye box of this system. Therefore, the exit pupil is imaged 80 cm in front of the HOE. The distance from the pupil to the HOE is 80 cm. This value is designed according the eye relief of general HUDs. When the human eye is placed just in front of the exit pupil to view the output information, the exit pupil does not limit the FOV of this optical system. The FOV only limited by the interference area of the HOE. Theoretically, as long as the interference area of the HOE is larger, the observable viewing angle is wider.

3 EXPERIMENT

3.1 Experimental principle

According to recent research on HUD and hologram theory, when an HOE is recorded as a result of a divergent point source and a plane wave interference, it can be regarded as a Fresnel lens and the point source located at the focus is displayed at the infinite.

In the aforementioned HOE, it is a holographic lens formed by interference with a plane wave and a point source, which is 40 cm in front of the HOE. The pattern generates an amplified intermediate image through the projection lens kits, and the intermediate image is imaged infinity by the HOE effect. The true image of this projection lens becomes an eye box.

The projection lens kit with short focal length was utilized to generate a magnifying intermediate image. The position of the intermediate image was arranged at 40 cm behind the projection lens, 40 cm in front of the HOE. In the case of a fixed image distance, the working distance is limited. Depending on the reversibility of the optical path, the lens is designed in the reverse optical path, i.e. the projected object is considered as the image of the projected image, which is useful for satisfying certain position of exit pupil.

3.2 The recording of HOE

This study uses HOE as the HUD display and the experimental recording architecture is illustrated in Fig. 2. The diode-pumped solid-state(DPSS) laser which wavelength is 532nm is split into two beams by a polarizing beam splitter(PBS), and the ratio of vertically polarized light to horizontally polarized light is distributed by the half-wave plate(HWP). Another HWP (HWP2, as shown in Fig. 2) is placed behind the PBS to convert the vertically transmitted polarized light to horizontally polarized light, thereby interfering with both lights.

Once the upper beam is reflected by the plane mirror (M1), it is expanded into a spherical wave after transmitted through spatial filter (SF) and crosses collimating lens to form a plan wave. The lower laser beam is expanded by spatial filter (SF2) and reflected by the plane mirror (M2) on collimating lens, so that the spherical wave transforms into plan wave and is irradiated on the HOE.

The spherical wave on the left side of Fig. 2 is diverged on HOE after focused on the front 40 cm of the HOE, interfering with the parallel light. After the interference of the spherical wave and the plane wave, the interference fringes recorded at the photopolymer on the HOE have the function of a lens which has focal length about 40 cm.

3.3 The Design of Head-up Display

In Fig. 3, using a DPPS laser as a light source, the laser beam is expanded into a spherical wave and illuminates the pattern, which is 2.16 cm wide and 2 cm high. The light passes through the lens to image a magnified intermediate image. The distance between the pattern and the lens is 14 cm. The specification of the projection lens as shown in Table 1. It is currently composed of three cylindrical lenses of the same specification having radius of curvature of +290, -290 mm and a focal length of 30 cm. Through the HOE, the observer can see the final image to infinity.

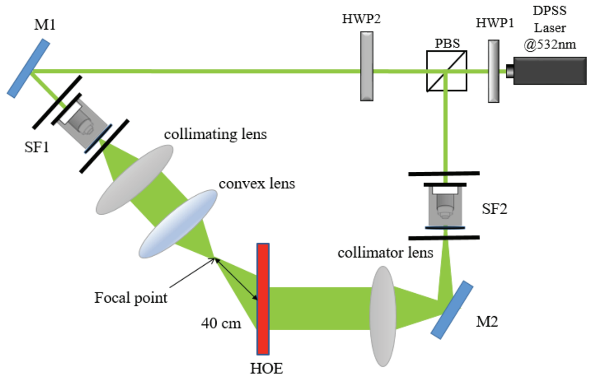


Fig. 2 HOE recording architecture

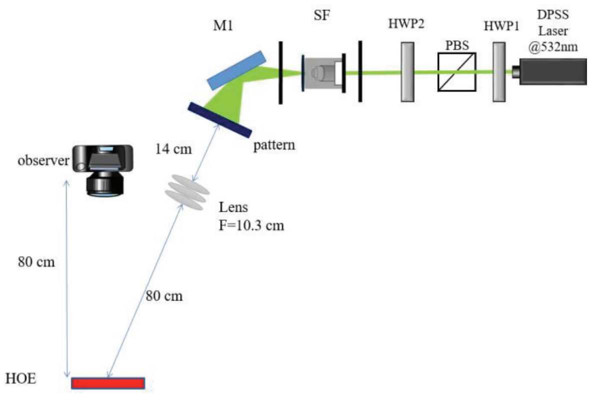


Fig. 3 Observation architecture

Radius R1	Radius R2	Width	Height	Thickness
290mm	-290mm	5 cm	10 cm	1.1cm

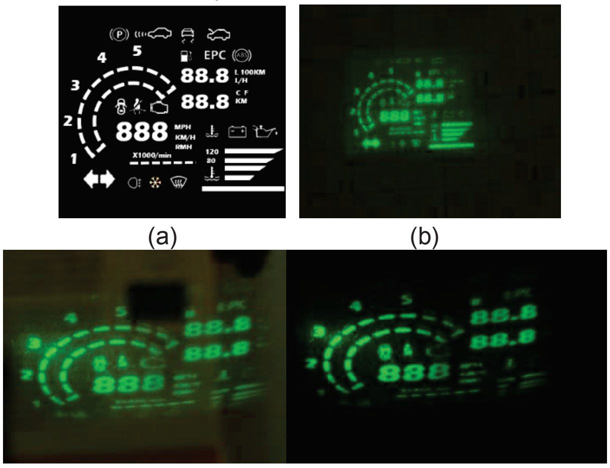
Table 1. The specification of the projection cylindrical lens.

4 RESULTS

4.1 Image Quality

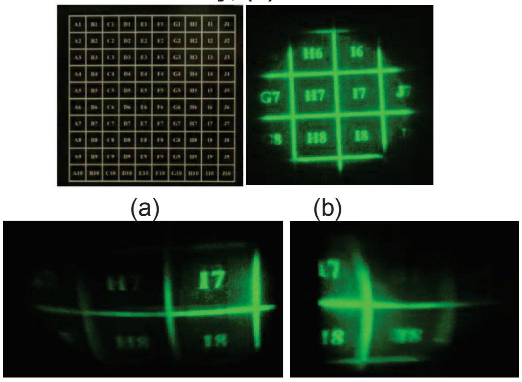
The observation architecture is illustrated in Figure 3. The final image is observed through the HOE. In Fig. 4, the images (b), (c) and (d) are images projected from the lens having a focal length 10.3 cm. And, the lens of the projection module directly affects the magnification of the image. Using a pattern with diffuser as the image source (as shown in Fig. 4 (a)), a projection lens with a focal length 10.3 cm is used to form an enlarged intermediate image 3.05 times. As a result, the final image observed is 3.05 times larger than the image source.

Fig. 5 (a) shows the source image (b) the intermediate image. Use the camera to move each 3 cm horizontally from the center of the HOE to simulate the images seen by the left and right eyes. It can be seen in Fig. 5 that the image after a horizontal displacement of 3 cm represents 70% of the final image. If observer place eyes in the center of HOE, you can see almost the complete final image. The current size of the eye box is 6×5.5 cm^2.



(a) (b) (c) (d)

Fig. 4 (a)The image source(b) The intermediate image. The final image through the camera in the (c) bright room at infinity; (d) in dark room



(a) (b) **(b)** **(d)**

Fig. 5 The final image is viewed with the left and right eyes, respectively.

4.2 FOV of Image

Through system imaging, the observer can see that the quality of the image meets the expectations. As shown in Fig. 1, the image source forms a clear intermediate image through the lens in the projection module, and the intermediate image is located behind the lens with 40 cm. The observer can observe the optical imaging at 80 cm in front of the HOE and the final image is locating at infinity as shown in Fig. 3.

In order to verify the image quality, the FOV of the image is also measured. Use Eq. (1) to calculate experimental FOV.

$$\theta = tan^{-1}\frac{h_{1/2}}{L} \ldots\ldots (1)$$

And, use Eq. (2) to calculate experimental FOV.

$$\theta = tan^{-1}\frac{h_{1/2}}{f} \ldots\ldots (2)$$

Where $h_{1/2}$ is the size of image, L is projection distance, and f is the focal length of the projection lens. The theoretical FOV in the horizontal direction is degrees 19.4, and the theoretical FOV in the vertical direction is 10.0 degrees. The experimental FOV in the horizontal direction is 27.3 degrees, and the experimental FOV in the vertical direction is 15.2 degrees.

5 DISCUSSION

It is feasible to use a short-focus lens as a projection lens. The display which is in this experiment provides a horizontal and vertical viewing angle of 15.2 and 10.0 degrees, respectively, to achieve a wide angle of vision. 80 cm in front of the HOE is used to simulate the HUD of the car, the distance between the driver's seat and the top of the dashboard. The projection lens passes through the HOE and becomes the exit pupil of the system. The shape of the exit pupil is not a perfect circle, but a drop-shaped figure. The exit pupil one by one is the eye box located in front of the human eye, but the size of the eye box is slightly smaller than the eyes. When the observation position moves slightly, the output information will be restricted by pupil, and will not be complete.

One of the problems is that the quality of the final image is not perfect. The Zemax optical software will be used to simulate the optical system. Then find out how to resolve the distortion of the image. The currently used projection lens is readily available and therefore is not necessarily the optimal imaging optics for this system. Since the system will eventually be installed in the automotive, the choice of the lens will also be simulated with Zemax to find the right lens.

(Another problem we are currently facing is to expand the area of the eye box. Since the eye distance of Asians is 7 cm on average, the solution might be to change the specification of the lens. Moreover, the other is that when viewing the final image, the image will be slightly deformed. The possible solution is to make the diffraction angle close to the one between the HOE and the spherical wave. That is, the diffraction angle approximately equal to the reflection angle, but exactly equal.

6 CONCLUSIONS

In this study, We have demonstrated that HUD is designed to achieve large FOV characteristics without taking up too much space in the vehicle and using fewer optical components. Also, by placing the exit pupil in front of the human eye, the observer do not be limited by the size of pupil, when viewing the image. The premise is that the size of the pupil should at least accommodate both eyes In addition, the position of the imaged pupil is the eye box of this experiment.

In the future, this implement will begin to eliminate aberrations and use wavelength multiplexing technology for full-color imaging, combining this system architecture with driving.

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