Aberration Analyses of Head-up Display Based on Holographic Optical Element and Exit Pupil Imaging System

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ABSTRACT

In this study, the HUD based on HOE and exit pupil imaging system is proposed. The exit pupil of this system will be imaged by the system and placed in front of the human eye, which contains both eyes. Finally, the aberration of the system is analyzed through Zemax.

1 INTRODUCTION

Head-up displays (HUD) first appeared on fighter jets [1]. In order to avoid pilots to look down at the dashboard, and let they can read the required information directly on the windshield. With advancement of science and technology, this technology has also been widely used in the automotive market. It can make drive have no need to look down at the dashboard frequently, which increases driving safety. To reduce the size of the device, in recent years, many design teams have tried to replace elements such as lenses, mirrors, and partial mirrors with HOE [2]. In addition, the design of the HUD must provide long-distance images, so it can avoid danger and eye fatigue when it closes the focal [3]. In the traditional design of the HUD, in order to reduce the size of the device, each researchers hope to use a small panel image source combined with a lens kit to enlarge the output image and provide a wide angle of view. Such a design necessarily requires large optical components but brings serious aberrations. To eliminate the aberrations, researchers must add more optical components, which leads to excessive volume [4]. HOE still has many disadvantages. For example, the HOE used for light guiding will cause aberrations, and the HOE used as a convex lens will have serious aberrations, etc.

The purpose of this project is to design a car HUD device based on reflective-type HOE without occupying too much volume. In this system, the imaging lens is placed at twice the focal length of the HOE and the same size is imaged in front of the observer through the HOE. This way, we can get the final image at infinity and is not affected by the imaging lens pupil. Finally, the lens group which is designed improve the aberration of the final image.

2 EXPERIMENT

2.1 The recording of HOE

The experimental architecture diagram is shown in Fig. 1. The 640nm wavelength of Diode-Pumped Solid-State Laser (DPSS laser) is used as a light source to record HOE. First, a polarizing beam splitter (PBS) divide the laser into two orthogonal beams. The half-wave plate (HWP1, as shown in Fig. 1) is used to adjust the proportion of the S wave and P wave. Another HWP (HWP2, as shown in Fig. 1) converts the S wave into P wave. In this experiment, one beam is 45 degrees and another beam is perpendicular to the holographic material. Two gaussian beam through the Space Filter (SF) and collimating lens (CL) to generate two collimating waves. The 45 degrees incident wave is focused by a convex lens with a focal length is 5 cm at 40 cm in front of the HOE, and the other wave is perpendicular the holographic material with a focal length of one meter lens and the two wave interferes on the holographic material. Finally, the holographic material records the interference fringes of two wave.

After recording, the HOE can be regarded as a lens. The focal length of the holographic lens is 40cm.

2.2 Observe image

The observation structure is shown in Fig. 2. The recorded holographic film uses a divergent spherical wave to incident pattern with 45 degrees. The projection lens is placed in front of the observer and then image source projected to the intermediate image located at 40 cm before HOE. Intermediate image and then across HOE to form an infinite image and allow the driver to see the output image combined with the real view. This design of the distance from the lens to the HOE is equal to the distance from the HOE to the observer, both are 80 cm achieved one-to-one imaging. When the human eye is placed in front of the exit pupil to observe the output information, the exit pupil is not affected by optical system FOV limit. Only interfered by the HOE interference area. If the interference area of HOE is larger, the observe of the viewing angle is wider.

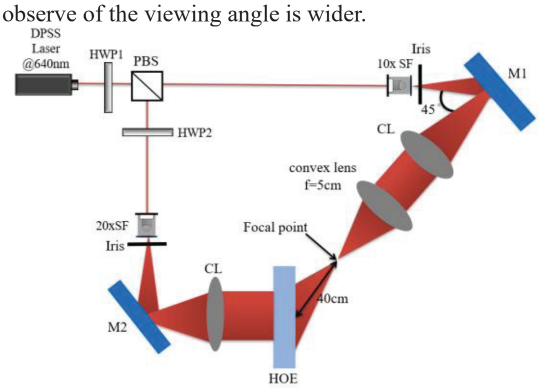


Fig. 1 experimental architecture diagram. HWP：half-wave plate, PBS：polarizing beam splitter, SF：Space Filter, M：mirror, CL：collimating lens

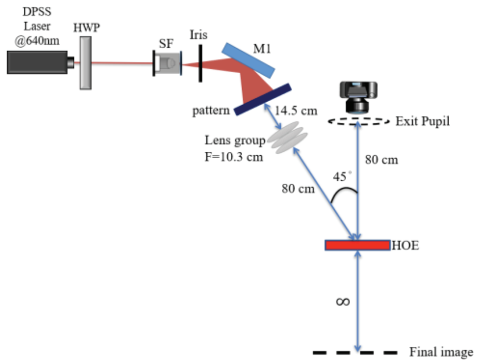
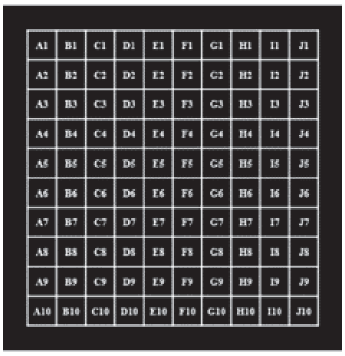


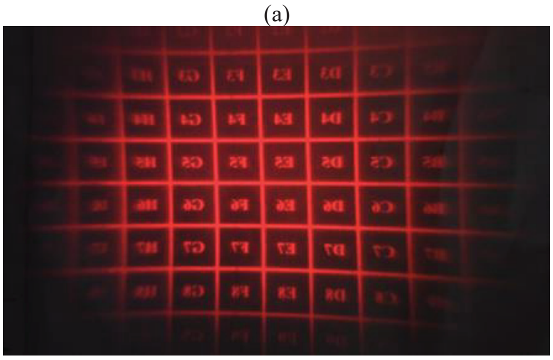
Fig. 2 the observation structure

3 RESULTS

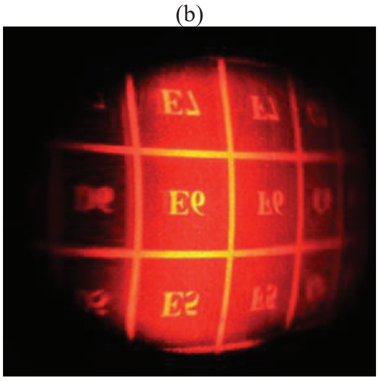
The diffraction efficiency of the HOE of this system is 11%. The pattern is put 14.5cm in front of the lens groups and pattern entered as shown in Fig. 3(a) its size is 6cm×6cm, the intermediate image is shown in Fig. 3(b), the final image is shown as Fig. 3(c). It can be seen that the final image have serious aberrations. The focal length of the projection lens group is 10.3 cm, which is used to magnify the intermediate image by 3.18 times, so the final image is 3.18 times larger than the image source.



(a)



(b)



(c)

Fig. 3 (a)pattern (b) intermediate image (c)final image

The FOV of this system is calculated through Eq. (1), where x is the size of image, and L is the projection distance.

$$\theta=2\tan^{-1}\frac{x/2}{L} \tag{1}$$

The vertical FOV is 7.31 degrees, the horizontal FOV is 5.49 degrees. And use Eq. (2) to calculate theoretical FOV, where h is the size of intermediate image and f is the focal length of the holographic lens

$$\theta=2\tan^{-1}\frac{h/2}{f} \tag{2}$$

The theoretical vertical FOV is 7.97 degrees, the theoretical horizontal FOV is 10.68 degrees. It can be found from the above that the horizontal FOV is similar. From the grating function, we know that the vertical FOV will be compressed, so we modify the grating function as shown as Eq. (3),

$$\cos\theta_i d\theta_i = \cos\theta_m d\,\theta_m \tag{3}$$

where θ_i is the angle of incidence and θ_m is the angle of diffraction. In this system, θ_m is zero. So, the equation become Ep. (4)

$$\frac{d\theta_m}{d\theta_i} = \cos\theta_i \tag{4}$$

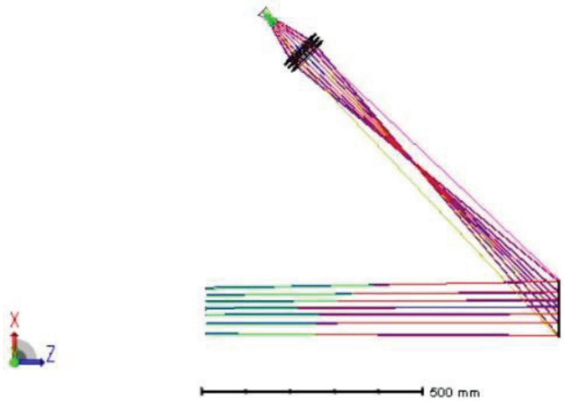
In vertical direction, the deviation of diffraction angle changes with the deviation of incident angle equally. Therefore, the FOV in the vertical direction will vary depending on the incident angle.

In addition, to discuss and correct the aberrations formed in the final image, the experimental parameters are input into Zemax to simulate the HUD based on HOE system. The pattern is 135mm away from the projection lens group. The projection lens group is composed of three lenses of the same specification. Because the lens group which is composed of three lenses can achieve short-focus effect and reduce the size of system and the size of the lens group is similar to the distance between the human eye. Its parameters are shown in Table 1.

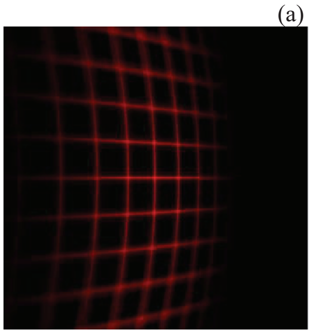
Table 1 parameters of projection lens

Radius1	Radius2	Width	Height	Thickness	Material
29cm	-29cm	5cm	10cm	1.1cm	BK7

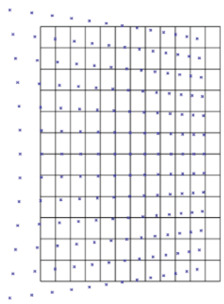
The projection lens group to the HOE is 80 cm and the incident angle is maintained at 45 degrees. The exit pupil is set to the human eye and the imaging position is set to infinity. The 3D layout diagram is shown in Fig. 4(a), and the result of the image simulation is shown in Fig. 4(b). The Grid distortion shows as Fig.4(c). In fact, there are some serious aberrations in the system. Besides the farther away from the center, the more serious of the aberration. From Fig.3 (c) and Fig.4(b), It can be seen that the final image is consistent with the Zemax image simulation and grid distortion results.



(a)



(b)



(c)

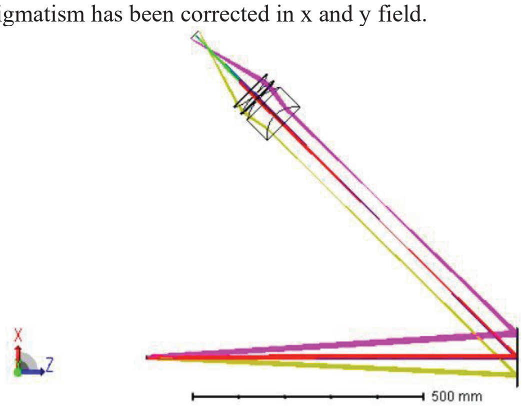
Figure 4 (a)3D Layout (b)Image simulation (c)Grid Distortion

Besides, from Fig.3 (c) and Fig.4 (b) can be observed whether it is an experiment or a Zemax simulation, the surrounding images are blurred. To eliminate these blurs, the system is inverse simulation. In the inverse simulation, the final image at infinity coupled into the observer eyes and through the HOE and lens groups to be imaged at the input plane. At the same time, by optimizing the lens group to remove the astigmatism and distortion. By the reversibility of light, to improve the aberration of this system. The corrected lens group data is shown as Table 2.

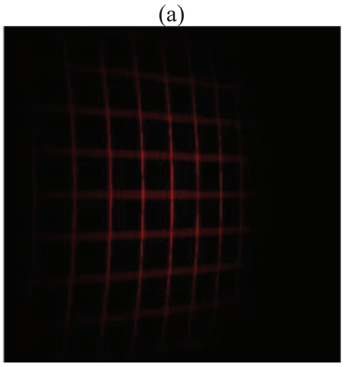
Table 2 parameters of corrected lens

	R1 (mm)	R2 (mm)	Height (mm)	Thickness (mm)	Material
Len 1	-1366	-110.7	100	14	Bk7
Len 2	-180.5	-586.9	100	12.2	Bk7
Len 3	91.3	61.2	100	50	Bk7

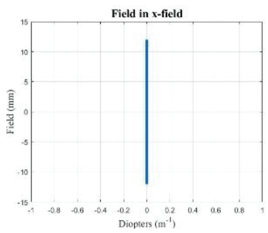
Enter the corrected lens group data into the initial simulation. The corrected 3D Layout is shown in Fig.5 (a) and the final image simulation is shown in Fig.5 (b). The field curvature of x field and y field are shown in Fig.5 (c) and (d). Astigmatism has been corrected in x and y field.

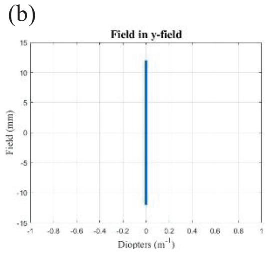


(a)



(b)

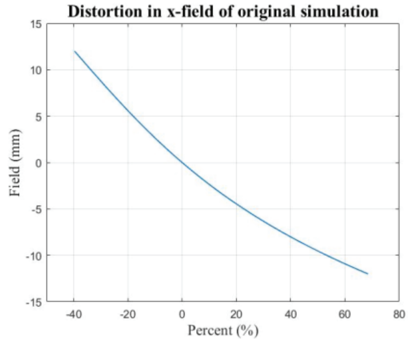




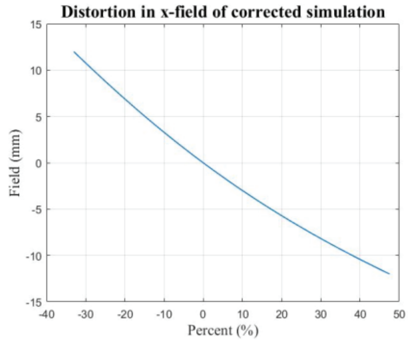
(c) (d)

Fig. 5 (a) corrected 3D Layout (b) image simulation (c) field curvature in the x field (d) field curvature in the y field

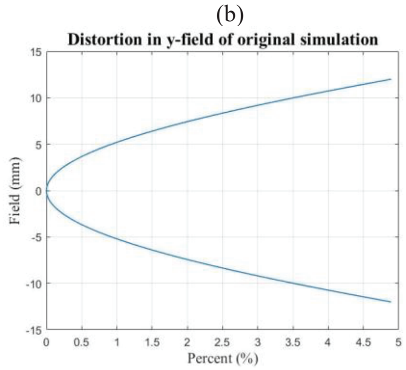
As for the comparison of the distortion, the distortion percentages in the x field and y field are shown in Fig. 6. From Fig. 6 (a) and (b), the original maximum percentage of distortion in the x-field is -40%~70%, and after correction the maximum percentage of distortion is -33%~48%. From Fig. 6 (c) and (d), the original maximum percentage of distortion in the y-field is 4.9%, and after correction the maximum percentage of distortion is 1.8%. It can be found that the corrected lens significantly reduces the distortion of the image.



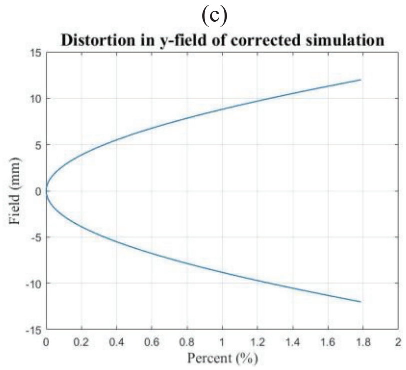
(a)



(b)



(c)



(d)

Fig. 6 (a) x-field before correction (b) x-field after correction (c) y-field before correction (d) y-field after correction

4 DISCUSSION

Because of the FOV of this system is limited by the size of the exposure area of the HOE. To increase the FOV of the system, expanding the interference area on the HOE and can see a larger FOV through the HOE. In addition, it can be observed from the simulation results of Zemax that this system has serious aberration. And the farther away from the center, the greater the influence of aberrations, so the surrounding image is blurry. In the future, the full-color display of this system can be achieved through the method of wavelength multiplexing. Due to the corrected lens has different thickness and curvature, the actual lens groups manufacturing cost is expensive. Perhaps the same result can be achieved with existing lens group or lenses are easier to make. The remaining distortion is expected to be compensated by digital correction or by adding more lenses or a small number of aspheric lenses

5 CONCLUSIONS

In this study, HOE is used for imaging and can see the images of FOV is 5.49 degrees in horizontal direction and 7.31 degrees in vertical direction. In addition, because the pupil of the imaging lens group is imaged in front of the observer's eyes. The final image is not restricted by the pupil of the imaging lens group and the FOV of this system is only limited by the size of the HOE interference area. And through Zemax simulation, this system has serious aberration and distortion, and these aberrations can be corrected through the design of the lens group.

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