Vehicle Head-Up Display based on Holographic Combiner and Projection Lens Design

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ABSTRACT

In this study HUD system which is composed of holographic combiner and the designed projection lens is proposed. Among, the exit pupil of the projection lens close to In-coupling HOE to get the large FOV. The HUD system FOV can reach 11.09°×5.03° (H×V).

1. INTRODUCTION

Head-up Display (HUD) was originally developed for military aviation use [1]. Due to the advancement of technology and the pursuit of convenience by human beings, the use of HUD is becoming more and more popular. Now most of them are used in cars, so that drivers can get the vehicle condition information and external information required for driving without bowing their heads while driving [2]. Messages of traditional HUD are projected to a fixed distance, which increase the time the driver needs to refocus when switching between the HUD and the road condition. To allow the driver to see both the HUD and the road without refocusing, we chose to project the image to infinity.

In order to present more information to driver, enlarge the exit pupil has become a necessary issue for HUD system. Currently, there are two ways for exit pupil expansion (EPE). They are micro-lens arrays exit pupil expanders and holographic waveguide exit pupil expanders. [3,4] Among them, the principle of the holographic waveguide exit pupil expanders is to transmit light in the waveguide, and then diffract the image through the HOE. By this process of transmission, the exit pupil is copied and expanded at the same time, which ensures that an image can be observed with its full length while the image-generation system can be reduced in size [5]. We are aiming here to use the version of the waveguide holographic exit pupil expanders.

To sum up, in order to make the driving experience more convenient and safe, the HUD system with EPE structure consisting of HOE and planar waveguide is proposed. The schematic diagram of the user is shown in Fig. 1. The diffraction angle of the input HOE will satisfy the condition of total internal reflection (TIR), and the image will be propagated to output HOE through the TIR, allowing the driver to see the information. In addition, to optimize the volume of the HUD system, a special specification projection lens was designed, and this lens has the characteristics of aperture stop is close to the light outlet of lens. Therefore, when the image enter the input HOE will not be limit by the stop of lens. The image FOV obtained by this system at a distance of about 300mm from the output HOE can reach 11.09°×5.03° (H×V).

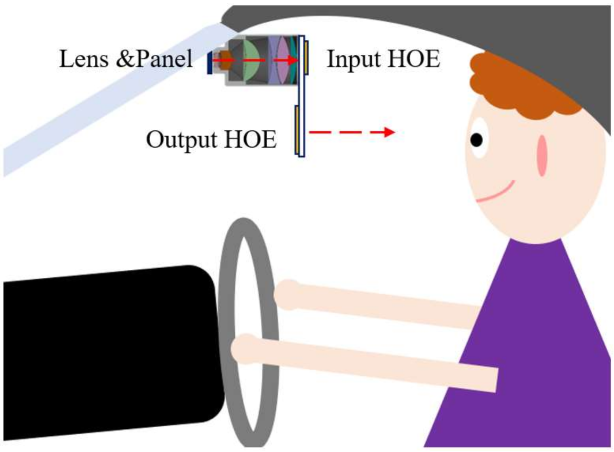


Fig.1 The schematic diagram of the location of the HUD in the car

2. OPTICAL DESIGN

In order to put the information into the system perfectly, a special lens is designed. The diameter of the lens is 100 mm, which is same size with HOE so that it will not affect the FOV of the HOE. The ultimate goal of the image is that the FOV can reach 10°×5° (H×V), so the FOV of the lens is set to a square range of 10°×10° (H×V), that is to say, the diagonal can reach 14.14°. The effective focal length is 88.3mm, and image the information at infinity. Due to the cost, the lens group chooses to use spherical lens. According to this specification, we need a panel for 0.86”. Since it is difficult to find a panel that is fully compatible with the HUD system, the projector will produce intermediate image at diffuser which is place at the front focal length before the information transmit into special design projection lens.

2.1 LENS DESIGN

In this study, the ray tracing simulation software ZEMAX is used to simulate the projection lens. First, the lens group was in inverse the optical axis to observe whether the MTF meets the requirements. The average human eye can see 3 arc min, which is acceptable. Therefore, according to the effective focal length and 3 arc min, it can be concluded that each pixel needs to be less than 0.026mm. That is, a pair of line pair needs to be equal to 0.052mm, which is about 20 lp/mm when converted into the modulation transfer function (MTF). Then a cemented lens is added to the structure to reduce chromatic aberration, the field lens is added to improve MTF. And the aperture stop is close to the light outlet of lens, so that the exit pupil is close to the waveguide, in order not to affect the FOV of the image. Because of this setting, the lens group diameters will be ordered from large to small. So, the lens of the diameter close to the panel is only 25mm, a smaller panel can be used to save space. Finally, the architecture is inverted for optical verification. Table 1 is the Lens Data set in inverse the optical axis of the lens group. Fig.2 shows the 3D Layout with the lens group arranged in inverse the optical axis.

Table.1 Lens Data set in inverse the optical axis of the lens group

Surface	Radius(mm)	Thickness(mm)	Material	Diameter(mm)
OBJ	infinity	infinity		infinity
STO	156.080	11.225	N-BK7	50
2	infinity	2.484		51.944
3	106.457	23.845	N-BK7	50.991
4	-154.323	2.383		50.476
5	-139.069	7.488	SF5	49.270
6	151.432	22.397		45.856
7	48.736	25.385	N-BK7	44.595
8	135.552	26.839		42.748
9	37.931	14.734	N-BK7	22.909
10	-41.923	.53957	SF5	22.608
11	318.215	7.213		16.516
12	-35.027	4.879	SF5	12.505
IMG	infinity	-		11.284

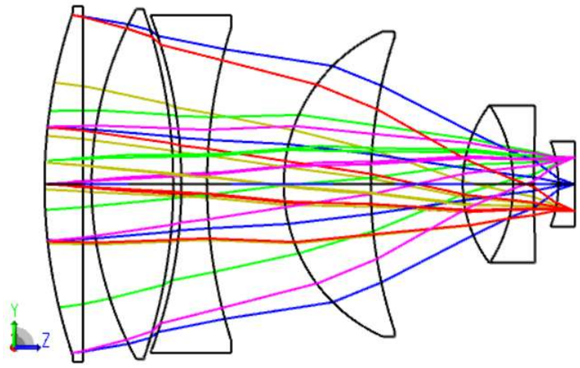


Fig.2 3D Layout with lenses arranged in inverse the optical axis

2.2 IMAGE QUALITY ANALYSIS

The image qualities of the lens group set were evaluated by examining the MTF, field curvature and distortion, and relative illumination. Fig.3 is the MTF set in inverse the optical axis of the lens group, the curves indicate the MTF in the tangential and sagittal directions for each field. It can be known that the MTF of all fields of view of this system reaches more than 28.6 lp/mm when the contrast is 30%. This achieves the MTF (20 lp/mm) originally set. The field curvature and distortion of this system are shown in Fig.4, where the largest tangential and sagittal field curvature are 0.0191 mm appears in 7.071°. And the maximum distortion is 0.8422%. This is acceptable, in general, human eyes can compensate for about 1-2% distortion error. The relative lamination is shown in Fig.5, the minimum illumination is is very high, it's about 89.96% of the central FOV. The image simulation result is shown in Fig. 6. The resolution of the original image is 640×480, the overall information is clear, and the peripheral image is not darker than the center image.

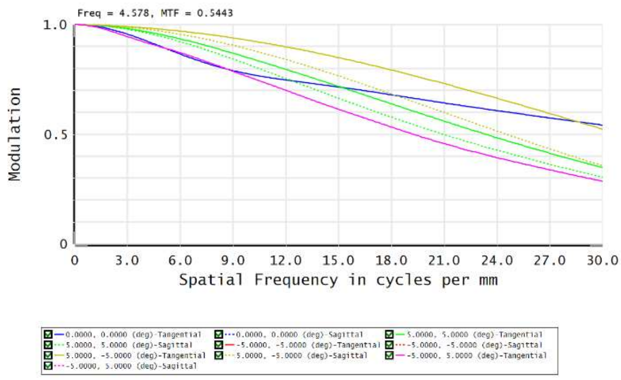


Fig.3 MTF set in inverse the optical axis of the lens group

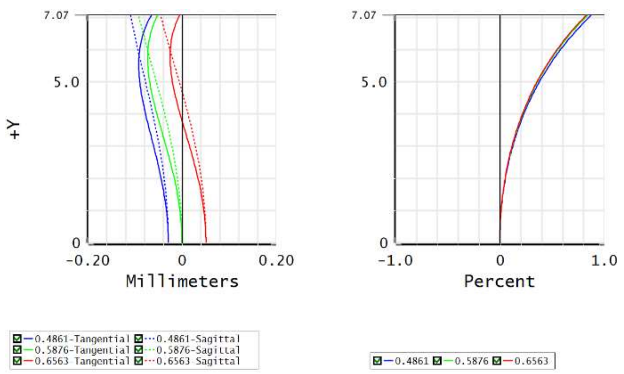


Fig.4 Field curvature and distortion of this system

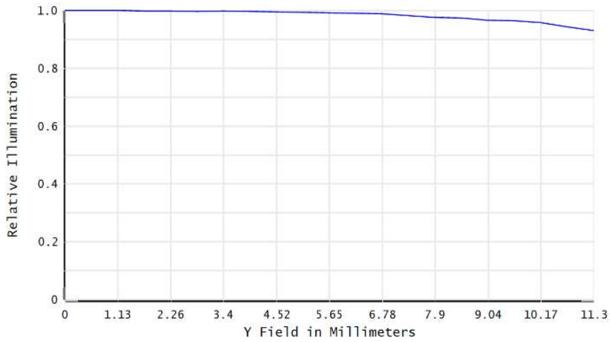


Fig.5 The relative lamination of the lens group

Fig.6 The image simulation result

3. EXPERIMENT

The recording system of the HOE is shown as Fig. 7. This experimental architecture uses the prism which size is 150mm×150mm and the diode-pumped solid-state (DPSS) laser with a wavelength of 532nm.The incident angles of the two collimated beam are 0° and 55°. After exposure, the HOE recorded interference fringes, and the interference area of the HOE reached 50 × 100 mm. Both HOEs are recorded by the same structure.

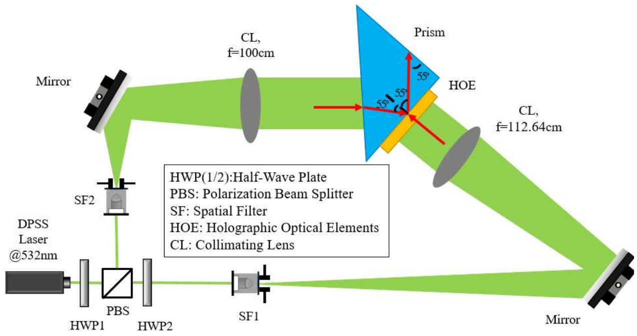


Fig.7 The experimental structure of recording HOE

After recording the interference fringes, HOEs were attached to the glass-made planar waveguide. The size of the waveguide is 110×200mm, the thickness is 5mm, and the distance between the center of two HOE is 100mm. Here I use a lens designed by myself, and put a diffuser at the front focus. Then use the lens to image the information of the diffuser at infinity. And the aberration of this device can be compensated by symmetrical linear grating structure. The camera is placed 300mm in front of the output HOE and focus on the infinity. The observation architecture is shown in Fig. 8.

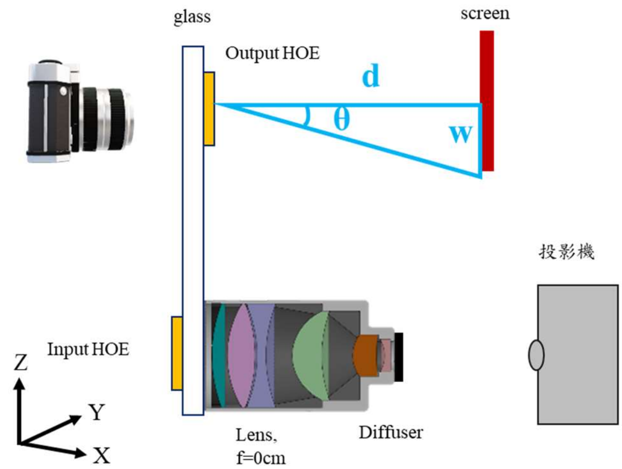


Fig.8 The observation architecture side view of image results

4. RESULTS

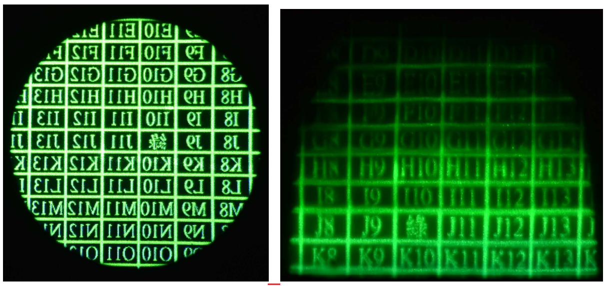
Calculate and get the horizontal and vertical FOV by measuring the height and width of the image area and bringing it into formula (1).

$$2\theta = 2\tan^{-1}\left(\frac{w}{d}\right) \quad (1)$$

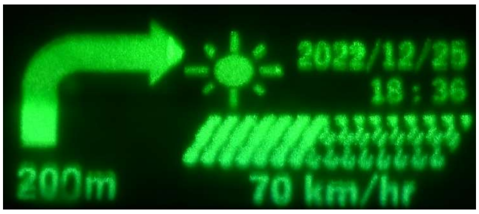
Where w is the half height or width of the marked area, and d is the distance between the camera and screen. Then place a screen 350mm in front of the camera, as shown in Fig. 8. Mark the area on the screen where the FOV is equal to the virtual image at infinity. After calculation, the FOV is 11.09°×5.03°

(H×V).

The input information is passed through a lens designed by myself as shown in Fig. 9(a). It can see the clarity of the original image. Fig. 9(b) is the image observed from the camera at a distance of 300mm from the output HOE. At a distance of 300mm from the output HOE, input a suitable size image, as shown in Fig. 9(c).



(a) (b)



(c)

Fig.9 (a) Image only pass through projection lens (b) Image from output HOE with eye relief of 300mm (c) Image from output HOE with eye relief 300mm and suitable size pattern

5. DISCUSSION

There still have space to improve the HOE image quality of the system. It can use wavelength multiplexing on the same piece of HOE in turn to make a full-color HOE to enhance the visual beauty. In the future, we will look for panels with suitable resolution to improve image quality and combine them into a HUD with a larger FOV.

6. CONCLUSIONS

In this study uses the method of the holographic waveguide to achieve the effect of EPE, enlarge the exit pupil and present more information to driver. In addition, it can also achieve the effect of Augmented Reality (AR), allowing drivers to obtain advanced driving information without moving their eyes. In order to allow the image generation system can be reduce the size, in the future, the lens will be cut to a size of 50×100 mm. And the lens of the diameter close to the panel is only 25mm, a smaller panel can be used, so that the optical machine of the input image can be relatively small. When the eye relief is 300mm, the horizontal and vertical FOV are 11.09° and 5.03°. At last, the lens, which is been designed and its aperture stop is close to the light outlet of lens, can make the FOV reach it maximum as possible.

Acknowledgement

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