Biocular Holographic Screen for Computer-generated Hologram

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ABSTRACT

In this study, the biocular CGH display is proposed. This system is composed of a biocular holographic screen and the CGH reconstruction system. Observers can watch 3D AR images on the holographic screen. The FOV of the proposed system can achieve 9.54° both in horizontal and vertical direction.

1 Introduction

With the rapid development of technology, many people consider that it is valuable to develop three-dimensional display in different fields. Most 3D displays use the biocular parallax to make observers obtain a sense of different depths. However, this may cause the vergence–accommodation conflicts (VAC) which is one of the main factors for users to feel dizzy. The holographic display can avoid this problem because it can reconstruct the wavefront of the 3D object correctly.[1] Moreover, the most common way to achieve dynamic holographic 3D display is using computer-generated hologram (CGH) technique. The CGH is often displayed by spatial light modulator (SLM). The FOV of the CGH is limited by the pixel size of SLM. [2]

In this study, a biocular holographic screen made of reflective holographic optical elements (HOE) is combined with CGH generated by SLM to achieve a 2D/3D display system. The SLM is imaged in front of observer's eyes by HOE with the angular multiplexing, and therefore FOV would not be limited by SLM pupil. However, since the diffraction angle of the image output by the SLM is limited by its pixel size, if the image needs to fill the entire holographic screen to achieve the maximum viewing angle under the geometric limitation of the system, the distance from the SLM to the HOE needs to be greatly increased. In this system, the pixel size of the SLM is reduced by adding a concave lens to enlarge the diffraction angle of the SLM, so that the final system only needs to be extended by about 6cm to achieve a full input holographic screen. The holographic screen records two gratings at different angles by means of angle multiplexing, so users can watch 2D/3D CGH images at different distances simultaneously with both eyes at 60cm from the holographic screen. According to the simulation from Zemax, astigmatism aberration of the system can be reduced by the concave lens.

2 Experiment

Fig.1 is the schematic diagram of the system in this experiment. First, the target information is calculated by the CGH algorithm to generate CGH in this research. The SLM and the information light from SLM will be transmitted to the HOE. The SLM is imaged at 30 cm in front of the HOE by the concave lens. Finally, the information light will be diffracted by the HOE into the human eyes in different diffraction angles which is 60 cm in front of the HOE. The image position of CGH can be decided freely by CGH algorithm.

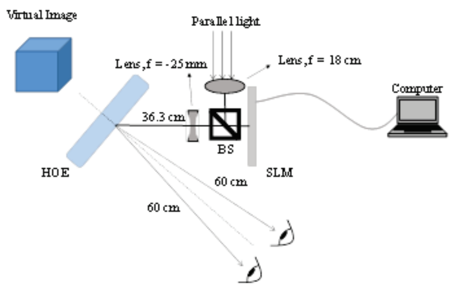


Fig.1 The schematic diagram of experimental architecture.

The recording structure of HOE in this experiment is shown as Fig. 2. At first, starting from a laser light with a wavelength of 532 nm and dividing it into two rays with the same polarization and same intensity by PBS and HWP. After lights pass through various components, the HOE is recorded by a reference light which is a 30 cm divergent spherical wave and two object lights which are both converging spherical waves. The object lights will converge to two points that is 6 cm apart and 60 cm behind the photosensitive material. It is recorded with different diffract angles by angular multiplexing and its size in this study is 4"× 5".

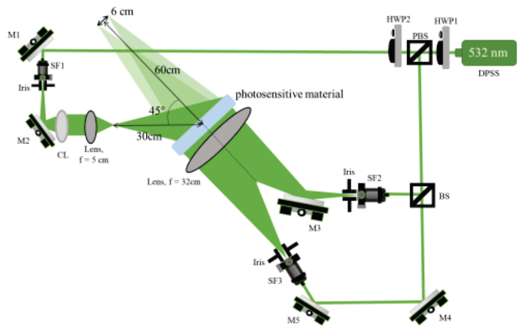
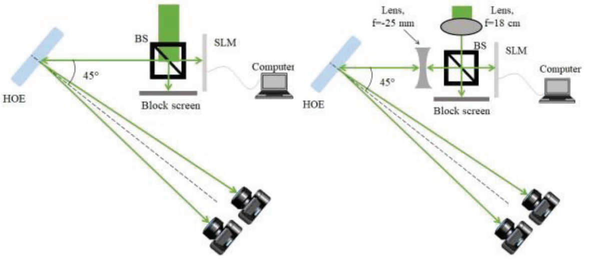


Fig.2 The schematic diagram of HOE recording architecture.

The observation architectures are shown in Fig.3. In the system without concave lens, we use parallel light to pass through BS and then reflect it to the SLM. The system with concave lens, we use a converging spherical wave, and the DC noise are separated from information light and blocked [3]. Then, the information will transmit by SLM and HOE. Finally, it will diffract to the camera which is 60 cm away from the HOE. In the system without concave lens, the distance between SLM and HOE is 30 cm. Different from this, after adding the concave lens, it makes the panel of SLM 4 time smaller than before, the relay imaging of its SLM is also 30cm away from the HOE, so the distance between two of them becomes 36.3 cm.



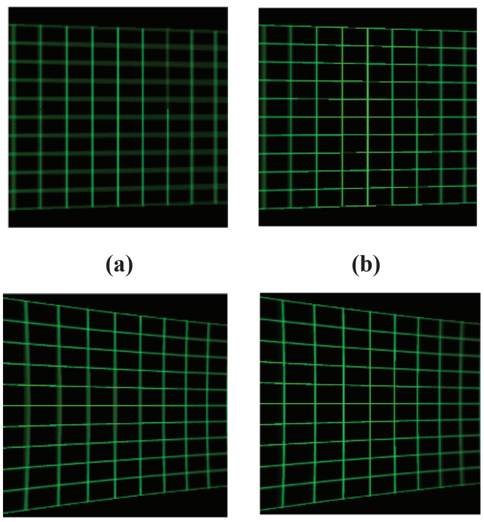
(a) (b)

Fig.3 The schematic diagram of observation architecture which composed of HOE and CGH (a) without concave lens (b) with concave lens.

3 Results

3.1 Astigmatism correction

In this research, the ray tracing simulation software Zemax is used to simulate astigmatism of the image results which are shown in Fig.4. In Fig.4 (a), there is an astigmatism in the system without concave lens. However, after adding the concave lens, astigmatism is reduced and become not serious which is shown in Fig.4 (c). To correct astigmatism, we inverse the simulation which means inputting a perfect image without astigmatism. By doing so, we can get the right position of tangential and sagittal plane respectively. Then, bring the data back to the simulation, and the astigmatism has been corrected which is shown in Fig.4 (b) and (d). After the simulation, the target image shown in Fig.5 is calculated by CGH algorithm with astigmatism correction. [4]



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

Fig.4 The image of simulation diagram (a) without astigmatism correction, without concave lens (b) with astigmatism correction, without concave lens (c) without astigmatism correction, with concave lens (d) with astigmatism correction, with concave lens.

(a) (b)

Fig.5 The target image put into algorithm (a) without concave lens (b) with concave lens.

The results are shown in Fig.6 and the virtual image is 20 cm behind HOE. The tangential and sagittal plane are shifted to different position by CGH algorithm. In the system without concave lens, the distance between the tangential and sagittal plane is about 40 mm and the value becomes 0.48 mm after adding concave lens.

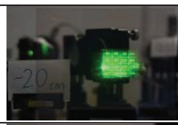
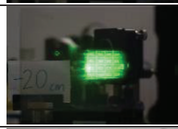
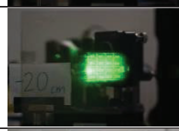
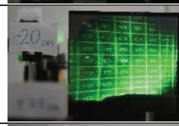
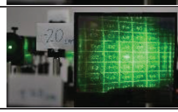
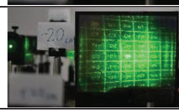
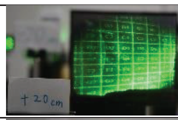
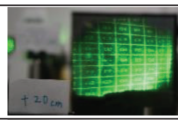
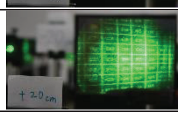
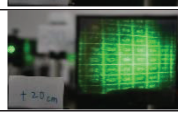
		without astigmatism correction	with astigmatism correction
without concave lens	left		
	right		
with concave lens	left		
	right		

Fig.6 The final image results in different observation architecture and with or without astigmatism correction.

In Fig.7, these are the results of changing the position of virtual image by CGH algorithm with concave lens in the system. It can find that the astigmatism is truly not serious even though the position of virtual image from HOE is changed. However, the astigmatism would still be corrected in the experiment below.

(cm)		without astigmatism correction	with astigmatism correction
+20	left		
	right		

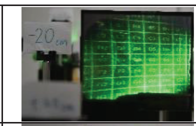
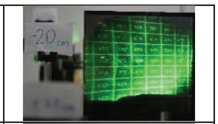
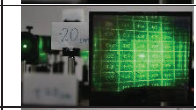
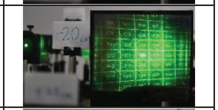
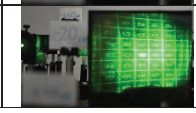
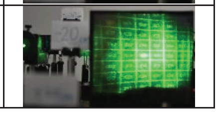
-20	left		
	right		
-100	left		
	right		

Fig.7 The results of changing the position of virtual image among the plus sign means that the virtual image is in front of HOE, and the minus sign is opposite.

3.2 Distortion Correction

Similarly, the simulation from Zemax shows that the distortion of this system is so serious that the grids are all deformed which is shown in Fig.8. First, we use the target image which is shown in Fig.9 (a) and the pictures in Fig.10 (a) and (c) are the results. Then, the target image is changed to offset this problem which is shown in Fig.9 (b). Finally, we can see that the distortion is corrected in Fig.10 (b) and (d).

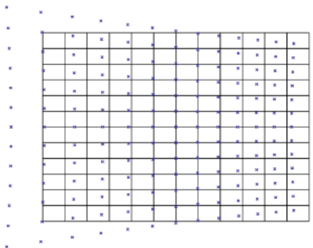
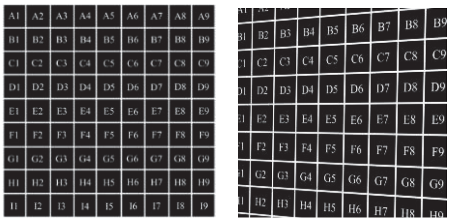
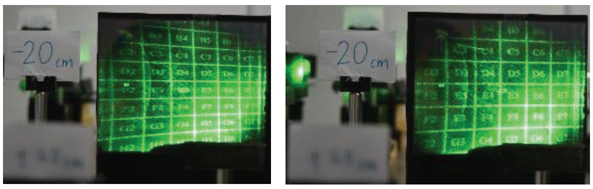


Fig.8 The simulation diagram of grid distortion.

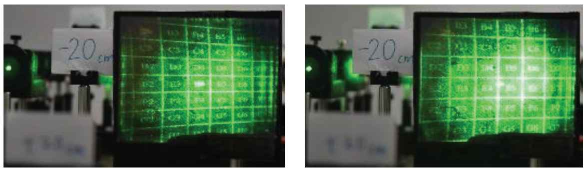


(a) (b)

Fig.9 The target image put into CGH algorithm (a) without distortion correction (b) with distortion correction.



(a) (b)



(c) (d)

Fig.10 The virtual image of left eye (a) without distortion correction (b) with distortion correction, right eye (c) without distortion correction (d) with distortion correction

3.3 FOV

The FOV of final image and HOE can be calculated by Eq.1

$$\theta = 2 \times \tan^{-1}\frac{\frac{d}{2}}{D} \cdots (1)$$

where θ is the FOV, d is the size of image, and D is the distance between the observer and final image. The paper screen which is overlapped with the final image is 20 cm behind HOE to measure the size of image. The image results are shown in Fig.11.

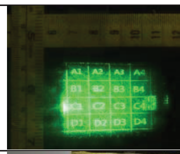
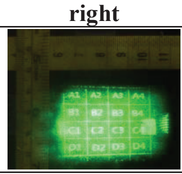
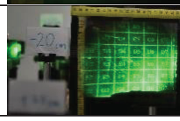
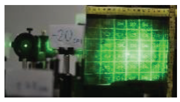
	left	right
without concave lens		
with concave lens		

Fig.11 The results of FOV measurement in different observation architecture with or without distortion correction, and the final image is 20 cm behind HOE.

The theoretical FOV of SLM can be calculated by Eq.2

$$\theta = 2 \times \sin^{-1}\frac{\lambda}{2p} \cdots (2)$$

where θ is the FOV, λ is the wavelength, and p is the pixel size of SLM which is 6.4 μm. In this study, the pixel size of SLM is enlarged 2 times by HOE and reduced 4 times by the concave lens. The results of FOV calculation are shown in the Table1.

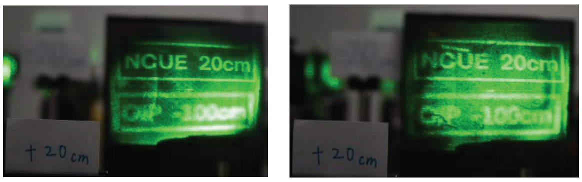
Table.1 The results of FOV calculation.

		left	right	theoretical
without concave lens	H	2.79°	2.79°	2.38°
	V	2.36°	2.36°	
with concavelens	H	11.83°	11.83°	9.54°
	V	9.37°	9.37°	
the FOV of HOE	H	12.08°		
	V	9.68°		

3.4 3D display

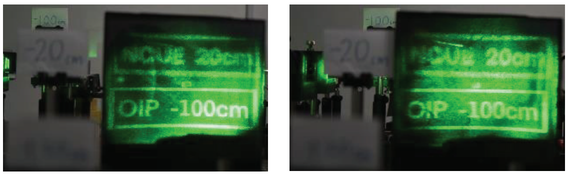
After observing one 2D image, we further observe two 3D images of different depths which means the virtual images will be at the different position base on HOE at the same time. In this section, two different type 3D images are showed. One is composed of two different depths of CGH. Among them, the virtual image is 20 cm in front of the HOE and 100 cm behind it. Another one is real 3D object.

In Fig.14 and Fig.15 show the results that the camera focus on the plane in front of HOE 20 cm and behind HOE 100 cm respectively.



(a) **(b)**

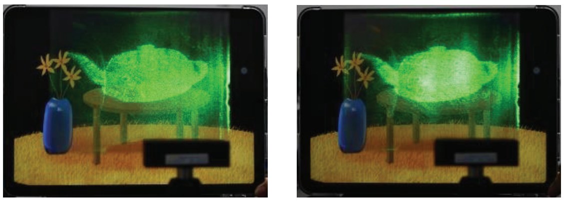
Fig.14 The virtual image of (a) left eye (b) right eye that the camera focus on the plane which is 20 cm in front of the HOE.



(a) **(b)**

Fig.15 The virtual image of (a) left eye (b) right eye that the camera focus on the plane which is 100 cm behind the HOE.

Eventually, we observe a 3D virtual image. As you can see the pictures in Fig.16, the 3D teapot image is combined with the 2D flat image behind the HOE.



(a) **(b)**

Fig.16 The 3D virtual image of (a) left eye (b) right eye

4 Discussions

From the above pictures of the results, the image quality still needs to be improved. The background noise and graininess are obvious. Since the SLM pixel sampling rate is too low, these problem decreases the image quality. In the future, we will improve this problem in the future. The problem of the SLM pixel sampling can be solved by reducing the pixel size of SLM. From the viewing angle calculation results, it can be found that there is a slight difference between the experimental viewing angle and the theoretical viewing angle. This part may be the error caused by the image measurement and the number of cells that can be seen within the viewing angle. Furthermore, because the current HOE is recorded by green laser, we only can see green images now. In the future, we can record HOE with different wavelengths of laser to achieve full-color images. [5]

5 Conclusions

In this topic, we successfully make HOE become a holographic lens that can let us reduce the use of traditional optical elements which will make the size of entire system too large and complicated. The addition of a concave lens can enlarge the diffraction angle of the SLM without greatly lengthening the system architecture, allowing the image to fill the entire holographic screen, and effectively reducing astigmatism. Besides, the combination of reflective HOE and CGH which is transmitted by SLM truly makes this architecture become a 3D display system, and with the angular multiplexing, both of our eyes can see the virtual image at the same time. Furthermore, the digital correction and CGH algorithm can successfully solved the astigmatism and serious distortion in this system. Because of the combination of HOE and concave lens, the FOV of this system can achieve 11.83°x9.37°.

Acknowledgement

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