The Holographic Information Projection System Based on Holographic Optical Element

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ABSTRACT

In this paper, a projection type holographic display based on HOE was proposed. The viewing angle of the holographic image is larger than the maximum diffraction angle of the SLM which was employed to display CGH. The theory and aberration were analyzed via the ray tracing technique.

1 INTRODUCTION

In recent year, many pieces of research about computer-generated hologram (CGH) technique were proposed [1-3]. The advantage of CGH technique is that it is suitable to provide images with depth information. It caused the CGH technique can provide natural 3D images without vergence-accommodation conflicts (VAC) [4]. Furthermore, produce the amplitude or phase distribution of CGH via a spatial light modulator (SLM) can achieve the dynamic display. However, the disadvantage of CGH technique is that the viewing angle is limited by the pixel pitch of SLMs. Nowadays, the viewing angle of the phase modulated SLM with the smallest pixel pitch is only about 8 degree. In 2016, K. Yamamoto et al. proposed a projection-type holographic display system which the viewing angle is larger than the diffraction angle of the SLM [5]. The viewing angle can be increased by a digitally designed holographic optical element (DDHOE).

In this paper, a holographic projection system was proposed. A reflection-type holographic optical element (HOE) was utilized to increase the viewing angle. The HOE was recorded by the interference of two spherical waves. The SLM would become a shrinking real image. It caused the viewing angle can be increased. In this system, the aberration can be analyzed by ray tracing.

2 EXPERIMENT

In this paper, the system configuration was shown as Fig. 1. A phase-modulated SLM was utilized to modulate the probe beam become the CGH phase distribution. The holographic information would be irradiated on the HOE screen and be guided into human eye. The HOE screen was recorded via two spherical waves. In this configuration, the distance between SLM and HOE is equal to the distance between the reference light source and HOE. Then the real image of SLM would located at the position of object point light source. The distance from HOE to SLM and real image of SLM are L and d separately. The real image of the SLM would become the exit pupil of the display system. Finally, the observer can obtain the holographic image when the eye placed in the exit pupil. The maximum viewing angle in vertical can be described as

$$\theta = 2sin^{-1}\left(\frac{\lambda}{p'}\right),$$

where λ is the wavelength of probe beam, p' is the pixel pitch of the real image of SLM.

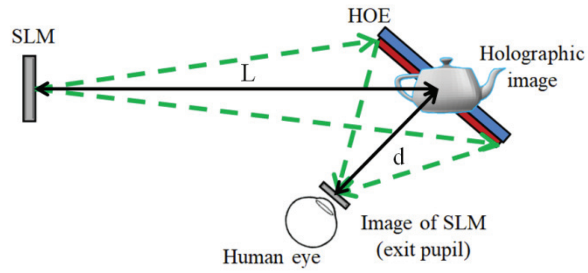


Fig. 1 The schematic figure of the projection system.

In order to simulate the pixel pitch of the real image, the system configuration in Zemax was arranged as shown in Fig. 2. In this case, the pixel pitch of the SLM is 19 μm which the maximum FoV is 1.60°. L and d are 1000 mm 500 mm separately. The simulated result of 2 by 2 pixels was shown in Fig.3. The pixel pitch of the real image is 6.4 μm and 9.4 μm in horizontal and vertical. Therefore, the theoretical maximum FoV became to 4.76° and 3.24° in horizontal and vertical.

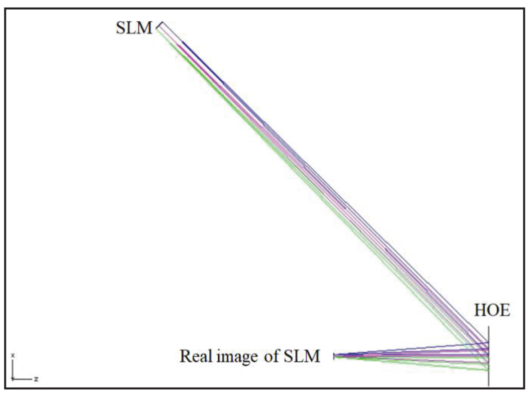


Fig. 2 The simulation configuration was used to determine the pixel pitch of the real image.

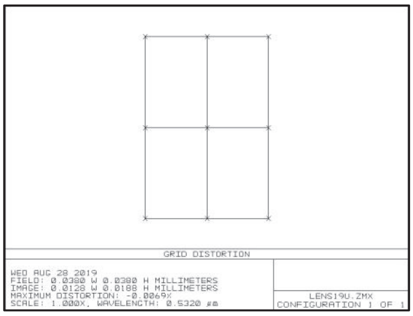


Fig. 3 The grid distortion result.

The reconstructed image as shown in Fig. 4 was located on the HOE screen. The square is the largest display area. The experimental maximum FoV in horizontal and vertical are 4.47° and 3.26°. The maximum FoV in two directions are both larger than the limitation of the SLM and matched to the theoretical value. For the system, the 3D images projection is also available. The result image was shown is Fig. 5.

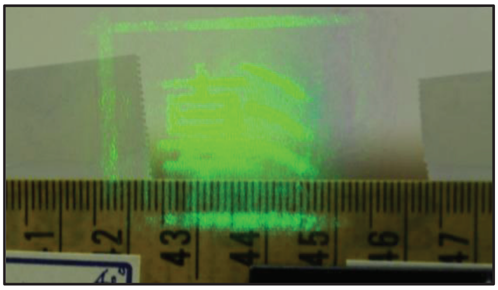


Fig. 4 The reconstructed image which projected on the HOE was used to determine the maximum FOV.

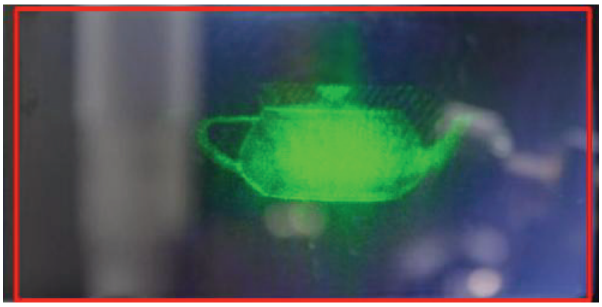


Fig. 5 The reconstructed 3D image.

Furthermore, increasing the ratio of L and d can enhance the FoV more obviously. When L and d became to 600 and 200 mm. The maximum FoV in vertical could be 3 times the FoV of SLM. The system which was employed in the following experiment was composed by the SLM with 6.4 µm pixel pitch and the HOE which L and d were 600 mm and 200 mm. The horizontal and vertical pitch of real image are 1.45 µm and 2.1 µm separately. The horizontal and vertical maximum FoV are 21.14° and 14.55°. On the other hand, the HOE can be approximated to a concave mirror to achieve the AR display with long virtual image distance. The resulting image as shown in Fig. 6 was located at 300 mm behind the HOE. The distance between the intermediate image and the SLM was 500 mm and the size of intermediate image was 41.6 mm by 41.6 mm. The size of the virtual image was 180 mm by 127 mm and the maximum FoV was 20.41° by 14.48°. The results and theoretical value matched to each other.

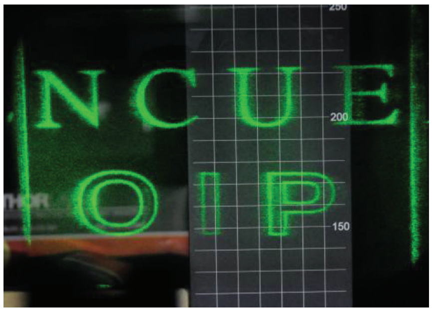


Fig. 6 The flouting image located at 300 mm behind the HOE screen.

3 ABERRATION ANALYZATION

In order to analyze the aberration, the simulated configuration in Zemax was shown in Fig. 7. The SLM was set as the aperture stop. The intermediate image was provided by the SLM and was magnified by the HOE. In this section, the grid pattern as shown as Fig. 8 was utilized to analyze the aberration. The dimension of the pattern is 35.3 mm by 35.3 mm. The distance between intermediate image and HOE is 100 mm. The final image is 150 mm by 106 mm in simulation and 149 mm by 108 mm in experiment.

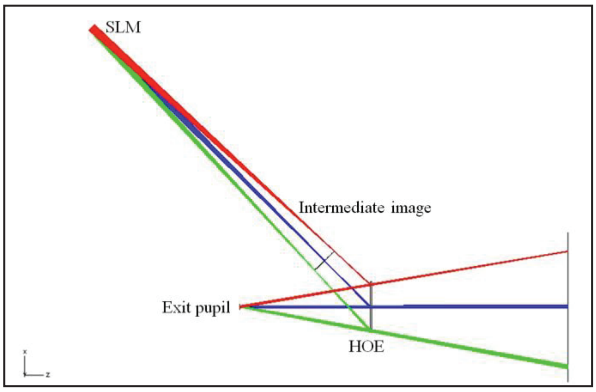


Fig. 7 The simulation configuration was used to analyze the aberration.

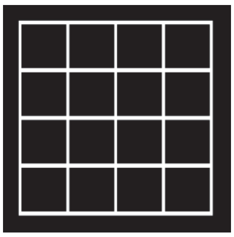
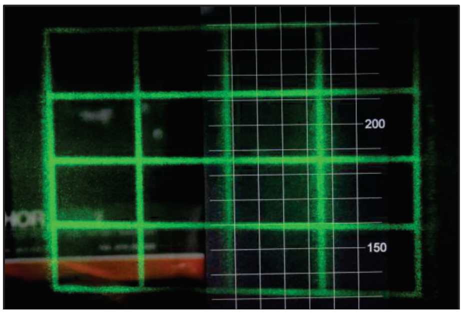


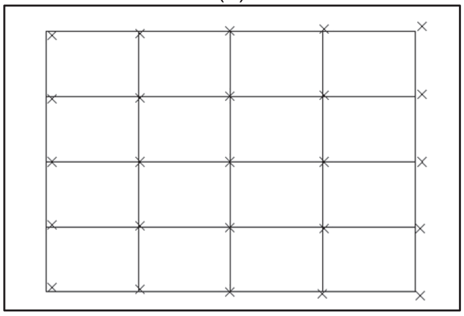
Fig. 8 The grid pattern used to analyze the aberration.

3.1 Distortion Aberration

The resulting image and the grid distortion analyzation were shown in Fig. 9 (a) and (b) separately. The final image became trapezoid. The height of the highest is 109.3mm in experimental and 109.5mm in simulation. The height of the shortest is 102.7mm in experimental and 102.4mm in simulation. The experimental and simulated results matched well.



(a)



(b)

Fig. 9 The final image with distortion aberration in (a) experiment; (b) simulation.

3.2 Astigmatism Aberration

In the Fig. 9 (a), the vertical lines were more blurred than the horizontal lines. The vertical lines were blurred because of the astigmatism aberration. According to the prior studies, astigmatism aberration can be corrected by the phase distribution of a cylindrical lens [6].

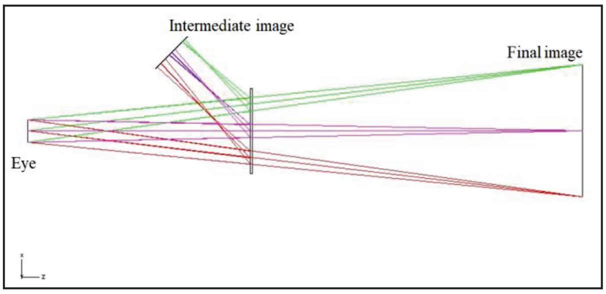
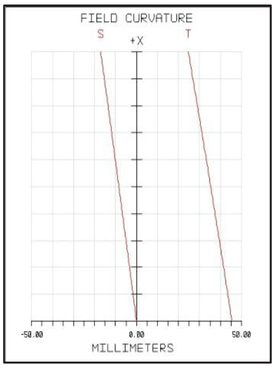
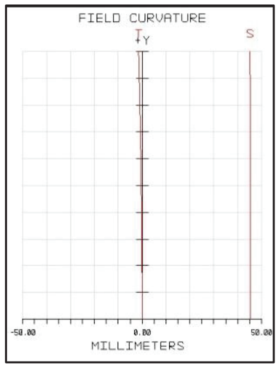


Fig. 10 The simulation configuration was used to analyze the astigmatism.

Following the configuration as Fig. 10, the light of astigmatism-free image inverse propagation to the HOE from human eye. Then the astigmatism intermediate image can be obtained. Finally, the astigmatism-free image can be obtained by the human eye when the astigmatism intermediate image is provided by the SLM.

The field curvature diagram of the plane at 300mm behind the HOE was shown in Fig. 11. The image plane of sagittal plane and tangential plane separated 50mm. Therefore, the vertical lines of the intermediate image should image at the position 150mm from the HOE.

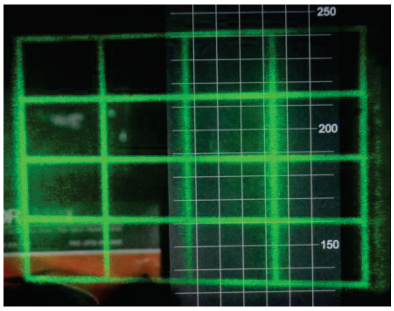




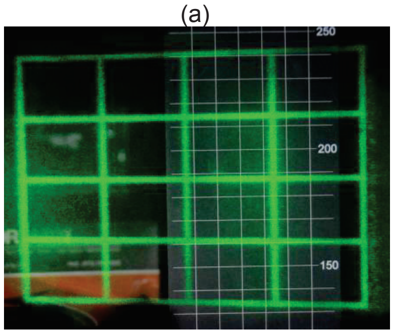
(a) (b)

Fig. 11 The field curvature diagram for different field height in (a) horizontal; (b) vertical.

When the intermediate image was arranged following the former section, the astigmatism can be compensated. The resulting image without astigmatism correction and with correction were shown in Fig. 11 (a) and (b). The vertical lines became more clearly when the astigmatism correction was utilized.



(a)



(b)

Fig. 11 The resulting image (a) without astigmatism correction; (b) with astigmatism correction.

4 DISCUSSION

In the proposed configuration, the maximum vertical FoV can be enhanced to N times the maximum diffraction angle of SLM, where N is almost equal to L/d. However, the horizontal magnification was larger than N. The reason is that the anamorphic is appeared for single linear grating. This characteristic was analyzed in ref. 6.

The astigmatism correction improved the image quality of vertical lines. However, the quality still has room to improve. The lines were still a little blurred. The quality degradation of vertical lines was dependent on the horizontal position. It was caused by the field curvature as shown in Fig. 11 (a). In future work, studying the method to simultaneously compensate astigmatism and field curvature is necessary.

5 CONCLUSIONS

In this paper, the maximum FoV of the holographic system can be enhanced by a HOE screen. The theoretical maximum FoV can be expected via the ray-tracing simulation. The horizontal and vertical maximum FoV are different because of the anamorphic. The distortion, astigmatism and field curvature aberration was analyzed by ray-tracing.

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