Enhance the Focus Cues of Holographic 3D Display Based on Multiple Directional Light Reconstruction

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Mini Review

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ABSTRACT

In hologram computation, adding random phase to the image plane can result in significant defocus blur during image reconstruction, providing strong focus or depth cues. However, the drawback is that random phase introduces strong speckle noise, reducing the image quality. On the other hand, adding uniform phase to the image plane suppresses speckle noise, improving the quality of the reconstructed image. However, the downside of uniform phase holograms is that the beam's divergence angle is smaller, resulting in less noticeable defocus blur, which diminishes focus cues and the sense of depth in holographic displays. Thus, holographic displays face a trade-off between image quality and focus cues, depending on whether the phase distribution used is random or uniform.

Keywords: Holographic; Reconstruction; Directional Light; OSA

INTRODUCTION

In light of this, researchers from Hefei University of Technology have proposed a multiple directional light reconstruction method to resolve the trade-off between image quality and focus cues in traditional methods [1-3]. This approach utilizes uniform phase holograms to ensure high-quality image reconstruction while employing multiple directional light reconstruction to enhance focus cues in holographic displays. This work was recently published in the journal optics letters by the Optical Society of America (OSA).

LITERATURE REVIEW

Technical route

The study first demonstrates the impact of different phases on holographic image reconstruction. As shown in Figure 1(a), when using random phase on the image plane to generate complex holograms, the reconstruction results exhibit strong focus cues but also significant speckle noise. Figure 1(b) uses uniform phase to generate complex holograms, resulting in

suppressed speckle noise and higher image quality, but the defocus blur is not obvious, making it difficult to produce strong focus cues. Figure 1(c) explains this phenomenon. Random phase holograms have a random phase distribution. When a laser beam illuminates the hologram, the reconstructed object's wave front can be seen as many coherent sub-waves, each with different phases. The random constructive and destructive interference of these coherent sub-waves with phase differences leads to a random intensity distribution on the image plane. The more random the phase distribution, the more sub-waves contribute to the reconstructed object points, leading to more pronounced speckle noise. At the same time, the scattering effect of random phase results in a larger numerical aperture for the beam, allowing the beam to defocus faster, thereby producing stronger focus cues. In contrast, uniform phase holograms have a smoother phase distribution, allowing only a few sub-waves with similar phases to reconstruct the object points through constructive interference, thus suppressing speckle noise. Additionally, the beam's numerical aperture is smaller, leading to slower defocusing, and therefore, weaker focus cues.

Figure 1. (a) Reconstruction result of random phase holograms, (b) Reconstruction result of uniform phase holograms, and (c) Explanation of the speckle principle.
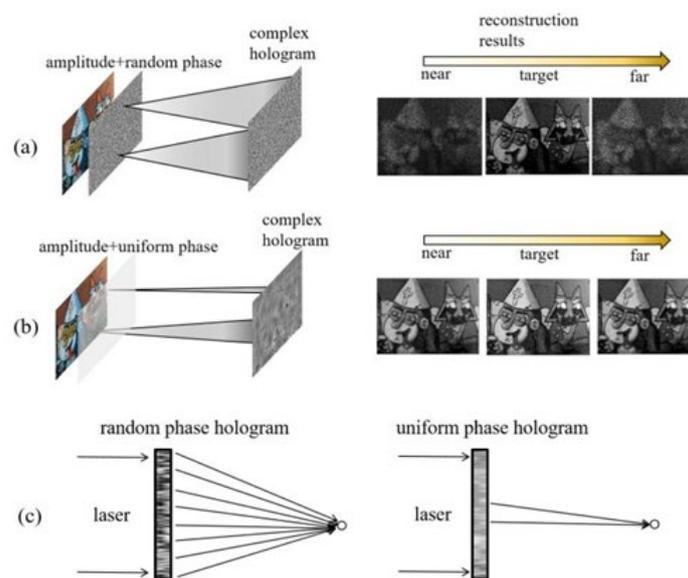

Figure 2 intuitively explains the principle of the proposed method, which uses multiple discrete light beams from different directions to reconstruct object points. Therefore, on the defocus plane, the different light beams will separate from each other, producing multiple defocused spots, thereby enhancing the defocus blur.

Figure 2. (a) Defocus blur of random phase holograms, (b) Defocus blur of uniform phase holograms, and (c) The proposed method's defocus blur.
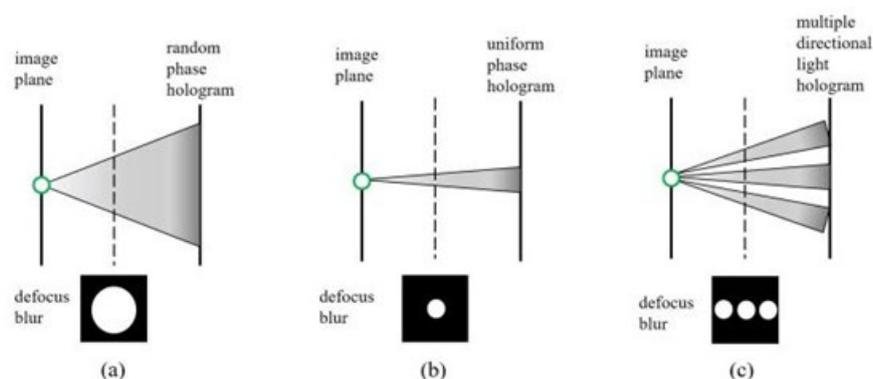
To produce beam direction deflection, it is only necessary to add a blazed grating phase to the image plane. As shown in Figure 3, by adding different blazed grating phases, multiple complex amplitude sub-holograms can be generated. By time-sequencing the reconstruction of these complex amplitude sub-holograms, the defocus blur of the reconstructed results is enhanced, as shown in the right image. Time sequencing is used here to avoid interference fringes caused by the mutual interference between different blazed gratings. However, limiting the phase distribution of the image plane requires complex amplitude modulation. To avoid complex amplitude modulation, consider loading different blazed grating phases on pure phase holograms rather than the image plane to produce beam deflection.

Figure 3. Generation of multi-directional light holograms and their simulation reconstruction results.
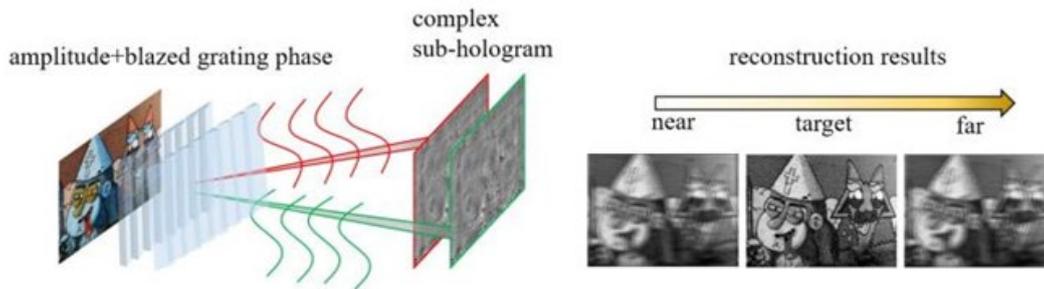
As shown in Figure 4, when the blaze angle of the blazed grating loaded on the hologram is changed, different directional beam deflections are generated, but the reconstructed image will also shift. To ensure the images reconstructed by beams from different directions overlap, a displacement d between the two sub-holograms needs to be set, given by the following equation:

$$d = 2z \tan \theta \qquad (1)$$

Where z is the reconstruction depth, and θ is the blaze angle. The study uses the SGD iterative algorithm to generate holograms.

Figure 4. (a) Loading a blazed grating with blaze angle -θ on the hologram, (b) Loading a blazed grating with blaze angle θ on the hologram, (c) Two sub-holograms reconstructing the image from different directions.
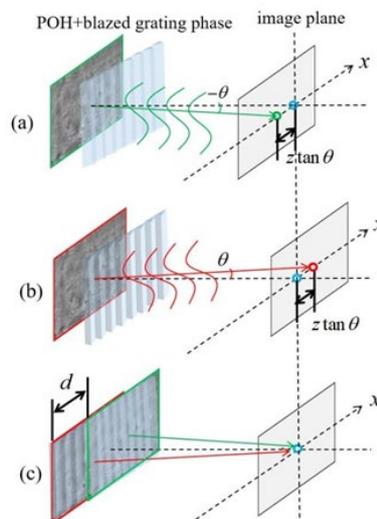

Figure 5(b) shows the optical result of the random phase hologram obtained by setting the initial phase to random. It shows strong focus cues but severe speckle noise. Figure 5(c) shows the optical result of refreshing three independent random phase holograms at 180 Hz. Due to the time-averaging effect, the speckle noise is suppressed to some extent, but the suppression effect is limited. Figure 5(d) shows the optical result of the uniform phase hologram obtained by setting the initial phase to uniform. It shows that the image quality of the reconstruction is high, and the speckle noise is effectively suppressed, but there are almost no focus cues. Figure 5(e) shows the optical result of the proposed method, which also

uses 180 Hz time sequencing to refresh three uniform phase holograms loaded with different blazed grating phases. It shows that the defocus blur and focus cues are enhanced while maintaining high image quality.

Figure 5. (a) Diagram of the experimental setup, (b) Reconstruction result of random phase holograms, (c) Optical result of refreshing three random phase holograms at 180 Hz, (d) Optical result of uniform phase holograms, (e) Optical result of the proposed method.
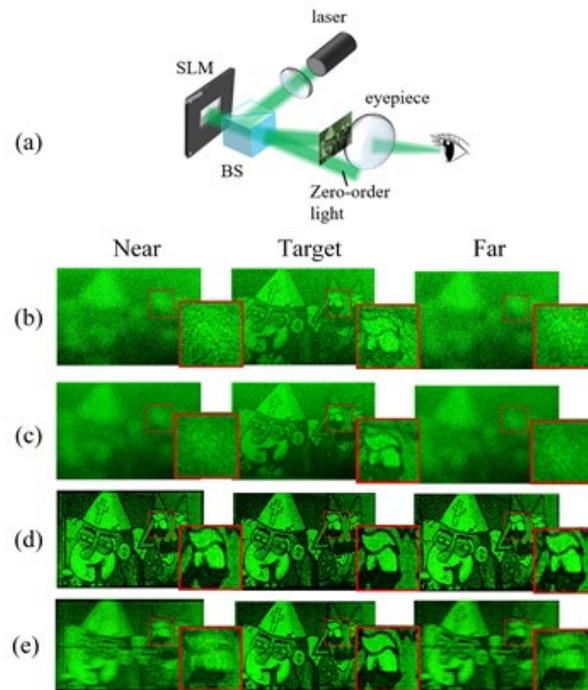
Furthermore, in achieving multi-plane 3D displays, there will be image separation issues as shown in Figure 6. Under the given sub-hologram displacement d and blaze angle θ, only the image at depth $z_0 = d/2\tan(\theta)$ is overlapped, while images from other planes will separate, and the separation amount is:

$$S_j = 2\tan\theta\,(Z_J - Z_0) \qquad\qquad (2)$$

Figure 6. Image separation issue in multi-plane displays.
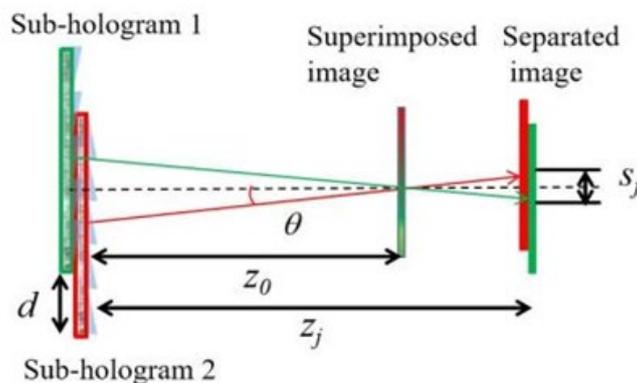
To ensure image overlap on each plane, pre-processing of each depth image is required, performing corresponding translations to offset the generated separation amount. Figure 7 shows the optical result of a three-plane display, where images at different depths overlap after pre-processing, solving the image separation problem in 3D displays. This further validates the advantages of the proposed method in terms of high image quality and enhanced focus cues.

Figure 7. (a) Multi-plane reconstruction result of random phase holograms, (b) Multi-plane reconstruction result of uniform phase holograms, (c) Multi-plane reconstruction result of the proposed method.
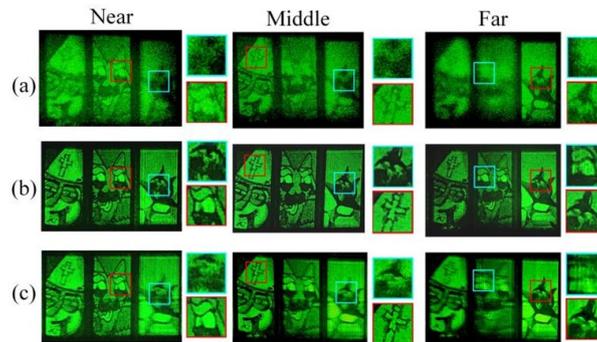
The study also further discusses that as the number of directional light beams increases, the defocus blur becomes more natural. However, this requires a higher refresh rate.

DISCUSSION

The proposed method produces a similar defocus blur as the Super Multi-View (SMV) display [4,5]. However, their differences could be discussed as follows:

Principle: The proposed method use multiple blazed grating phases to produce multiple directional light. Then, each point emits multiple narrow light rays and form more apparent defocus blur. The hologram calculation is basically the same as the layer-based calculation. The SMV display provides defocus blur by projecting more than (or equal to) two view images into the eye pupil, simultaneously. The depth cue is provided by the parallax image information [6].

Depth of field: Since the proposed method is a CGH method, the depth of field could be very large due to the wavefront reconstruction. The SMV display usually has a limited depth of field due to the fixed image plane.

CONCLUSION

To address the respective advantages and disadvantages of random phase and uniform phase holograms in reconstruction, a multiple directional light beam reconstruction method is proposed, which enhances focus cues while maintaining high image quality. This method uses a blazed grating phase to deflect image beams and solves the image misalignment problem in multi-plane reconstruction. The separation of multiple defocused spots enhances the defocus blur. This method utilizes time-division multiplexing, which is commonly used in speckle averaging to improve image quality. However, compared to speckle averaging through time-division multiplexing, this method does not require a high refresh rate, which is one of its advantages.

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