Holographic Caustic Optical Element Analysis based on Scalar Fourier Modal Method and Deep Neural Network

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Abstract: This paper introduces a novel holographic caustic optical element, explores its analysis using SFMM, and demonstrates the benefits of applying multiplexing techniques. Simulations determine optimal parameters, including photolithography efficiency. A deep neural network is introduced for parameter optimization.

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1. Introduction

Holographic optical element (HOE) is optical components with various application potentials, currently gaining attention in the AR field. Many approaches to fabricate HOE have been proposed using SLM-based wavefront hologram printer [1, 2]. The SLM, however, is unreasonable to use for generating caustic images because numerical aperture of the SLM is limited. Therefore, a new hogel-based HOE lithography system is needed. This paper proposes a recording system for hogel-based holographic caustic optical element (HCOE) and presents the HCOE reconstructed results [3]. The hologram printer records grating on the hologram that manipulates light direction. Additionally, a simulation of HOE analysis, based on scalar Fourier modal method (SFMM), is necessary to achieve uniform caustic images. Furthermore, to accelerate HOE optimization calculations using SFMM [4], we propose the utilization of deep neural networks (DNNs) for constructing an HOE optimization network.

2. Caustic Holographic Optical Elements

Figure 1 shows the proposed system with a comparison to the conventional freeform refractive surface. In conventional caustic as shown in Fig. 1(a), the light source illuminates the freeform lens perpendicularly. An incident ray is refracted by the surface power where the ray intersects one point on freeform lens plane.

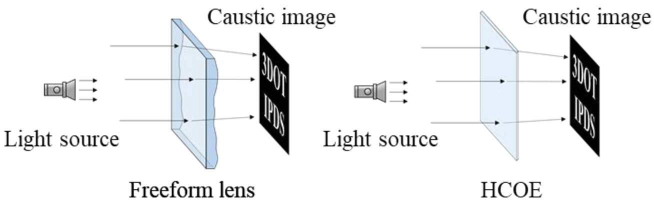

Fig. 1. Caustics images using (a) conventional freeform lens and (b) holographic caustic optical elements.

Then, the rays form one intensity distribution and it generates a caustic image at specific distance. Similarly, as shown in Fig. 1(b), the HCOE lens steers incoming rays using diffraction to form intensity distribution of caustic image. The ray that intersects at HOE plane meets Bragg condition of volume hologram, so the ray is diffracted to one direction. Thus, the HCOE has many gratings on each portion. The HCOE has the property of transfer function as follows:

$$h(x,y) = \sum\sum \exp\left(j\mathbf{G}_{nm}\right) rect\left\{\frac{x-n}{\Delta x}\right\} rect\left\{\frac{y-m}{\Delta y}\right\}, \tag{1}$$

where Δx and Δy are the size of hogel which is recording unit in the hologram printing method, and $\mathbf{G}_{mn}$ is the grating vector that determines the diffraction direction of rays. To design HCOE pattern for generating caustic image, backward calculation from the caustic image is required. Target caustic image consists of a set of unit image pixels and each unit pixel in the image plane has different intensity for expressing the brightness that can be expressed by the number of hogel. Each hogel expresses a unit image pixel, and several rays from hogels are needed to be incident on a pixel to control the brightness of each image pixel. Thus, the brightness of the image is easily manifested when the large number of hogels exists and the number of hogels are larger than the number of image pixels. The way to assign hogels to image pixels is taking the nearest hogels from the image pixels along the vertical direction. As the diffracted rays from each hogel are incident on the nearest image pixel, the diffracted angles are minimum and therefore prevents unexpected interference between diffracted rays with large angle of diffraction.

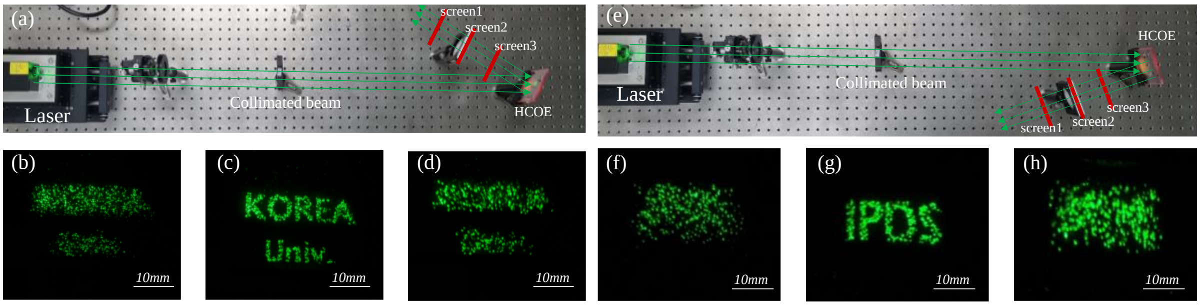

Fig. 2. Experimental reconstruction setup of projected HCOE image in (a)left and (e)right direction with an angle of 27 degrees. First projected images are observed at three depths from the HCOE: (b) 25 cm, (c) 20 cm, and (d) 15 cm. Second projected images are observed at three depths from HCOE: (f) 25 cm, (g) 20 cm, and (h) 15 cm. Experimental reconstruction setup of projected HCOE

Figure 2 shows image reconstruction experimental results of HCOE. One of the biggest advantages is that angular multiplexing is possible [5]. Therefore, different images are reconstructed at two angles, but non-uniform brightness is observed as shown in Fig. 2(c) and (g). To record HCOE with uniform light intensity, it is necessary to find photolithography power producing equal efficiency. Therefore, research is needed to analyze HOE through simulation to find an optimal photolithography power for recording each hologram with consistent intensity and an optimal thickness for maximum efficiency of HOE. Additionally, we aim to build a network for optimizing HOE recording methods based on deep neural networks.

3. Conclusion

This paper introduced a hogel-based holographic recording system for fabricating Holographic Caustic Optical Elements (HCOE). Experimental results are demonstrated the system's capability to project HCOE images with various angles and depths. However, the non-uniform brightness was observed. To address this issue, an optimization method is proposed using the Scalar Fourier Modal Method (SFMM) to determine optimal photolithography parameters. Additionally, we introduce the application of deep neural networks for optimizing the photolithography process of HOE. These methodologies would be directions for improving the efficiency and uniformity of HOE in practical applications.

4. Acknowledgements

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5. References

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