Direct Light Removal and Image Quality Evaluation of Large Screen Holographic Projection

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ABSTRACT

In this paper, we constructed a time-division reproduction system of holographic projection using a DMD (Digital Mirror Device). We succeeded in removing the direct light in projected images and enlarging the projected images by changing a sampling pitch of the original image.

1 INTRODUCTION

Holography [1] is a technology that can record and reproduce three-dimensional (3D) images by using the interference and diffraction of light. Especially, electronic holography [2-3] utilizes computer-generated holograms (CGHs) obtained by calculating propagation and interference of light on a computer. Holographic projection, in which an image is projected onto a screen using electronic holography technology, can miniaturize the system size because the optical system becomes simple. Therefore, it is required to project a large reproduced image from a small hologram. The ARSS Fresnel diffraction calculation [4] is used for the calculation of the hologram, and the reproduced image can be enlarged by setting the sampling pitch of the original image freely. However, a problem of holographic projection is that the image quality of the reproduced image deteriorates when the reproduced image is enlarged. For this reason, we need to maintain the image quality while reproducing large projected images. For this purpose, we have proposed time division reproduction in which we divided the original images, and the holograms corresponding to the divided images were time-sequentially reproduced at high-speed. This method makes it possible to enlarge the reproduced image while keeping the image quality. However, in reproduced images, the direct light reflected from the DMD contaminates the projected images as shown in Fig. 1. Further, due to the limitation of the frame rate of the DMD, the number of divisions of the reproduced image is limited. In this paper, we removed the direct light using a lens and filter, and compared the image quality of the reproduced images when we used the time-division manner and when we enlarged the sampling pitch of the original image. In addition, we investigated to further expand the reproduced image by combining the time-division manner with enlarging sampling pitch.

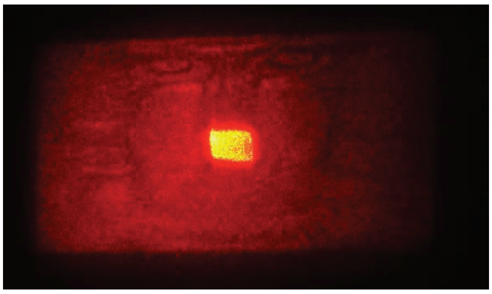

Fig. 1 Contamination by a direct light.

2 PROPOSED METHOD

2.1 Direct light removal

Conventionally, when a reproduction from a DMD displaying a hologram was performed without a filter between the DMD and the screen, the direct light reflected from the DMD contaminated a part of the reproduced image. Therefore, as shown in Fig. 2, two convex lenses with the same focal length are placed between the DMD and the screen at intervals of twice the focal length. The direct light that is parallel light gathers in the center at the focal plane of the first lens, and the direct light can be removed by filtering out this point. The actual optical system is shown in Fig. 3. For the filter, we used a transparent plate with a small shield in the center of the focal plane, and then only a reproduced image can be projected. Then, we removed the direct light in the 64-divided reproduced image.

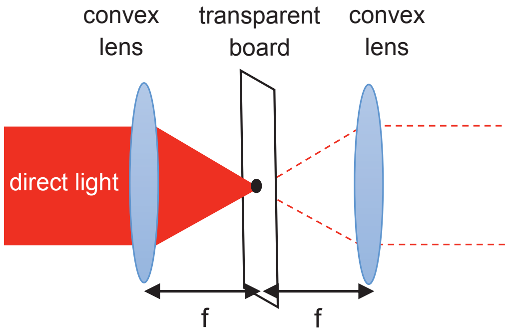

Fig. 2 Optical setup for direct light removal.

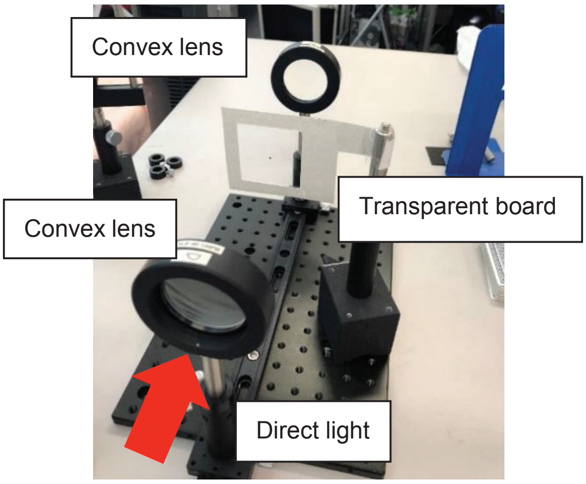

Fig. 3 Photograph of direct light removal optical system.

2.2 Time-division reproduction image

In holographic projection, a reproduced image can be enlarged or reduced by changing the sampling pitch of the original image. We found that the quality of the reproduced image would be degraded in too large sampling pitch. In order to maintain the image quality, we also proposed time-division manner, in which small reproduced images are projected, and in the next frame, adjacent reproduced images are projected at a high speed.

In this study, we compared the image quality of reproduced images enlarged by time-division reproduction and by increasing the sampling pitch. We used a 64-divided reproduced image and the reproduced image when the sampling pitch of original images is 8 times larger than that of the hologram vertically and horizontally. The size of the two reproduced images using the time-division and the sampling changing methods is the same.

2.3 Enlargement of reproduction image by combining the time-division and the sampling changing methods

We enlarged projected images by time-sequentially displaying holograms onto the DMD, and the enlargement ratio can increase as increasing the number of time-sequentially holograms. However, the number of holograms is limited to 64 due to the maximum frame rate of the DMD currently used is 9523 Hz. If the number of holograms is increased further, we cannot observe reproduced images without flicker. When the sampling pitches of the original image and the hologram were set to the same value, the size of the 64-divided reproduced image was only 6.5 cm × 11.6 cm. In order to further magnify the reproduced image, the sampling pitch of the original image was set to 1.5 times larger than the sampling pitch of the hologram.

3 RESULTS

Table 1 Experimental conditions

Digital Mirror Device	DLP LightCrafter 6500
Laser	LSR-RGB-300
Number of pixels	1920×1080
Pixel pitch of DMD	7.56[μm]
Wavelength of laser	638[nm]
Refresh rate	9523[Hz]

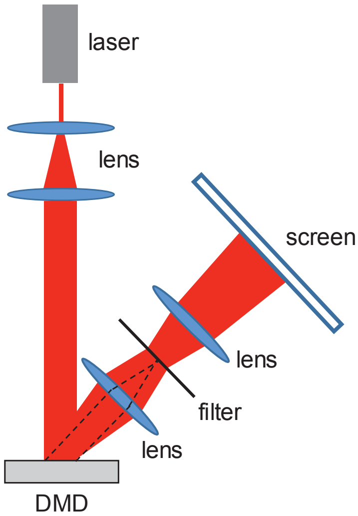

Fig. 4 Optical setup of our holographic projection.

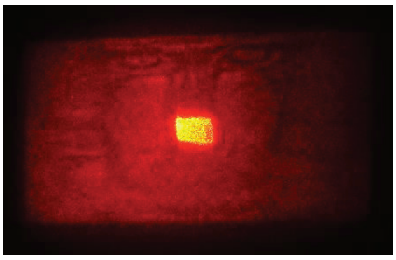

Fig. 5 64-divided reproduced image before direct light removal.

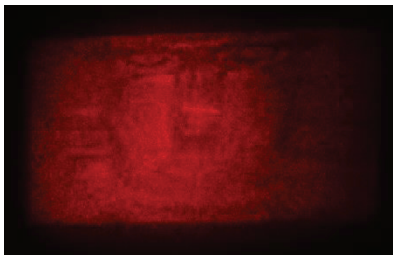

Fig. 6 64-divided reproduced image after direct light removal.

Table 1 shows experimental conditions. Fig. 4 shows a schematic of the optical setup for our holographic projection. First, the light emitted from the laser is converted into parallel light by using two lenses. The light is irradiated to the DMD on which holograms are displayed, and the diffracted light is obtained. The black dotted lines show the path of the direct light. The distance between the lens closest to the DMD and the DMD is set to the focal length of the two convex lenses which remove the direct light. The direct light is removed by the filter, and only diffracted light is projected onto the screen.

Fig. 5 shows a projected image overlapping the direct light. Fig. 6 shows a projected image after applying the filter technique. We succeeded in removing the direct light without affecting other parts.

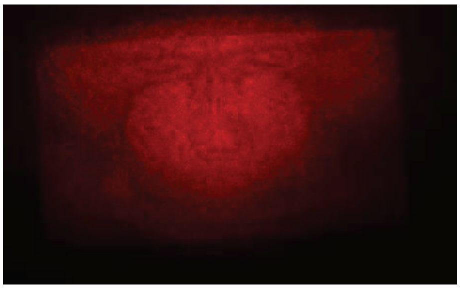

Fig. 7 Reproduced image when the sampling pitch is increased.

Fig. 7 shows the reproduced image when the sampling pitch of the original image is magnified by 8 times than that of the hologram vertically and horizontally. The size of the reproduced Images of Fig. 6 and Fig. 7 is the same. Comparing the two images, it can be seen that Fig. 7 has larger noise than Fig. 6. The reason why the projected images are degraded would be because the detail of original images cannot be represented by increasing the sampling pitch. We confirmed that the quality of the reproduced image is improved by using time-division method in cooperation with the sampling changing method.

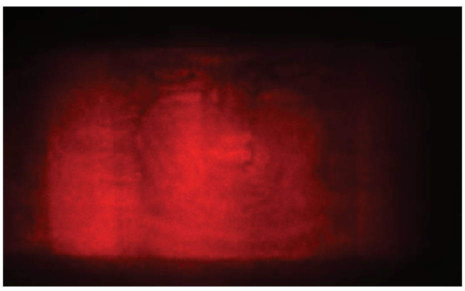

Fig. 8 The 64-divided reproduced image when the sampling pitch is 1.5 times larger.

Fig. 8 shows a 64-divided reproduced image when the sampling pitch is magnified by 1.5 times vertically and horizontally. The size of this image was 9.7 cm × 17.4 cm. Compared to Fig. 6, this result shows that the size of the reproduced image increases 1.5 times larger in vertical and horizontal. Comparing Fig. 6 and Fig. 8, it can be seen that Fig. 8 has better image quality.

4 CONCLUSION

In this study, the direct light contaminating a part of the reproduced image was removed, then it was possible to observe the entire reproduced image. In addition, we compared the image quality of the time-division reproduced image and the reproduced image by enlarging a sampling pitch. We confirmed the time-division manner was superior to the sampling pitch changing method. Furthermore, by combining the time-division manner with the enlargement of the sampling pitch, we succeeded in increasing the size of the reproduced image while maintaining the quality of the image.

In future work, we will work to further expand the reproduced image using lenses and to make the full-color reproduced image using three colors of laser lights.

Acknowledgements

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REFERENCES

[1] M. K. Kim, "Principles and techniques of digital holographic microscopy", SPIE Reviews. **1**, 018005 (2010).

[2] P. S. Hilaire, S. A. Benton, M. L. Jepsen, J. Kollin, H. Yoshikawa and J. Underkoffle, “Electronic display system for computational holography,” Proc. SPIE, **1212**, 174-182 (1990).

[3] S. Yamada, T. Kakue, T. Shimobaba and T. Ito, “Interactive Holographic Display Based on Finger Gestures,” Sci. Rep, **8**, 2010 (2018).

[4] T. Shimobaba, T. Kakue, N. Okada, M. Oikawa, Y. Yamaguchi, T. Ito , “Aliasing- reduced Fresnel diffraction with scale and shift operations”, J. Opt., **15**, 075302(5pp) (2013).