[Citation] International Display Workshop 2024 (IDW'24), Sapporo, paper 3Dp2-4, 794-797 (2024.12.4).

Dual-color holographic AR Effect display using full-parallax high-definition computer-generated volume holograms

Shion Okai[1], Hirohito Nishi[1], Kyoji Matsushima[1]

k060630@kansai-u.ac.jp (S. Okai)
[1] Department of Electrical, Electronic and Information Engineering, Kansai University
Yamate-cho 3-3-35, Suita, Osaka 564-8680, Japan.
Keywords: CGH, FPHD-CGH, CGVH, AR, holographic signage

ABSTRACT

The holographic AR effect is a technique that generate virtual 3D images around physical objects by placing computer-generated volume holograms in front of the physical objects. Proper occlusion processing between self-occluded objects and holographic images are presented not only for single-color but also dual-color effects.

1 Introduction

Full-parallax high-definition computer-generated holograms (FPHD-CGH), studied for a long time, continue to attract attention because of the amazing deep 3D images. In recent years, several challenges to create actual FPHD-CGHs are gradually being resolved by advances in computation techniques, performance of computers, and micro fabrication technology [1]. As a result, FPHD-CGHs whose number of pixels exceeding 100 billion pixels have been created [2]. In the latest FPHD-CGHs, the size is over 30 cm × 30 cm and the pixel scale are approaching tera-pixels [3,4]. These FPHD-CGHs can reconstruct real 3D images with deep depth as if there are real objects behind the hologram.

In this study, we try to create static image displays that allows us to generate holographic 3D images around physical objects. This is aimed at social implementation of FPHD-CGHs, such as holographic signages. In this display, an FPHD-CGH or FPHD-CGVH (computer-generated volume hologram) is placed in front of the physical objects, as shown in Fig.1(a). When turning on the illumination light, the holographic image is reconstructed around the real object and adds some effect, such as magic circles, flames, lightning, and lightsabers, as in (b). We refer to the effects as holographic AR effects (HARE), named after well-known augmented reality [5].

The hologram for HARE should be as transparent as possible because viewers see the real objects through the hologram. We use CGVHs transferred from the original CGH for HARE because CGVHs are commonly more transparent than CGHs. Use of CGVH also allow us to produce HARE with multiple colors because of wavelength selectivity of CGVH [6]. Furthermore, it is very important in HARE to process occlusion between the real objects and the holographic images correctly. When the holographic 3D image appears behind the real object, the 3D image must seem to be obscured by the foreground real objects. We use the switch-back technique for occlusion processing between real objects and holographic images [7].

In this paper, we report HARE displays with single and dual colors and occlusion processing in a very complex-shaped real object.

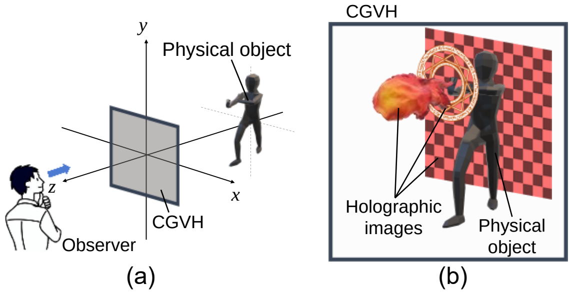

Fig1. The concept of the holographic AR effects.

2 Techniques for holographic AR effect display

2.1 Occlusion Processing

In HARE display, it is significant to handle occlusion between physical objects and 3D images especially in cases where the holographic 3D images are reconstructed behind the real objects. In the previous study, the technique of object-by-object light shielding [7] was used in a simple-shaped object [5]. In this case, the wavefield reconstructed by the hologram is masked with the same shape as the silhouette of the physical object when calculating the original CGH used for fabricating the CGVH. The physical object was fabricated using a 3D printer from the 3D model used for calculation of the original CGH, because the silhouette of the real object must exactly agree with the mask used for the calculation.

A drawback of the technique in the previous study is that the physical object must not have self-occlusion; a part of the object must not hide other parts of the same object. Consequently, the shape of the physical objects was limited to a simple shape. In this study, we performed occlusion processing using the polygon-by-polygon light-shielding in computation of the original CGH. This technique is applicable to self-occluded objects. Here, there is a technique called the switch-back technique, which can perform the polygon-by-polygon

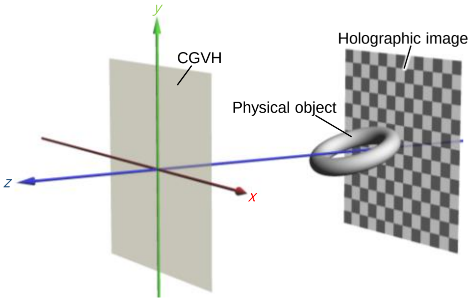

Fig. 2 An example of the self-occluded physical object: A torus.

light-shielding very fast [7].

For example, in a HARE display for the 3D scene shown in Fig. 2, the physical object is a torus that has self-occlusion. In this case, the 3D model of the torus is used for calculation of the original CGH using the switch-back technique. Here, note that the conventional switch-back technique calculates and adds light of the torus itself to the resultant wavefield. However, light of the torus is emitted from the physical object in this study. Therefore, we calculate the original CGH for the 3D scene with a completely black torus that does not emit any light.

Like previous work, this method requires a real object that is perfectly matched to the 3D model used to calculate the original CGH. Thus, we printed the 3D model using a 3D printer and used it for the physical object of the HARE display.

2.2 Fabrication of CGVH

We use contact-copy, a technique for transferring the original CGH to photopolymer, to fabricate CGVH for the HARE display [6]. In this technique, transfer light passing through the photopolymer illuminates and reconstructs the original CGH. The reconstructed light of the original CGH is recorded on the photopolymer as a volume hologram.

We also use a technique of tiling contact copy [8], where collimated light passing through a rectangular aperture is used as the transfer light that illuminate only a rectangular region. The entire original CGH is transferred by moving the rectangular region. This technique allows us to transfer a large original CGH to the CGVH.

2.3 Dual-color HARE display

Because the CGVH is a volume hologram, the holographic image is reconstructed only by the illumination at the same wavelength as the transfer light. As shown in Fig. 3, When we stack two CGVHs, for example a red and green CGVHs, red light reconstructs only red CGVH while green light reconstructs only green CGVH. Therefore, we can switch the color and effect produced by the holographic image. It is possible to produce both effects at the same time as well.

3 Fabrication of HARE displays

To verify the holographic AR effect in practice, we fabricated two HARE displays: the single-color display and

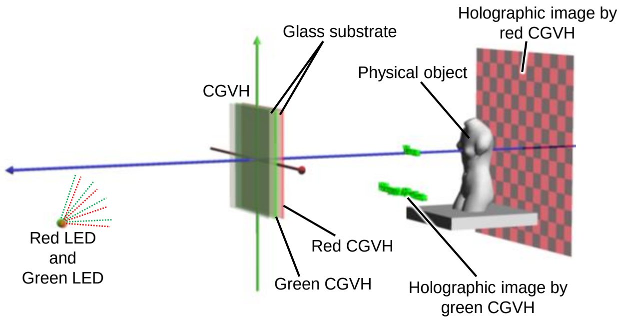

Fig.3 The basic arrangement of a dual-color HARE display.

dual-color display. In both displays, physical objects have self-occlusion. Arrangements of the single and dual color displays are shown in Fig. 4 and 5, respectively. The parameters of the CGVHs for these displays are summarized in Table 1. The area of the CGVH for the dual-color display are four times larger than that of the single-color display. Therefore, the CGVH is fabricated using tiling contact copy.

Photographs of optical reconstruction of the fabricated single-color display is shown in Fig. 6. Figure 7 also shows the optical reconstruction of the dual-color display when only red and green are turned on, and when both are turned on. All photographs are taken from different viewpoints. It is verified that holographic AR effects are successfully generated around the physical objects. Even in a very complex-shaped object as in Fig. 7, occlusion between the physical object and holographic images is properly processed from any viewpoint. As a result, the viewer sees the virtual background image as

Table 1 Parameters of CGVHs

	Single-color	Dual-color
Wavelength [nm]	640	640, 532
Number of pixels of original CGH	65,536 × 131,072	131,072 × 262,144
Pixel Pitches [μm]	0.8 × 0.4	
Photopolymer	HX-200	

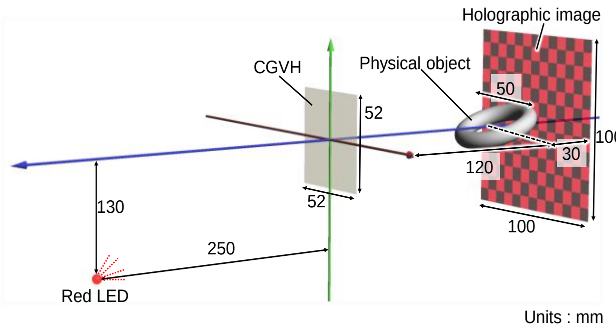

Fig.4 The arrangement of the fabricated single-color HARE display.

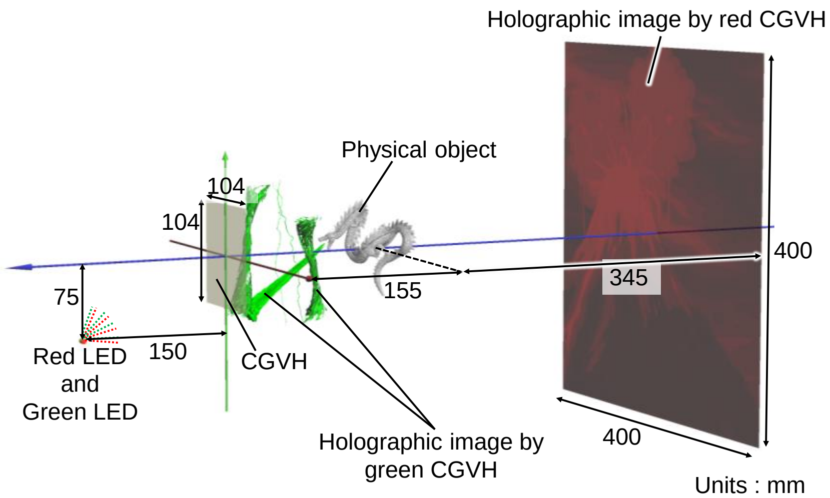

Fig.5 The arrangement of the fabricated dual-color HARE display.

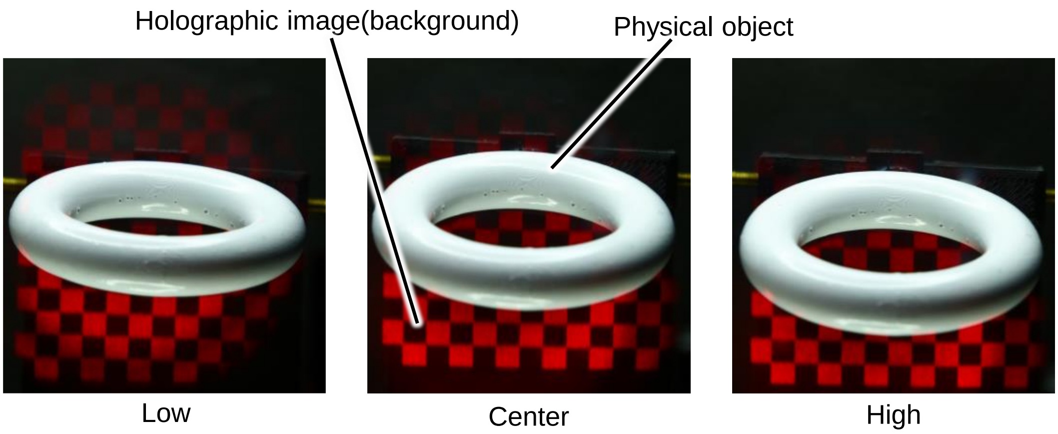

Fig.6 Photographs of the fabricated single-color HARE display.

if it exists behind the physical object.

4 Conclusion

We fabricated not only single-color holographic AR effect displays but also dual-color displays. In both displays, AR effects are generated by holographic images around the physical objects. Although both objects have self-occlusion and the object of the dual-color display has very complex shape, we can confirm that the occlusion is processed correctly from any viewpoint. Furthermore, it is verified that holographic AR effects are successfully generated with dual-color before and behind the physical object.

This work was supported by Japan Society for the Promotion of Science (JSPS) KAKENHI 22H03712 and the commissioned research (JPJ012368C06801) by National Institute of Information and Communications Technology (NICT), Japan.

References

[1] K. Matsushima and S. Nakahara, "Extremely high-definition full-parallax computer-generated hologram created by the polygon-based method," Appl. Opt. 48, H54-H63 (2009).

[2] K. Matsushima, *Introduction to Computer Holography*, Sect. 1.3 (Springer, 2020).

[3] K. Matsushima, H. Nishi, R. Katsura, and C. -J. Lee, "Computation techniques in tera-pixel-scale full-parallax computer holography for 3D display," The 12th Laser Display and Lighting Conf. 2023 (LDC2023), LDC10-02 (2023).

[4] K. Matsushima and H. Nishi, "Challenges to tera-pixel-scale full-parallax computer holography for 3D Imaging," in Frontiers in Optics + Laser Science (FiO, LS), FM5E, (2022).

[5] H. Nishi, H. Uchida, and K. Matsushima, "Development of very transparent high-definition CGH for holographic AR effects" 3D Image Conference 2023, p-10, (2023), in Japanese.

[6] O. Kunieda and K. Matsushima, "High-quality full-parallax full-color three-dimensional image reconstructed by stacking large -scale computer-generated volume holograms", Appl. Opt. **58**, Issue

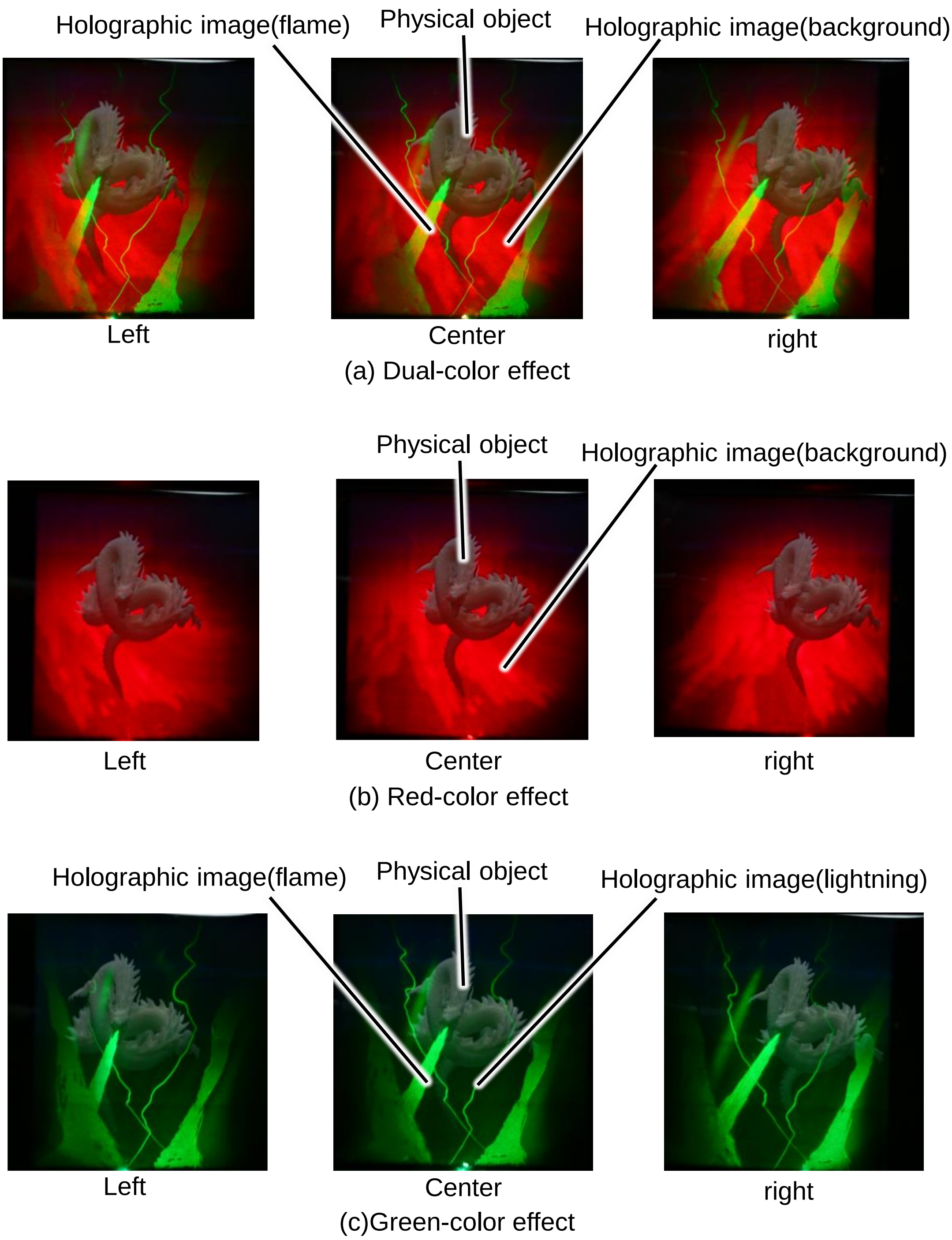

Fig.7 Photographs of the fabricated dual-color HARE display.

34, G104-G111(2019).

[7] K. Matsushima, M. Nakamura and S. Nakahara, “Silhouette method for hidden surface removal in computer holography and its acceleration using the switch-back technique,” Opt. Express 22, 24450-24465 (2014).

[8] S. Fujiki, H. Nishi, and K. Matsushima, “Large-scale high-quality full-color computer-generated volume hologram fabricated by stacking and tiling technique,” Opt. Lett. 49, No.10, 2673-2675 (2024).