Increase in size of full-color stacked CGVH by tiling contact-copy

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ABSTRACT

A novel technique is presented for increasing in the size of stacked CGVHs (computer-generated volume hologram) that reconstruct high-quality full-color full-parallax 3D images. A tiling technique is introduced to extend the size without increasing the laser power used for contact-copy.

1 Introduction

Computer-generated holograms (CGH) commonly reconstruct monochrome images unless special optical setup is used. Full-parallax high-definition CGHs (FPHD-CGH) calculated by the polygon-based method and silhouette method are printed using laser lithography and reconstruct monochrome images of amazing deep 3D scenes with natural motion parallax and no sensational conflicts [1,2]. For the FPHD-CGHs, two practical methods have been proposed for full-color reconstruction: the methods using RGB color filters [3] and stacked CGVH (computer-generated volume hologram) [4].

In the RGB color filters method, large FPHD-CGHs whose size is 18cm × 18cm have been created [5], but an RGB laser is necessary to reconstruct clear 3D images because of the broadband property of the RGB color filters. In addition, the reconstructed full-color images are deteriorated in quality because of splitting the fringe pattern. On the other hands, the stacked CGVH features brighter and less noisy full-color 3D images. Furthermore, the quality images are obtained by illumination using a white LED; we do not need any laser light source. However, the size of quality full-color CGVHs was limited to approximately 5cm × 5cm. This is mainly because the output power of the laser used for fabricating CGVH is limited to hundreds mW due to the workers safety. Although a beam-scan technique was attempted to increase the size of stacked CGVHs, degradation is reported in the image quality [6]

In this paper, we proposed a novel method to increase the size of full-color stacked CGVHs by employing a low power laser and the technique referred to as tiling contact-copy. Not only a presentation on the technique but also actual full-color stacked CGVHs will be exhibited in the poster or exhibition room.

2 Principle of tiling contact-copy

2.1 Contact-copy

The contact-copy is a method to transfer an original printed CGH to volume holograms and produce CGVHs. As shown in Fig. 1, the original CGH and a sheet of photopolymer, attached in contact with the original CGH, are illuminated with monochromatic light referred to as transfer light. Here, the transfer light is the same light as the reference wave used for calculating the original CGH. The transfer light illuminates the original CGH through the photopolymer and reconstructs 3D images of the original CGH that is a reflection hologram because of the metallic fringe printed by laser lithography. The light of the 3D image works as an object wave and interferes with the transfer light itself.

The fringe recorded in the photopolymer has a 3D structure because the object wave and transfer light enter the photopolymer in the opposite direction. Accordingly, a CGVH copying the 3D image of the original CGH is formed in the photopolymer. This CGVH
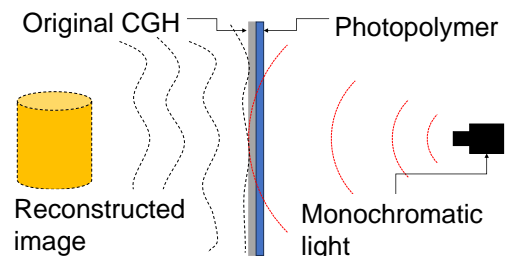

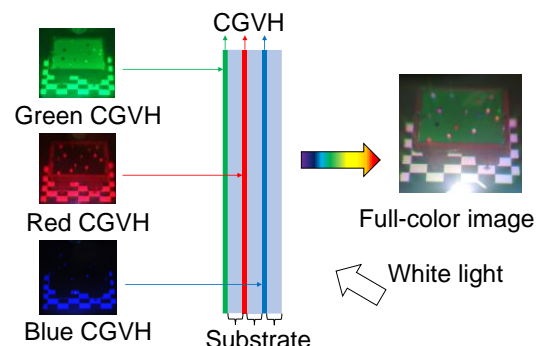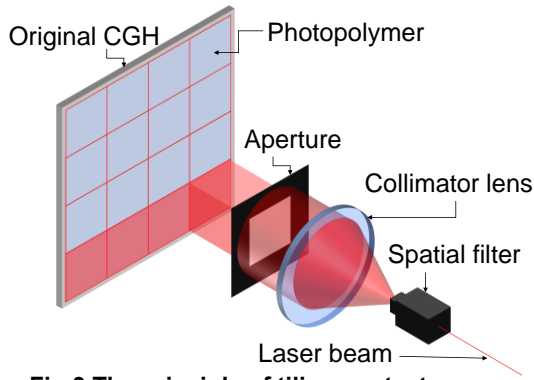**Fig.1 The principle of the contact-copy**

Fig.2 The principle of full-color reconstruction.

Fig.3 The principle of tiling contact-copy

can reconstruct high-quality monochromatic image by reflection of illumination light. Here, note that a broadband light source such as a white LED can be used for illumination because of the property of wavelength selectivity inherited from volume holograms.

2.2 Full-color reconstruction by stacking CGVHs

When illuminating a CGVH with a white light, the CGVH reconstructs the 3D image by reflection at the same wavelength as that of the transfer light. Therefore, as shown in Fig.2, by stacking three CGVHs fabricated at three wavelengths corresponding to R, G and B primary colors, we can obtain a full-color image by integration of RGB monochrome images [4]. Here, note that the original CGH must be calculated with compensation for thickness of the CGVH substrates to superpose RGB color images exactly.
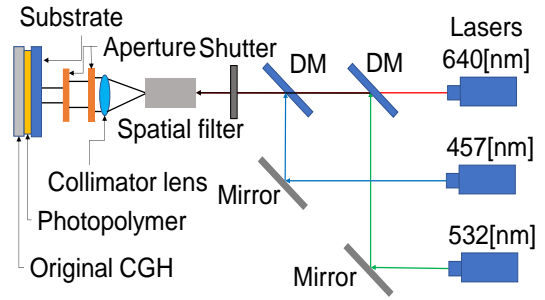
2.3 Tiling contact-copy

In the contact-copy, a certain level of optical intensity is required for the transfer light to form a CGVH in the photopolymer. Because optical intensity of the transfer light is reduced with increasing the area of the contact-copy, a high power laser must be introduced to achieve expansion of the CGVH.

To avoid the problem, we introduced a novel technique, called tiling contact-copy, for extending the size of CGVHs. In this technique, as shown in Fig.3, a part of the original CGH and photopolymer is illuminated by the square collimated transfer light. The original CGH and photopolymer are installed on an automatic stage to move the area of contact-copy. By repeating the process until filling the whole area of the original CGH, we can fabricate a large CGVH. After fabricating three large CGVHs in RGB colors, the CGVHs are stacked with accurate alignment to reconstruct full-color images, as mentioned in the previous section.

3 Fabrication of large stacked CGVH

We attempted to produce a full-color stacked CGVH over 10cm by tiling contact-copy. Figure 4 shows the optical setup for tiling contact-copy in three colors. The size of the rectangular aperture is 26.2 mm × 26.2 mm. The outputs of three lasers whose wavelength is

Fig.4 Optical setup for tiling contact-copy at three wavelengths.

Table 1 Parameters of the original CGHs.

Number of pixels	131,072 × 262,144
Pixel pitches [μm]	0.8 × 0.4
Wavelengths [nm] (R, G, B)	(640,532,457)
Number of polygons	5,292
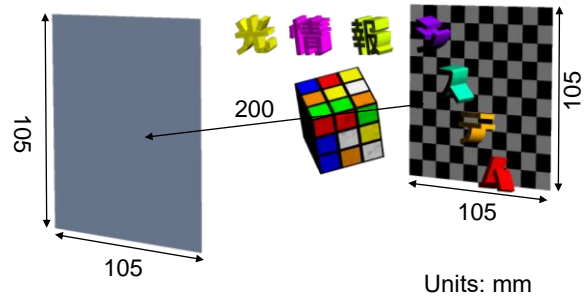
Fig.5 3D scene used for calculating the original CGHs.

corresponding to primary colors are superposed in a coaxial beam using dichroic mirrors (DM). Note that only one laser is turned on to fabricate a single CGVH and the laser is switched after completing the single CGVH.

We actually created a large stacked CGVH using the proposed technique. The 3D scene and parameters of the original CGHs are shown in Fig. 5 and Table 1, respectively. The original CGHs for each color are composed of approximately 17 billion pixels. The CGVHs whose size is 105mm × 105mm are fabricated by 4 × 4 tiling contact-copy of the original CGHs. Time of tiling contact-copy was less than 15 min for each CGVH. Table 2 summarizes the parameters of the tiling contact-copy.

4 Optical reconstruction and discussion

4.1 Optical reconstruction of stacked CGVH

Figure 6 shows optical reconstruction of the fabricated stacked CGVH. The illumination light source is a white LED with fiber output. It is verified that a high-quality full-color 3D image is reconstructed by the white illumination when staring the reconstructed 3D images. However, as shown in Fig.7, when focusing on the surface of the stacked CGVH, the boundaries between tiles are noticeable.

4.2 Discussion on boundaries

The boundaries between tiles seem to be thicker than that we expected from the accuracy of the automatic stage used. In addition, thickness of the boundaries of upper tiles tends to be larger than that of lower tiles as shown in Fig.7.

Figure 8(a) shows layered structure of the original printed CGH whose fringe pattern is generated by numerical interference by a spherical reference wave. Here, the center of the spherical wave is placed under the CGH. The recorded wave of the CGH is exactly reconstructed when the same spherical wave as the reference wave illuminates the CGH. However, in the tiling contact-copy, a collimated transfer light enters perpendicularly to the photopolymer and original CGH, as shown in Fig. 8(b). As a result, the photopolymer records reconstruction light of the original CGH with a carrier offset. When the same spherical wave as the reference wave illuminates the photopolymer, the carrier offset is canceled and the 3D images of the original CGH is reconstructed in the proper direction.

However, when copying the tile 1 in tiling contact-copy as in Fig. 8(b), at the edge of the tile, light of the original CGH reaches photopolymer of the neighboring tile 2. But the photopolymer does not record the light because there is no transfer light in the tile 2. As a result, light reconstructed by the original CGH is not recorded on photopolymer at the edge of the tile. This is most likely the reason that boundaries are much noticeable.

This problem can be relieved by changing the order of layers so that photopolymer directly contacts with the fringe, as shown in Fig. 8(c). Figure 9 shows photographs of boundaries in green CGVHs. It is verified that the boundaries in (a) are more noticeable than that in (b) where photopolymer directly contacts with the reflection fringe as in Fig. 8(c). However, in this case, another noise is caused by interference of backside surface reflection of the glass substrate. This effect is most likely avoided by anti-reflection coating or using a phase-only reflection CGH for the original CGH [7].

5 Conclusions

We have successfully fabricated high-quality full-color stacked CGVH exceeding 10 cm in the size by using the

Table 2 Parameters of tiling contact-copy.

	Red	Green	Blue
Wavelength [nm]	640	532	457
Exposure [mJ/cm^2]	2.1	1.4	0.6
Exposure time [s]	8	30	30
Number of tiles		4×4	
Size [mm]		26.2×26.2	
Settling time [s]		15	
Photopolymer		Bayfol®HX200	

| Left | Center | Right |

Fig.6 Photographs of optical reconstruction of the stacked CGVH fabricated by tiling contact-copy. The camera is focused on the reconstructed 3D image.

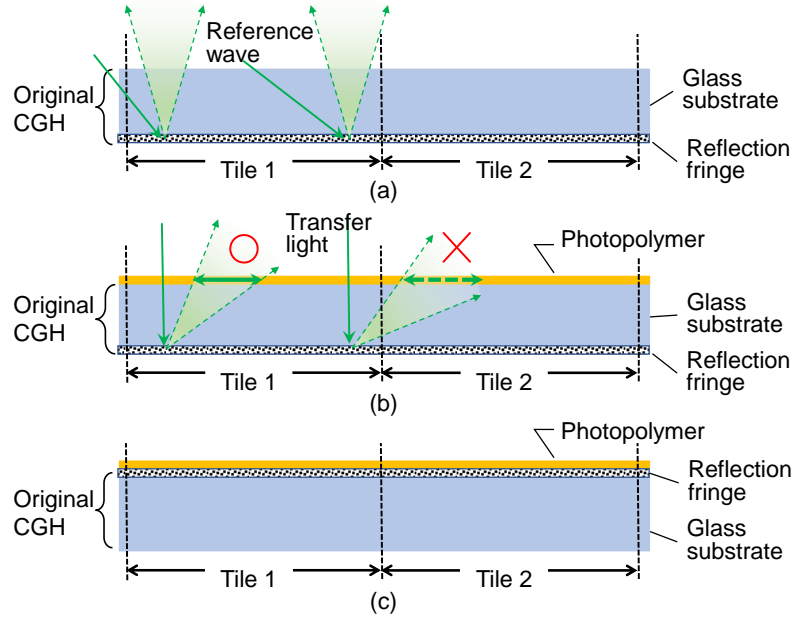

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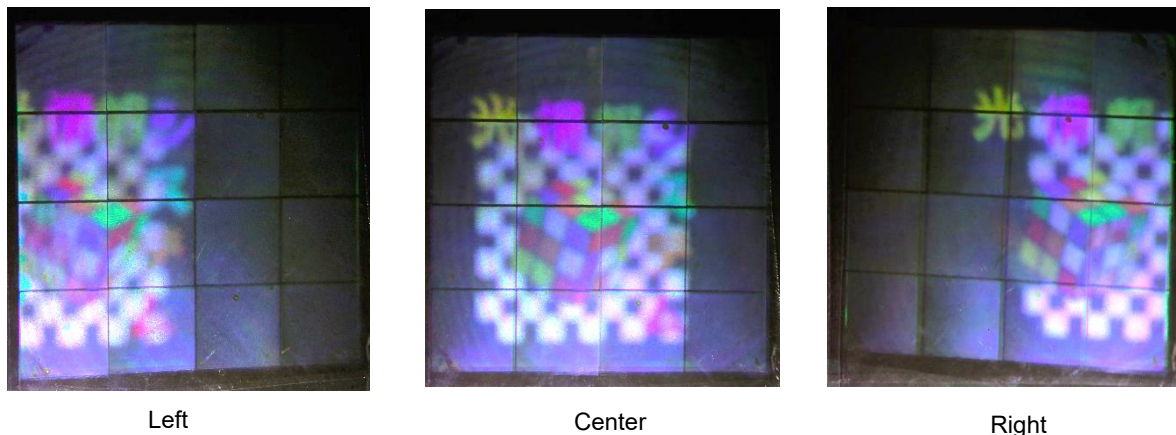
Fig.7 Photographs of the stacked CGVH. The camera is focused on the surface of the CGVH.

proposed tiling contact-copy. It is verified that a high-quality full-color 3D image is reconstructed by white illumination. However, boundaries between tiles are slightly detected. We discussed on the cause and suggested a method for improvement.

**Fig.8 The cause of producing noticeable boundaries.**

References

[1] K. Matsushima, *Introduction to Computer Holography*, Sect. 1, (Springer, 2020).

[2] K. Matsushima, S. Nakahara: Extremely high-definition full-parallax computer-generated hologram created by the polygon-based method, Appl. Opt. **48**, Issue 34, H54-H63 (2009).

[3] Y. Tsuchiyama and K. Matsushima, "Full-color large-scaled computer-generated holograms using RGB color filters," Opt. Express **25**, Issue 3, 2016-2030 (2017).

[4] 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 34, G104-G111(2019).

[5] K. Matsushima, H. Nishi, "Challenges to tera-pixel-scale full-parallax computer holography for 3D imaging," Frontier in Optics + Laser Science 2022 (FiO+LS2022), FM5E.2 (2022).

[6] O. Kunieda, K. Matsushima, "Large-scale full-color computer-generated display holograms created by stacking transferred volume holograms," SPIE Digital Optical Technologies 2019, SPIE Proc. 11062, 1106203(2019).

[7] K. Matsushima, *Introduction to Computer Holography*, Sect. 15.3.5, (Springer, 2020).
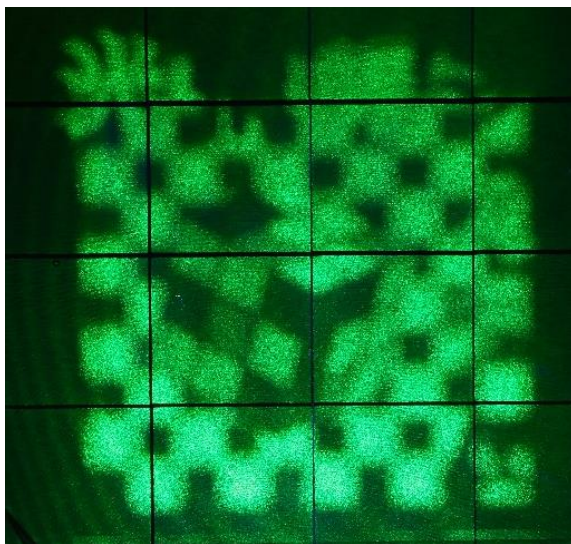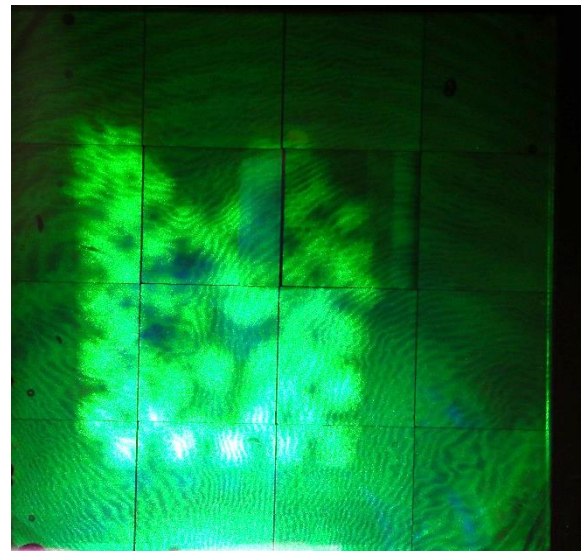
Fig.9 Photographs of boundaries of CGVHs. Photopolymer does not directly contact with the reflection fringe in (a), while it directly contacts with the fringe in (b).