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A Simulation Technique for Selection of Color Filter Used for Full-Color High-Definition CGH

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1. Introduction

Recently, it has been possible to create computer-generated holograms (CGH) composed of several billion or several ten billion pixels[1)]. These high-definition CGHs make it possible to reconstruct high-quality 3D images comparable to that by conventional optical holography. Several techniques also have been reported for full-color reconstruction of CGHs. For example, three images reconstructed by CGHs for RGB color are combined into a full-color 3D image by using dichroic mirrors[2)]. However, complex and large optical system required in this approach has no portability and causes difficulty in adjusting alignment. As a result, it is difficult to display full-color CGHs using the technique at museums and exhibitions. The technique of stacked CGHs has also been proposed[3)]. In this technique, layers of RGB CGHs printed on dichroic thin films are deposited on a single substrate. This is excellent technique but requires a sophisticated fine processing and film formation technology. Thus, it is difficult to apply the technique to high-definition CGHs. In this paper, we propose a technique for high-definition full-color CGHs by using color filters and present a simulation technique to select filter properties appropriate for bright full-color reconstruction.

2. The principle of full-color reconstruction using a color filter

The principle of full-color reconstruction is shown in Fig.1. In this technique, the fringe pattern is spatially divided into RGB blocks and the fringe pattern for each block is generated by numerical interference of the object and reference waves whose wavelength corresponds to each color. A color filter is attached to the blockwise fringe patterns so as to filter the band of illumination light. When irradiating white illumination light, the full-color 3D image emerges by combining RGB images reconstructed by each block.

The layered structure of full-color CGHs is shown in Fig.2. The fringe pattern is formed by chromium thin film and a color filter is attached on it. The 'guard gap' indicated in Fig.2 is the gaps between blocks of the fringe pattern. This guard gap allows us to increase the tolerance for positioning errors of the color filter.

3. Simulated reconstruction of full-color CGHs using color filter

Suppose that $O(x,y)$ and $R(x,y)$ are monochromatic object and reference wave fields with a wavelength of λ_0, the binary fringe pattern is given by:

$$I(x,y) = B\left\{Re\left[OR^*(x,y)\right]\right\} \tag{1}$$

where $B\{\}$ represents binarizing operator and thus the value of $I(x,y)$ is either 0 or 1. When a light with spectrum of $L(\lambda)$ illuminates the CGH, the reflected wave field immediately after the color filter may be written as:

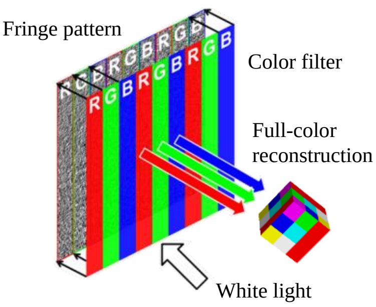

Fig. 1 The principle of full-color reconstruction of high-definition CGHs using a color filter.

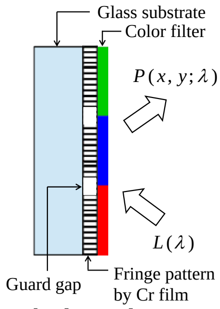

Fig. 2 The layered structure of full-color high-definition CGHs.

$$P(x,y;\lambda) = \left\{ \left(I(x,y)\, r_{Cr} + r_{glass} \right) t_{CF}^{2}(\lambda) + r_{CF} \right\} L(\lambda) \tag{2}$$

where r_{Cr} is reflectance of chromium film, which corresponds to the pixels having the value of '1' in $I(x,y)$. The r_{glass} is also reflectance of the glass substrate, corresponding to '0'-value pixels. We assume that these are constants with respect to the wavelength. The transmittance and reflectance of the color filter are given by $t_{CF}(\lambda)$ and r_{CF}, respectively. While the former is a function of λ, the latter is assumed to be a constant. Note that the square in $t_{CF}(\lambda)$ expresses a double transmission of the filter.

We calculated many monochromatic images from $P(x,y;\lambda)$ using discrete spectrum of $L(\lambda)$, where the images are of simulated reconstruction given by numerical image formation in virtual optics. These monochromatic images were combined into a XYZ color image using the CIE XYZ color matching function, and finally, converted to the sRGB color image.

4. Optical and simulated full-color reconstruction of CGH

The 3D scene and parameters of the test CGH are shown in Fig. 3 and Table 1. We assessed two color filters; Filter 1 and 2. Filter 1 is the simplified low-cost filter made by a reversal film, while Filter 2 is one of genuine filters used for LCD panels. Here, Filter 1 is real existing but Filter 2 is only catalog data. Figure 4 shows optical or simulated reconstruction using these filters. Measured constants $r_{glass} = 7.1\%$, $r_{Cr} = 60.6\%$ and $r_{CF} = 3.5\%$ are used in the simulation. Figure 4 (a) and (b) are optical and simulated reconstruction using Filter 1, while (c) is only simulation using Filter 2. The simulated reconstruction in (b) is definitely darker than that in (c) and well fit with optical reconstruction in (a). In fact, the CGH using Filter 1 is too dark to exhibit it in ordinary room. This problem is most likely relieved by adopting Filter 2 because of its higher transmission.

5. Conclusion

In this paper, full-color CGHs using a color filter and the simulation technique are proposed for selection of the color filter. The result shows that this technique makes it possible to reconstruct full-color images and the filter used for LCD panel most likely gives better reconstruction.

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Reference

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2) T. Miyaoka, K. Matsushima, S. Nakahara: "Optimization of design-wavelength for unobtrusive chromatic aberration in high-definition color computer holography", SPIE Proc. **9386**, 93860N(2015).
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Table 1 Parameters used for creating the full-color test CGH.

Number of pixels	65,536 × 65,536
Pixel pitches	0.8 μm × 0.8 μm
Design Wavelength	630, 520, 460 nm
RGB stripe width	100 μm
Guard-gap width	50 μm

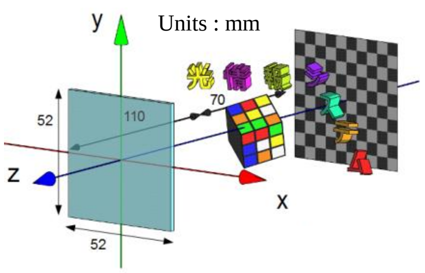
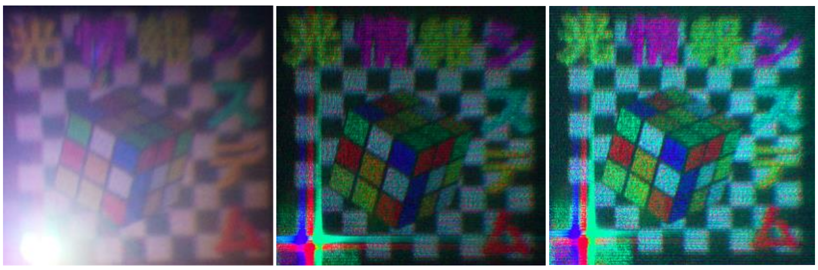


Fig. 3 3D scene of the full-color test CGH.



(a) Filter 1 (b) Filter 1 (c) Filter 2

Fig. 4 (a) Optical and (b) simulated reconstruction using Filter 1. (c) Simulated reconstruction using Filter 2.