Design & Fabrication (ODF'18), Hiroshima, 30S4-02 (2018.11.30, Invited talk).

Very Large-Scale Computer-Generated Hologram for 3D Display

Kyoji Matsushima
Department of Electrical and Electronic Engineering, Kansai University, Japan

Abstract: Computer-generated holograms for 3D imaging have much different properties from that for optical devices. Several techniques are introduced to reconstruct high-quality monochrome and full-color 3D images by using very large-scale computer-generated holograms.

Keywords: 3D image, CGH, Computer holography, full-color image, volume hologram

1. Introduction

A computer-generated hologram (CGH) is the hologram whose fringe pattern is numerically generated by using a computer. The idea was first proposed by A. W. Lohmann [1]. However, the proposed concept was not of three-dimensional (3D) imaging but wavefront conversion. There is a considerable difference between the CGHs for a 3D display and an optical device. The former CGH requires high diffraction efficiency and accuracy but does not need a large space-band product (SBP). In contrast, the latter CGH requires less efficiency and accuracy but needs a large-scale SBP.

To generate large-scale CGHs for 3D display, we have proposed the polygon-based method, where polygonal surface sources of light form an object [2]. This technique makes it possible to create display CGHs, which are composed of billions or sometimes tens of billions of pixels [3-8]. These CGHs could reconstruct only monochrome 3D images before. Recently, however, full-color CGHs have also been created by large-scale fringe patterns. These full-color CGHs utilize either RGB color filters [9-10] or volume holograms [11] for reconstructing color images.

In addition, the large-scale CGHs mentioned so far mainly reconstruct 3D images of a virtual object, whose shape is given by CG models. However, some CGHs reconstruct physical objects [4,10], whose large-scale wave-field is captured by synthetic aperture digital holography [12].

These techniques based on large-scale wave-fields and fringe patterns are summarized in this paper.

2. Difference between CGHs as optical device and 3D display

As is well known, a hologram fringe is generated by interference between an object wave and reference wave. The fringe intensity is given by:

$$I(x,y) = \left|O(x,y) + R(x,y)\right|^2 , \qquad (1)$$

where $O(x, y)$ and $R(x, y)$ are an object field and reference field, respectively.

In creating a CGH used for optical devices, $O(x, y)$ represents the target field after wavefront conversion, such as a beam shape. The fringe pattern, which sometimes modulates the phase of the input field, is directly optimized to gain high efficiency and accuracy.

In contrast, $O(x, y)$ is not unequivocal in CGHs for 3D display. It must be calculated from the numerical model of an object or scene, whose 3D image is reconstructed by the CGH. In addition, in the sampled field of $O(x, y)$, the sampling interval determines the travelling angle of the field, and thus, gives the viewing-zone angle of the 3D image. Hence, we must choose a small sampling interval such as sub-microns. As a result, a gigantic number of sample points is required to achieve a given large size of the 3D image. This is the problem of SBP in computer holography. Since a large-scale SBP leads to a large-scale computational effort, the problem of SBP is, in the other word, the problem of calculation of object fields.

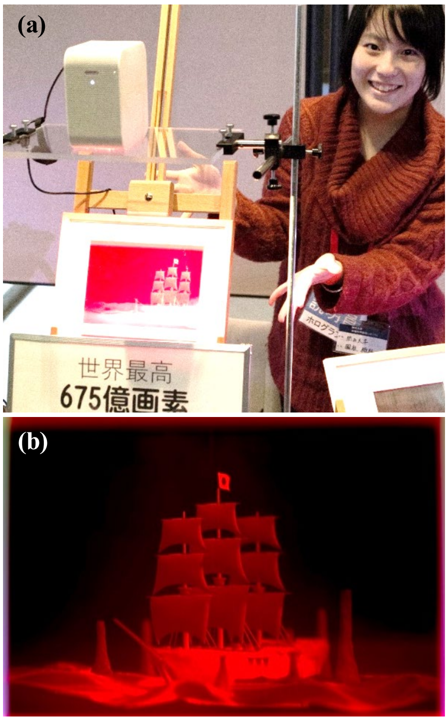

Fig.1. Large-scale monochrome CGH "Sailing Warship-II"
(a) Distant and (b) close-up pictures

Table 1. Parameters of "Sailing Warship-II"

Number of pixels	67.5×10^9 ($225{,}000 \times 300{,}000$)
Pixel pitches [μm]	0.8×0.4
Size [cm]	18×12
Design wavelength [nm]	633
Sampling interval of object field [μm]	0.8×0.8

3. Monochrome CGH

Figure 1 shows a large-scale monochrome CGH composed of 67.4 G pixels. In this CGH, a vertical pixel pitch of 0.4 μm and fringe over-sampling technique are adopted to remove the zeroth order diffraction light and conjugate image from the reconstructed image. A very large-scale CGH over 0.1 trillion pixels has also been developed in the same vein.

4. Full-color CGH

Two methods have been proposed to realize large-scale full-color CGHs.

4.1 Method using RGB color filters

One of techniques to achieve full-color reconstruction of large-scale CGHs is to make use of RGB color filters that are usually used in LCD panels and image sensors [9]. Figure 2 (a) shows the principle. A large-scale fringe pattern is spatially divided into three regions corresponding to RGB colors. The fringe of each region is generated at a wavelength of the color, and RGB color filters are attached to the corresponding fringes. By illuminating the CGH with white light, viewers can see a color 3D image. An example of optical reconstruction is shown in Fig.2 (b).

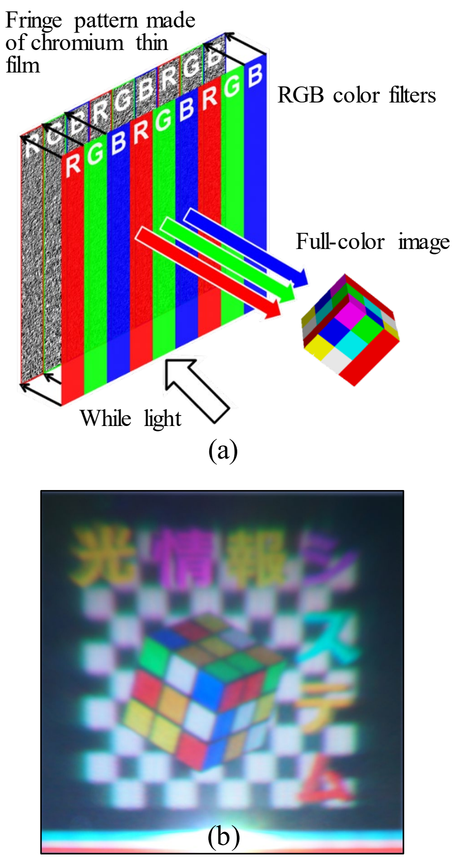

Fig. 2 Full-color CGH using RGB color filters [9].
(a) Principle and (b) optical reconstruction.

4.2 Method using volume hologram

Another technique is to make contact-copies of original monochrome CGHs as a volume hologram [11]. Figure 3 shows the principle. In this technique, three large-scale CGHs generated for RGB colors are transferred to three volume CGHs with the wavelength corresponding to the RGB color, and then, the volume CGHs are stacked to superimpose the RGB images.

5. Conclusions

Diffrences between CGHs as an optical device and 3D display are presented. A CGH for reconstructing 3D images inevitably has a gigantic number of SBP and pixels. Several techniques were introduced to reconstruct monochrome and full-color 3D images.

This work is partially supported by JSPS KAKENHI 18H03349 and the Matching Planner Program from Japan Science and Technology Agency, JST: Grant No. VP29117941340.

6. References

[1] A. W. Lohmann and D. P. Paris: Appl. Opt. 6 (1967) 1739
[2] K. Matsushima: Appl. Opt. **44** (2005) 4607.
[3] K. Matsushima, S. Nakahara: Appl. Opt. **48** (2009) H54
[4] K. Matsushima, Y. Arima, S. Nakahara: Appl. Opt. **50** (2011) H278
[5] H. Nishi, K. Matsushima, S. Nakahara: Appl. Opt. **50** (2011) H245
[6] K. Matsushima, H. Nishi, S. Nakahara: J. Electron. Imaging **21** (2012) 023002
[7] K. Matsushima, M. Nakamura, S. Nakahara: Opt. Express **22** (2014) 24450
[8] H. Nishi, K. Matsushima: Appl. Opt. **56** (2017) F37
[9] Y. Tsuchiyama, K. Matsushima: Opt. Express **25** (2017) 2016
[10] K. Matsushima, N. Sonobe: Appl. Opt. **57** (2017) A150
[11] O. Kunieda, H. Nakao, K. Matsushima: International Symposium on Display Holography 2018 (ISDH2018), Aveiro (Portugal), (2018)
[12] T. Nakatsuji, K. Matsushima: Appl. Opt. **47** (2008) D136

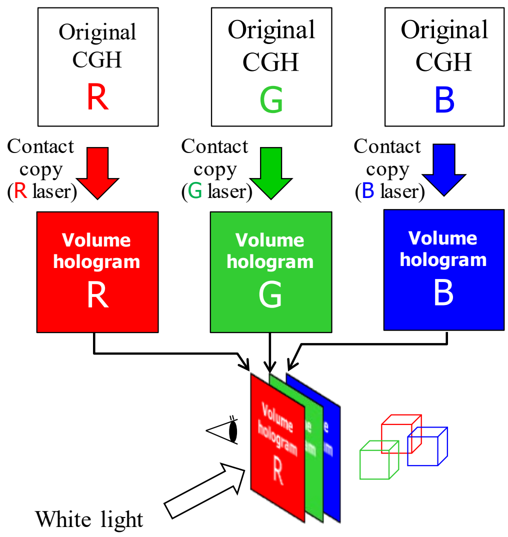

Fig 3. Principle of stacked-volume CGH