Color electroholography by three colored reference lights simultaneously incident upon one hologram panel

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Abstract: A color-reconstruction method for electroholography is proposed in which three colored reference lights, namely, red, green, and blue light-emitting diodes, simultaneously illuminate one hologram plane. Three colored light-emitting diodes are placed at the apexes of a small right-angled triangle. Inasmuch as there is a small gap between consecutive light axes, three colored diffraction lights can be piled up at the place where a three-dimensional image is focused. In our experiment we used a high-resolution liquid-crystal display panel as a spatial light modulator with a pixel pitch of 10 µm and a resolution of 1400×1050. The system clearly reconstructed a colored moving image including a mixture of colors, for example, cyan, yellow, magenta, and white.

OCIS codes: (090.1760) Computer holography; (090.2870) Holographic display.

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1. Introduction

In electroholography [1-3] by computer-generated holograms (CGHs) [4] we need a spatial light modulator (SLM) with high resolution to display the minute fringe pattern of a hologram because holography uses the diffraction of light for its reconstruction. The pixel pitch ideally should be of the same order as visible light, i.e., 1 μm. At present, unfortunately, we have no electronic display device with a pixel pitch of 1 μm. Recently, however, the resolution of reflective-mode display devices, such as reflective liquid-crystal displays (LCDs) and digital micromirror devices (DMDs), has become increasingly higher. A panel with a pixel pitch of less than 10 μm is now available. A relatively good reconstruction of a hologram by use of a reflective LCD or DMD as a SLM has been reported [5, 6]. In Ref. 5, reconstructive electroholography by use of a reflective LCD as a SLM and a light-emitting diode (LED) as a reference light was described. Also, it was suggested that a simple setup with a LCD and three colored LEDs can achieve color electroholography. In this paper we describe our color electroholography method and show some results.

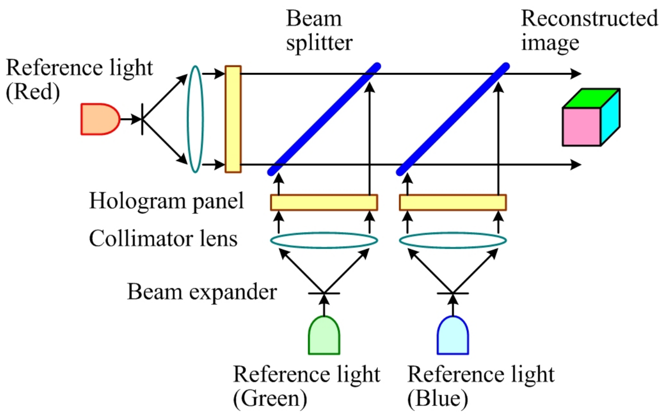

Fig. 1. Color electroholography setup: three hologram panels combined with three colored reference lights.

It was proposed that, like an ordinary two-dimensional color display, three-dimensional color electroholography use three optical setups for three primary-color images [red, green, and blue (RGB)], as shown in Fig. 1 [7]. In this system we use three display panels for a CGH that are illuminated by RGB reference lights. Three colored reconstructions are superposed on the same axis. Note that for simplicity we have illustrated the system by using transparent devices as the hologram panels. Of course, reflective devices can also be used to form the same system.

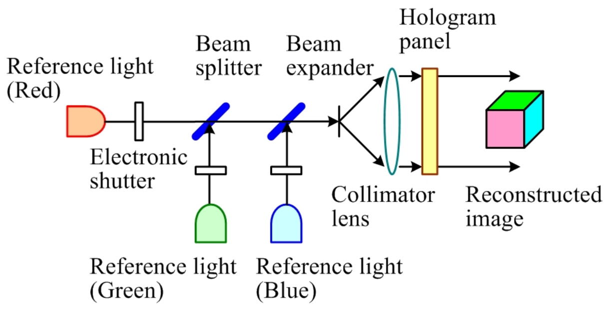

Fig. 2. Color electroholography by time-division multiplexing with one hologram panel.

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Recently, color electroholography by time-division multiplexing was also proposed, [8] because a display device will have a high frame-refresh rate. In that system we use only one display panel, illuminated by R, G, and B reference lights in turn. The displayed CGH and the corresponding colored reference lights are synchronized by an electronic control mechanism such as the electronic shuttering system shown in Fig. 2.

A three-panel system is large and requires a calibration system. A time-division multiplexing system is small but requires a synchronizing system between holograms and reference lights. In this paper we propose a method for color electroholography that is simpler than the previous methods in that it requires one display panel with no need for any additional setup such as an electronic shutter. Three colored (RGB) reference lights illuminate the hologram simultaneously at all times.

In Section 2 we describe the proposed method. In Section 3 we show some experimental results, including mixtures of colors and an animation that we made by using the experimental setup. In Section 4 we briefly discuss our conclusions and describe the next project that we plan to undertake with the proposed method.

2. Color electroholography method without additional devices

Figure 3 is a schematic drawing of the optical setup of our proposed method. As the reference light system, we arrange RGB LEDs covered with pinhole filters as shown at the left in the figure. Because the pixel pitch of a LCD or a DMD is roughly 10 µm, the diffracted angle is narrow at ~3°. At present, therefore, distance d_1 needs to be small to enable piles of RGB diffracted lights that reconstruct a color image to be collected. That is, $d_1 << L_1$ or $d_1 << L_2$, where L_1 is the distance between the pinhole plate and the collimator lens and L_2 is the distance between the hologram panel and the place where the reconstructed image is focused. Note that parameter L_1 is selected to correspond to the focal length of the collimator lens because of generation of plane-wave reference lights.

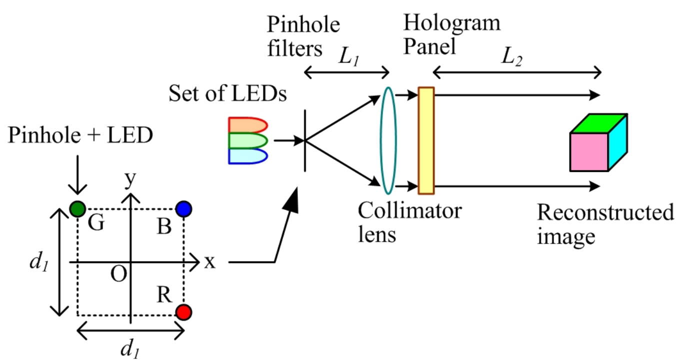

Fig. 3. Color electroholography setup for our proposed method. The reference light system is shown at the left.

Because there are gaps among the positions of the RGB light sources, the incident angles of the collimated lights on the hologram plate are a little different from one another. The angle between R and B (or between G and B) lights is ~ (d_1/L_1). At the place where a reconstructed image is focused, the distance between R and B (or between G and B) direct lights from the hologram panel is $d_2 \sim (L_2 \times d_1/L_1)$, as shown in Fig. 4(a). In Fig. 4 the size of the rectangle that marks direct light from the hologram panel is equal to the size of the hologram panel itself. Note that we draw nothing in the area of direct light from the hologram panel because direct light obscures any image.

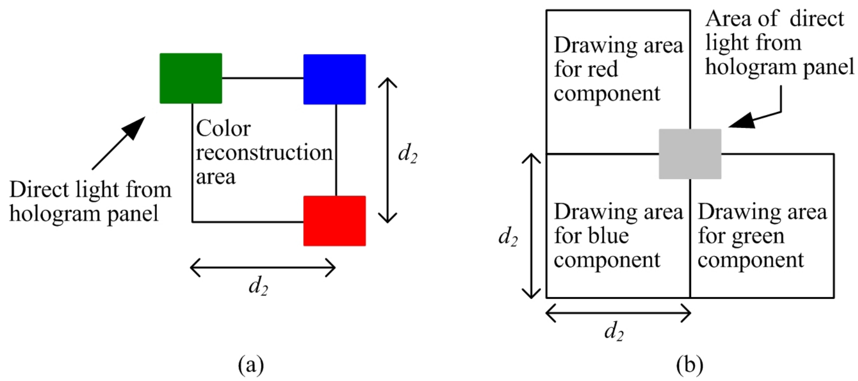

Fig. 4. (a) Color reconstruction of the area where a reconstructed image is focused and (b) areas of a three-dimensional object redrawn according to RGB color components.

We explain our method with the concrete example shown in Fig. 5. Figure 5(a) is a cube consisting of colored surfaces. First we divide the cube into three components that represent the RGB colors and redraw them in the areas as shown in Fig. 4(b); that is, we obtain Fig. 5(b). Next, we make a CGH of Fig. 5(b). If we reconstruct the CGH with one LED as a reference light, of course we will obtain a three-dimensional image like Fig. 5(b). By using the set of LEDs shown in Fig. 3, however, we pile up RGB diffracted lights, and we can obtain the three-dimensional image shown in Fig. 5(c). The color cube is reconstructed in the area surrounded by the RGB direct lights of the hologram panel.

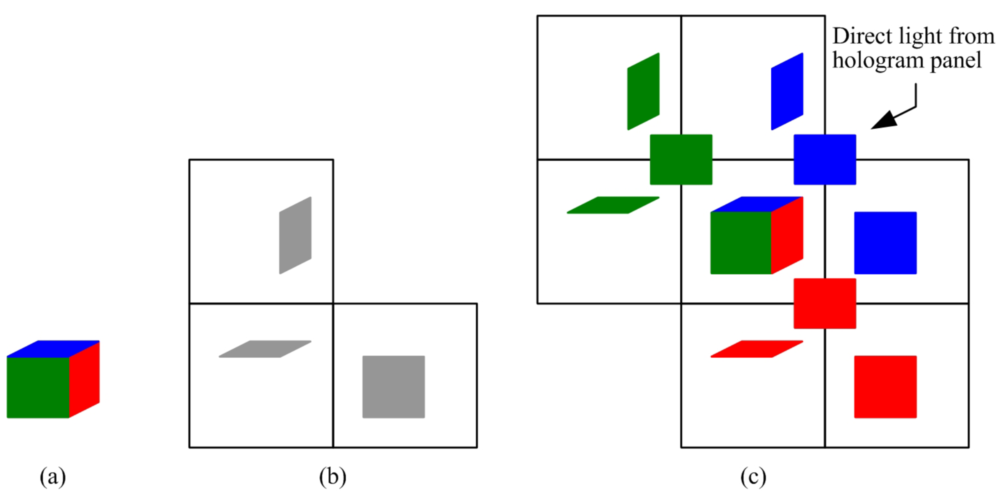

Fig. 5. (a) Cube with three colors, (b) separation of the color components, and (c) reconstruction by RGB reference lights.

3. Experimental results

Figure 6 is the optical setup that we used in experimenting with our proposed method. It consists of the reflective LCD panel as a SLM, RGB LEDs and pinhole filters as a reference light system, a beam splitter, a collimator lens, a field lens, and a personal computer (PC). The LCD panel used here is Model DILA-SX070 by Victor Company of Japan (JVC) [9]; the pixel pitch is 10.4 μm × 10.4 μm and the resolution is 1400 × 1050. The panel size is 14.6

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mm × 10.9 mm. The red LED used here is Model TOL-50aURsCEs by Taiwan Oasis, the green LED is Model NSPG500S by Nichia, and the blue LED is Model NSPB500S by Nichia. These LEDs are of the high-brightness type. Each reference LED light goes through each pinhole filter (diameter, 0.5 mm) and is converted into a plane wave by the collimator lens (focal length, 300 mm). Compared with the setup shown in Fig. 3, this one uses two extra optical parts, namely, a beam splitter for using a reflective-mode LCD and a field lens (or output lens) for observing a real image of holography.

As shown in Fig. 6, we set d_1 = 10 mm, L_1 = 300 mm, and L_2 = 1000 mm. These parameters give us d_2 = 33 mm.

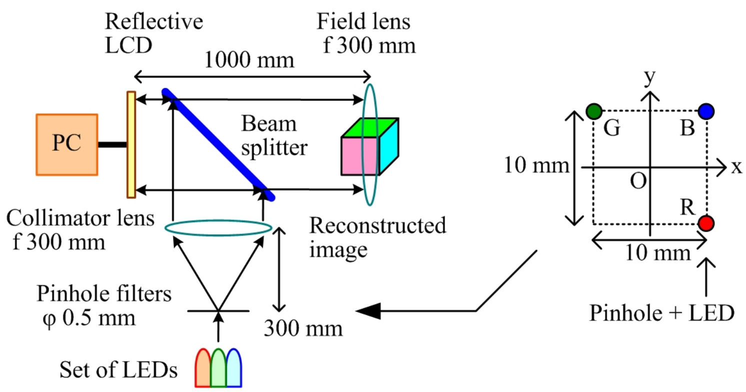

Fig. 6. Experimental setup for the color-reconstruction method presented here.

Figure 7 is a colored die that corresponds to Fig. 5. The lights at three corners are the direct reflections by the LCD panel of the RGB reference lights. Note that the experimental results that we show here, including the animation, are pictures taken with an ordinary digital camera, Model MVC-FD97 by Sony. Of course, we can also directly observe the reconstructed images clearly.

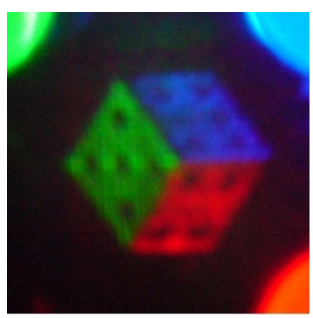

Fig. 7. Colored die.

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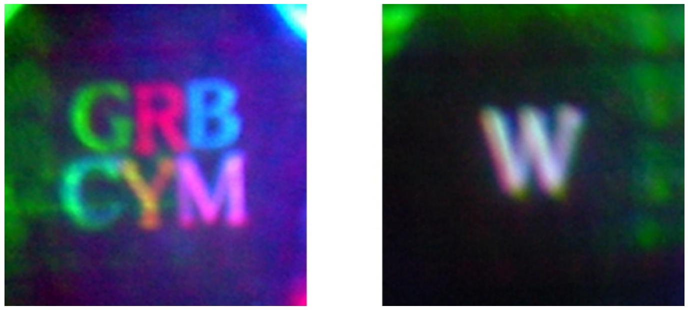

(a) (b)

Fig. 8. Mixed-color characters.

Figure 8 shows mixed-color results. In Fig. 8(a), two-mixed-colored characters cyan (C), yellow (Y), and magenta (M) are reconstructed with primary-colored characters red (R), green (G), and blue (B). In Fig. 8(b) a three-mixed-colored character, white (W), is reconstructed. These results suggest that one can reconstruct a full-color image by changing the ratio of RGB intensities.

Figure 9 is an example of a color-moving image that was made with three-dimensional graphics software: In Fig. 9 a green pot pours blue water into a red cup. A multimedia file corresponding to Fig. 9 was also prepared.

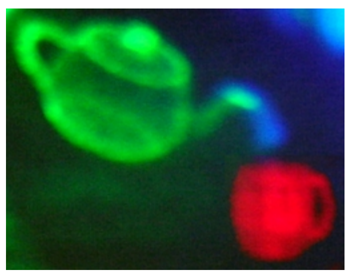

Fig. 9. (656 KB) Color reconstruction from complicated three-dimensional graphics.

4. Conclusions and directions for future research

A method of performing color electroholography has been proposed. The method is simple but has produced good experimental results. As a prototype system for electroholography, we developed a one-unit board upon which a calculation chip for CGH and a LCD panel for displaying a hologram are mounted [10]. The board size is approximately 14 cm $\times$28 cm. The optical setup in our proposed method is small enough that we can mount it on the board. With it we intend to develop a personal color electroholography system as a step toward achieving three-dimensional television by electroholography.

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