Time-division color electroholography using one-chip RGB LED and synchronizing controller

Minoru Oikawa,[1] **Tomoyoshi Shimobaba,**[1,*] **Takuto Yoda,**[1]
Hirotaka Nakayama,[1] **Atushi Shiraki,**[2] **Nobuyuki Masuda,**[1] **and**
Tomoyoshi Ito[1]

[1]*Graduate School of Engineering, Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba
263-8522, Japan*
[2]*Department of Imformation and Computer Engineering, Kisarazu National College of
Technology, Kiyomi-dai Higashi 2-11-1, Kisarazu, Chiba, 292-0041 Japan*

*shimobaba@faculty.chiba-u.jp

Abstract: We propose time-division based color electroholography with a one-chip RGB Light Emitting Diode (LED) and a low-priced synchronizing controller. In electroholography, although color reconstruction methods via time-division have already been proposed, the methods require an LCD with a high refresh rate and output signals from the LCD for synchronizing the RGB reference lights such as laser sources, which consequently increase the development cost. Instead of using such an LCD, the proposed method is capable of using a general LCD panel with a normal refresh rate of 60 Hz. In addition, the LCD panel used in the proposed method does not require the output signals from the LCD. Instead, we generated synchronized signals using an external controller developed by a low-priced one-chip microprocessor, and, use a one-chip RGB LED instead of lasers as the RGB reference lights. The one-chip LED allows us to decrease the development cost and to facilitate optical-axis alignment. Using this method, we observed a multi-color 3D reconstructed movie at a frame rate of 20 Hz.

OCIS codes: (090.1705) Color holography; (090.2870) Holographic display; (090.1760) Computer holography.

References and links

1. K. Maeno, N. Fukaya, O. Nishikawa, K. Sato, and T. Honda, "Electro-holographic display using 15MEGA pixels LCD," Proc. SPIE **2652**, 15–13 (1996).
2. M. Lucente, "Interactive computation of holograms using a look-up table," J. Electron. Imaging **2**, 28–34 (1993).
3. T. C. Poon (ed.), *Digital Holography and Three-Dimensional Display* (Springer, 2006).
4. K. Sato, "Animated color 3D image using kinoforms by liquid crystal devices," J. Inst. Telev. Eng. Jpn. **48**, 1261–1266 (1994).
5. F. Yaras, H. Kang, and L. Onural, "Real-time phase-only color holographic video display system using LED illumination," Appl. Opt. **48**, H48–H53 (2009).
6. F. Yaras and L. Onural, "Color holographic reconstruction using multiple SLMs and LED illumination," Proc. SPIE **7237**, 72370O (2009).
7. H. Yoshikawa, T. Yamaguchi, and R. Kitayama, "Real-time generation of full color image hologram with compact distance look-up table," OSA Topical Meeting on Digital Holography and Three-Dimensional Imaging 2009, DWC4 (2009).

8. H. Nakayama, N. Takada, Y. Ichihashi, S. Awazu, T. Shimobaba, N. Masuda, and T. Ito, "Real-time color electro-holography using multiple graphics processing units and multiple high-definition liquid-crystal display panels," Appl. Opt. **49**, 5993–5996 (2010).
9. K. Takano and K. Sato, "Color electro-holographic display using a single white light source and a focal adjustment method," Opt. Eng. **41**, 2427–2433 (2002).
10. T. Ito, T. Shimobaba, H. Godo, and M. Horiuchi, "Holographic reconstruction with a 10-μ m pixel-pitch reflective liquid-crystal display by use of a light-emitting diode reference light," Opt. Lett. **27**, 1406–1408 (2002).
11. T. Ito and K. Okano, "Color electroholography by three colored reference lights simultaneously incident upon one hologram panel," Opt. Express **12**, 4320–4325 (2004) .
12. M. Makowski, M. Sypek, and A. Kolodziejczyk, "Colorful reconstructions from a thin multi-plane phase hologram," Opt. Express **16**, 11618–11623 (2008).
13. M. Makowski, M. Sypek, I. Ducin, A. Fajst, A. Siemion, J. Suszek, and A. Kolodziejczyk, "Experimental evaluation of a full-color compact lensless holographic display," Opt. Express **17**, 20840–20846 (2009).
14. T. Shimobaba and T. Ito, "A color holographic reconstruction system by time division multiplexing method with reference lights of laser," Opt. Rev. **10**, 339–341 (2003).
15. T. Shimobaba, A. Shiraki, N. Masuda, and T. Ito, "An electroholographic colour reconstruction by time division switching of reference lights," J. Opt. A, Pure Appl. Opt. **9**, 757–760 (2007).
16. T. Shimobaba, A. Shiraki, Y. Ichihashi, N. Masuda, and T. Ito, "Interactive color electroholography using the FPGA technology and time division switching method," IEICE Electron. Express **5**, 271–277 (2008).
17. R. Haussler, S. Reichelt, N. Leister, E. Zschau, R. Missbach, and A. Schwerdtner, "Large real-time holographic displays: from prototypes to a consumer product," Proc. SPIE **7237**, 72370S (2009).
18. 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).
19. H. Kang, T. Yamaguchi, and H. Yoshikawa, "Accurate phase-added stereogram to improve the coherent stereogram," Appl. Opt. **47**, D44–D54 (2008).

1. Introduction

In recent years, three dimensional (3D) displays have been studied using computer-generated holograms (CGH), since the information of 3D objects can be recorded on a CGH and reconstructed from the same [1, 2]. Such 3D displays are referred to as electroholography and although expected to become the standard, they are difficult to develop because the CGH technique requires a spatial light modulator (SLM), which can display the high-resolution interference fringe of a CGH. The interval of the latter is almost equivalent to a light wavelength because the CGH technique utilizes the phenomena of diffraction and interference of a light wave. In current electroholography, a liquid crystal display (LCD) often functions as an SLM.

In the field of electroholography, color reconstruction has been studied. Here, the system used three LCD panels (amplitude or phase-modulated type) to display CGHs, upon which the red, green and blue components of a 3D object were recorded [4–8]. The system can reconstruct a color 3D object by compounding the diffracted light from each LCD. Other researchers have also proposed a system with a white light source [9] for which three LCD panels are required.

Color reconstruction methods using a single SLM have also been proposed, for example, via the space-division [10, 11] and depth-division [12, 13] methods. Another approach is time-division, which temporally switches RGB reference lights by synchronizing signals [14–17]. The first attempt at time-division color reconstruction was developed by using a high refresh rate LCD (CMD8X6D made by Colorado Microdisplay Inc.) with a refresh rate of 360 Hz and electric shutters for switching reference lights from lasers [14]. The LCD directly outputs three synchronized signals, indicating that one of the red, green and blue CGHs is currently displayed on the LCD panel. The synchronized signals are connected to each of the electric shutters via the buffer circuit. We developed a second system of time-division color reconstruction by using LCD and RGB Light Emitting Diodes (LEDs), instead of lasers and electric shutters [15]. In ref. [16], we report an interactive color electroholography with a time-division method and a special-purpose computational chip for CGH. These systems could reconstruct a color object, but require a high refresh LCD.

In this paper, we propose time-division based color electroholography with a one-chip RGB

LED and low-priced synchronizing controller. Instead of using a high refresh-rate LCD, the proposed method is capable of using a general LCD panel with a normal refresh rate of 60 Hz. In addition, the LCD panel used in the proposed method does not require the outputs of synchronized signals from the LCD. In the proposed method, we generated synchronized signals by an external controller developed by a low-priced one-chip microprocessor. And, we used a one-chip RGB LED instead of lasers as the RGB reference lights. Using this method, we observed a multi-color 3D reconstructed movie at a frame rate of 20 Hz.

In Section 2, we describe the proposed method in detail. In Section 3, we show the results of an optical experiment. In Section 4, we conclude this work.

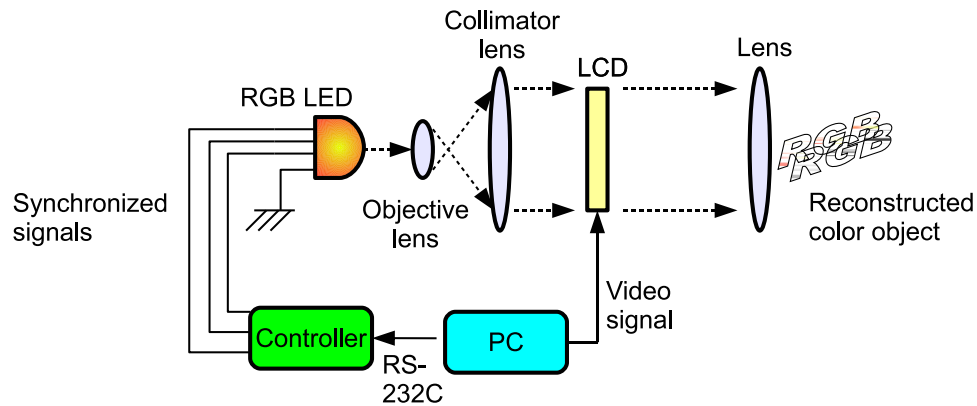## 2. Time-division electroholography using a RGB LED and synchronizing controller

Fig. 1. Outline of the time division color electroholography using an one-chip RGB LED and synchronizing controller.
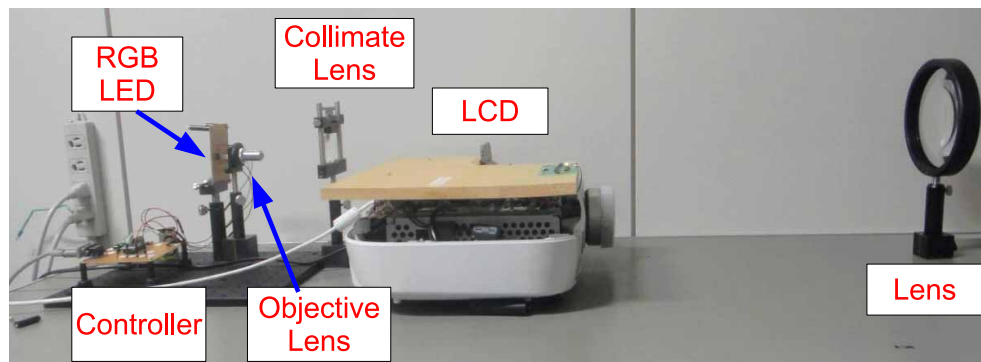

Fig. 2. Photograph of the time division color electroholography using an one-chip RGB LED and synchronizing controller.

Our approach has originality in terms of the following points as compared with previous works [14–17]:

1. The proposed method can reconstruct a color 3D object, using any display device with 60 Hz or over.

2. The synchronizing circuit is realized at low-cost, using a one-chip microprocessor.

3. The one-chip RGB LED allows us to decrease the development cost and to facilitate optical-axis alignment.

Figures 1 and 2 show an outline and photograph of the system for time-division based color reconstruction. The host computer (PC) prepares a color 3D object and divides it into red, green and blue components, and then, the host computer computes three CGHs corresponding to the wavelength of the components using the following equation [2, 3]:

$$I(x_\alpha, y_\alpha) = \sum_j^N A_j \cos\left(\frac{2\pi}{\lambda_t}\left(\frac{(x_\alpha - x_j)^2 + (y_\alpha - y_j)^2}{2z_j}\right)\right), \qquad (1)$$

where the subscripts α and j mean a CGH and a 3D object, N and A_j are the total number of object points and the intensities of the object points, respectively. (x_α, y_α) and (x_j, y_j, z_j) are the coordinates on the CGH and the 3D objects, respectively. λ_t is the wavelength of the reference lights. Although the wavelength is generally constant in monochrome reconstruction, in the time-division based color reconstruction λ_t becomes variable for a time due to the need to switch the RGB reference lights at certain intervals. The proposed color reconstruction is also capable of reconstructing from a CGH created by other CGH calculations, for example, polygon-based CGH calculation, accurate phase-added stereogram method and so on [18, 19].

The LCD diverted from an Epson EMP-TW1000 projector has a resolution of $1,920 \times 1,080$ pixels, a pixel pitch of $8.5\mu m$ and a maximum refresh rate of 60 Hz. The LCD is an amplitude-modulated type LCD. Therefore, the PC displays corresponding CGHs in sequence from red, green and blue on the LCD at a refresh rate of 60 Hz. The one-chip RGB LED is OSTA5131A made by OptoSupply. The one-chip RGB LED allows us to decrease the development cost and to facilitate optical-axis alignment. We set up a field lens positioned behind the LCD to observe a real image of holography, whose diameter and focal length were 100 mm and 300 mm, respectively, at the reconstruction location and observed a reconstruction image at 300 mm from the field lens [10, 11]. The size of the reconstructed image is about 30 mm × 30 mm.

Unlike a high refresh rate LCD, the LCD is a normal LCD panel and hence does not output three synchronized signals indicating that one of the red, green and blue CGHs is currently displayed on the LCD panel. Such synchronized signals must thus be generated. The controller in Fig. 1 generates these synchronized signals. The controller is developed by a low-priced one-chip microprocessor, which is the Peripheral Interface Controller (PIC) of PIC16F88 made by Microchip. The total cost of the controller, including the remaining circuit, was less than 10 US dollars. The PC-PIC communication link is RS-232C.

Figure 3 shows the timing chart of the time-division color reconstruction. The PC sends the switching signal when displaying a new CGH on the LCD. The upper chart shows the switching signal from the PC to the PIC. Note that the current system has a delay of 37 ms until a new CGH is displayed on on the LCD (the middle chart of Fig. 3).

When the PIC receives the switching signal from the PC via RS-232C, the PIC starts generating the synchronized signals for the RGB LED. To synchronize the display timing with a switch-on time of the LED, the synchronized signals must be delayed 37 ms after receiving the switching signal (the bottom chart of Fig. 3). This delay can be easily controlled by the PIC. The synchronized signals outputted from the ports on the PIC are connected to the LED directly. In the bottom chart, to avoid mixing up one color with the others, the switch-off time of each color is prepared within 2 ms. A 3D color movie can be reconstructed at a frame rate of 20 Hz.
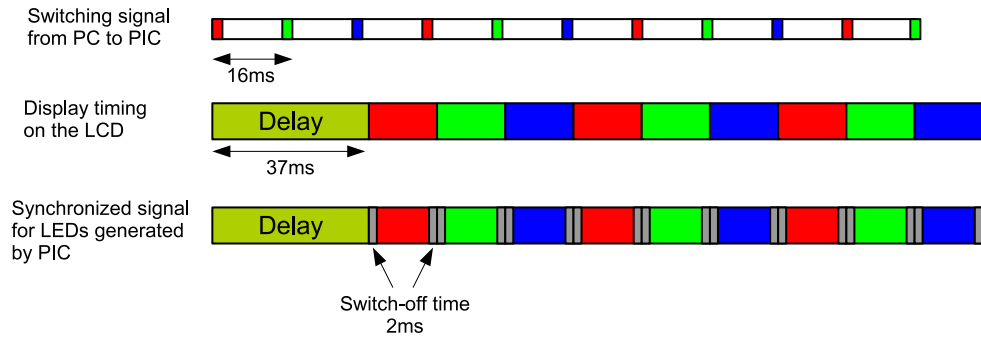
Fig. 3. Timing chart of the time-division color reconstruction. The upper figure is the switching signal from PC to PIC. The middle chart is the display timing of CGH on the LCD. The bottom chart is the synchronized signal for the LED generated by the PIC.
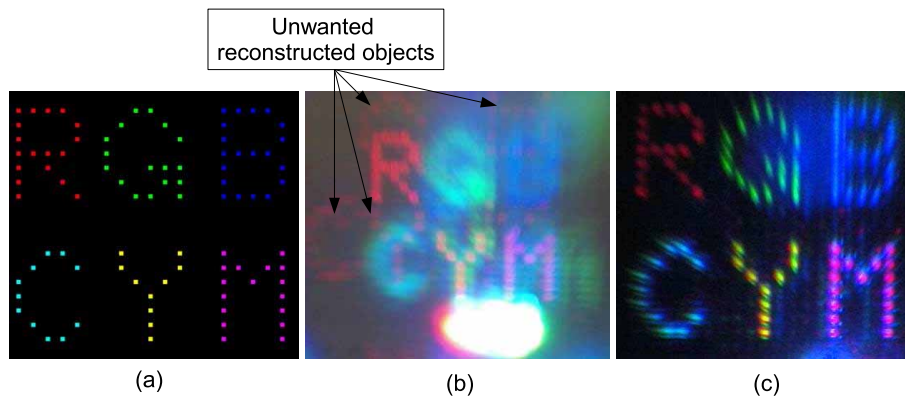

Fig. 4. Optical color reconstruction using the proposed method. (a) and (b) are an original color object and the color reconstruction without the collimator (the collimator and objective lenses) and the switch-off time, respectively. (c) is introduced the collimator and the switch-off time to improve blurring and remove unwanted reconstructed objects.

3. Results

Figure 4 shows color reconstruction by the time-division method. Figures 4(a) and 4(b) are an original color object and the color reconstruction without the collimator (the collimate lens and objective lens) and the switch-off time, respectively. As we can see from the figure, the color reconstruction includes unwanted reconstructed objects around the desired reconstructed object because of there being no switch-off time. In addition, the color reconstruction is blurred because of there being no collimator. Figure 4(c) introduces the collimator and the switch-off time to improve the blur and remove unwanted reconstructed objects. The color reconstruction improves the image quality as compared with Fig. 4(b).

Figure 5(a) is an original multi-color 3D movie (Media 1), and Figs. 5(b) to 5(e) are a snapshot of the color reconstructed movie, respectively. This is an animation scene whereby the color phase of the character "Color" is changing and the color circle is rotating. The strong light spots at the bottoms of Figs. 5(b)–5(e) are direct light from the one-chip RGB LED.
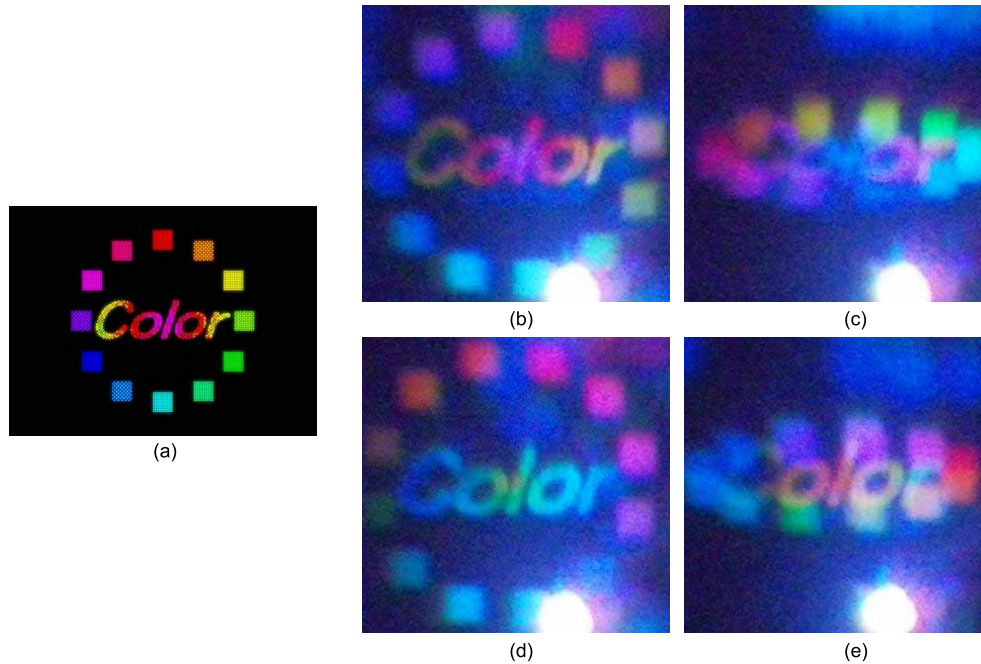
Fig. 5. (a) is an original multi-color 3D movie, and (b) to (e) are the snapshot of the color reconstructed movie, respectively. This is an animation scene whereby the color phase of the character "Color" is changing and the color circle is rotating (Media 1).

4. Conclusion

In this paper, a time-division form of color electroholography is proposed with a low-priced microprocessor, a one-chip RGB LED and a normal LCD with a refresh rate of 60 Hz. The proposed method reduces the development cost using a low-priced microprocessor and RS-232C instead of a high refresh rate LCD.The method could also be reconstructed with mixed colors. Although we used an amplitude-modulated type LCD, the proposed method will use a phase-modulated type LCD [5,6].

Acknowledgments