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## **Color holographic display method based on a single-spatial light modulator**

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# Color holographic display method based on a single-spatial light modulator

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**Abstract.** A color holographic display method is proposed. It uses a spatial light modulator with a synthetic computer-generated hologram, which includes red, green, and blue three monochromatic scenes' information. We calculate three holograms corresponding to red, green, and blue, and then generate a color hologram according to the law of sampling. A filter owning the pixel structure is designed so that white light emitting diode can be used as reconstructed light. We numerically evaluate the image quality of color-reconstructed images and compare the quality of color-reconstructed images with that of reconstructed color images using another color holographic projection method. The experimental results verify the feasibility of the method. © The Authors. Published by SPIE under a Creative Commons Attribution 3.0 Unported License. Distribution or reproduction of this work in whole or in part requires full attribution of the original publication, including its DOI. [DOI: [10.1117/1.OE.53.4.045104](https://doi.org/10.1117/1.OE.53.4.045104)]

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## 1 Introduction

Holographic display is an ideal three-dimensional display technology,<sup>1-4</sup> and it records and reproduces all light field information, which includes the amplitude and phase in the form of a fringe pattern generated by interfering<sup>5,6</sup> with a reference beam. There are two methods to achieve color holographic display:<sup>7-9</sup> one is using three spatial light modulators (SLMs)<sup>10,11</sup> to reconstruct the image. For example, Japanese scholars<sup>12</sup> use three liquid crystal display (LCD) panels to display holograms, upon which they record the red, green, and blue components of a color image. The reconstructed image could be seen by compounding the diffracted lights from each LCD. However, this method has three color holography space synthetic registrations, and the system is large and complicated. The other is to use one SLM such as a phase-modulated LCD. Time-division method uses red, green, and blue lights to illuminate SLM in turns.<sup>13</sup> It records three color components holograms of the image individually, the SLM displays one of the holograms in sequence and outputs synchronized signals. Three reference lights are switched by the synchronized signals and color-reconstructed image could be seen due to the afterimage effect on human eyes. However, the use of synchronous control circuit increases the complexity of the system. In addition, spatial-division method is also used to reconstruct a color image by one hologram.<sup>14</sup> In this method, a color image is divided into RGB components, and each component is distributed on one third of the hologram. The method also needs three filters to adjust the direction of three laser beams, which can ensure the lasers illuminates one third of the SLM, respectively.

In order to realize full-color holographic display by using a simple optic system, we propose a method to achieve full-color display based on one SLM in this article. Using this method, we generate a synthetic computer-generated

hologram according to the law of sampling. Furthermore, a filter with the pixel structure is designed so that white light emitting diode (LED) can be used as the reconstructed light, which makes holographic display more practical.

## 2 Method

The hologram design procedure begins with a separation of a color input bitmap into three primary color components, as shown in Fig. 1. The wavelength of recording light is  $\lambda_r = 632.8$  nm,  $\lambda_g = 532$  nm,  $\lambda_b = 488$  nm, respectively, and the sampling interval of the object on the hologram in the horizontal and vertical direction are  $\Delta x$ ,  $\Delta y$ . According to the law of sampling,  $\Delta x$ ,  $\Delta y$  satisfy the following formulas:

$$\Delta x \leq \frac{1}{4B_x}, \quad (1)$$

$$\Delta y \leq \frac{1}{2B_y}, \quad (2)$$

where  $2B_x$  and  $2B_y$  are the frequency bandwidth of the object light. Owing to the wavelength-dependence of the size of reconstructed images, the green and red input bitmaps are adequately prescaled by factors of  $532$  nm/ $488$  nm =  $1.09$  and  $632.8$  nm/ $488$  nm =  $1.27$ , respectively. Hence, the three reconstructed images are matched in size. The hologram of each color component is then calculated separately using an iterative Fourier transform algorithm (IFTA) in 60 iterations. The information is stored in the corresponding matrix— $r(m, n)$ ,  $g(m, n)$ , and  $b(m, n)$ .

The block of IFTA is shown in Fig. 2. First, we initialize the amplitude and phase of the object wave field, and set the frequency domain amplitude  $B$ . The amplitude  $a$  and random phase  $\varphi$  constitute an original complex amplitude function  $f$ . Then, the complex amplitude function  $f$  is Fourier transformed into the frequency domain, yielding the complex amplitude function  $F$ . At last, the error values  $e$  is calculated. If  $e$  is less than the threshold  $\varepsilon$ ,  $\varphi$  is the

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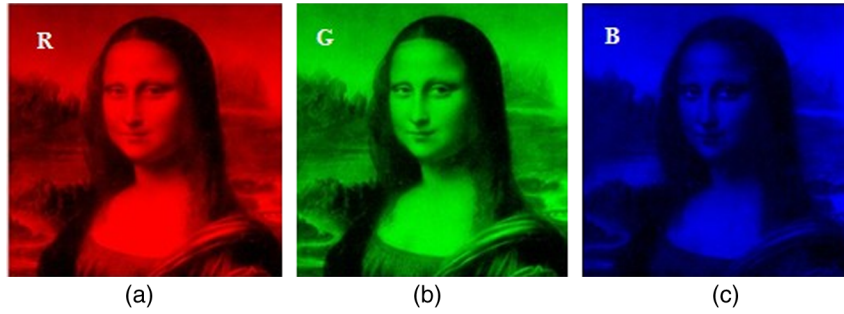


Fig. 1 Color separation. (a) Red scene. (b) Green scene. (c) Blue scene.

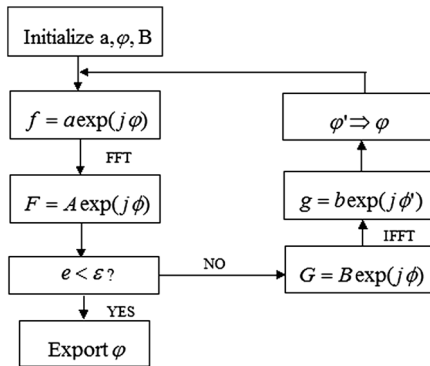


Fig. 2 Iterative Fourier transform algorithm (IFTA).

desired phase, or continue the calculations. Here, the error value  $e$  is defined by

$$e = \sqrt{\frac{\sum_{x,y} (|A| - |B|)^2}{M \times N}}, \quad (3)$$

where  $M \times N$  is the pixel resolution of the target image. Then, remaining the previous phase  $\phi$  unchanged we can construct a new complex amplitude function  $G$  with the given amplitude  $|B|$ . A new phase  $\phi'$  on the hologram can be obtained by the inverse Fourier transformation of  $G$ . At last we use the new function which is constituted by the phase  $\phi'$  and the amplitude  $A$  to repeat the above operations until the error value meets the set value.

Then we make a synthetic hologram to record three monochromatic scenes' information. The information is stored in the matrix— $c(m, n)$ . The part structure of the synthetic hologram is shown in Fig. 3. Here,  $r$ ,  $g$ , and  $b$  represent the sampling units of the red, green, and blue components scene on the hologram, respectively.

In order to guarantee that the synthetic hologram includes the information of red, green, and blue scene, each sampled color component hologram records the object's information at the specific location. So, the information  $c(m, n)$  of synthetic hologram needs to satisfy the following relationships:

$$c(m, 3k - 2) = r(m, 3k - 2), \quad (4)$$

$$c(m, 3k - 1) = g(m, 3k - 1), \quad (5)$$

$$c(m, 3k) = b(m, 3k), \quad (6)$$

where  $k$  and  $m$  are positive integers.

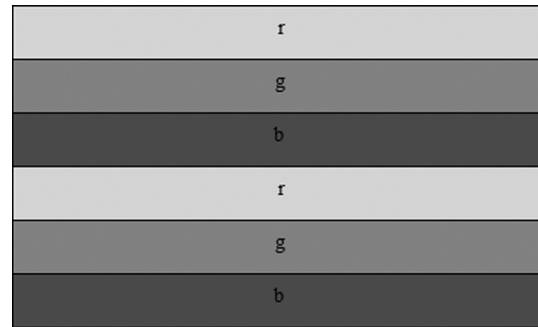


Fig. 3 Structure of the synthetic computer-generated hologram.

The horizontal and vertical sampling intervals of the synthetic hologram are  $\Delta x$  and, respectively. In order to make sure the information is not lost on the synthetic hologram, the sampling interval needs to satisfy the law of sampling. According to Eqs. (1)–(2), we can get the following equations:

$$\Delta x \leq \frac{1}{4B_x}, \quad (7)$$

$$\Delta y \leq \frac{1}{6B_y}. \quad (8)$$

Each sampling line on the synthetic hologram records one particular color information, and every adjacent three lines of the hologram record information of different color component, respectively, which can avoid crosstalk caused by different hologram superposition. This method can achieve uniform light intensity and stereo watching continuity of tricolor-reconstructed images.

Plane light is used as the reference light and reconstructed light. In order to get the color reconstruct image, we need to keep the wavelengths of the reference light and the reconstructed light same. Here, we designed a filter with pixel structure so that white LED can be used as reconstructed light. Figure 4 illustrates the part structure of the filter, where  $r$ ,  $g$  and  $b$  represent the red, green, and blue filter part, respectively. The filter has the unit structure of micrometers, and it can be produced by lithography process. The filter is placed between the reconstructed light and the hologram. The pixel interval is equal to the sampling interval on the hologram.

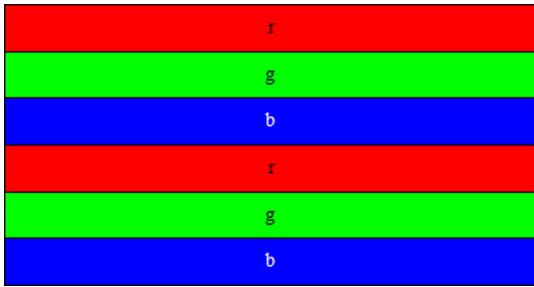


Fig. 4 Structure of the filter.

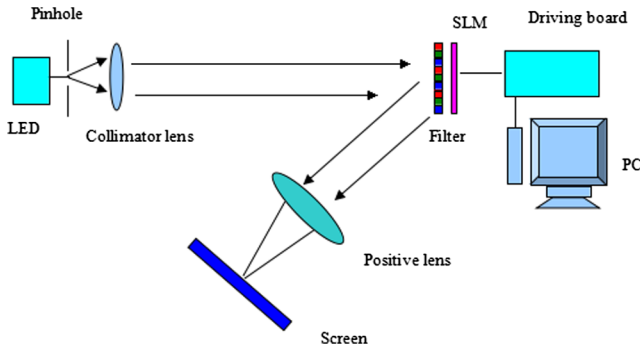


Fig. 5 Setup of the experiment.

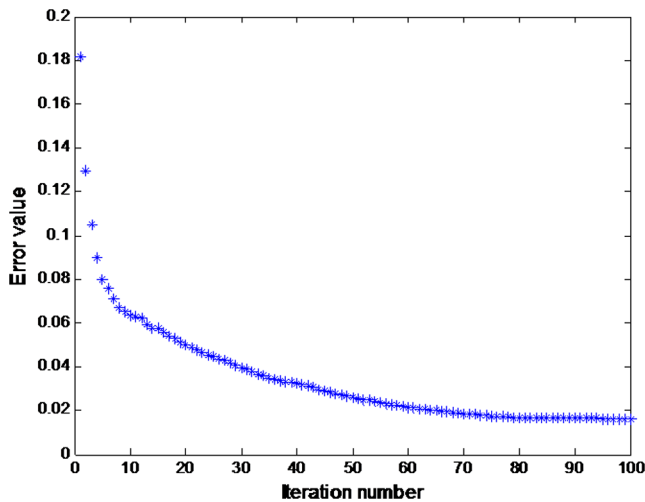


Fig. 6 Error curve of IFTA algorithm.

### 3 Result and Analysis

Figure 5 is the schematic layout using the proposed method. The optical system for the holographic display comprises a LED light source, a pinhole, a collimator lens, a filter, a positive lens, a driving board, a PC, a display screen, and a SLM. The computer sends holograms instead of typical images to the SLM via SLM driver circuit for generating the desired redistributing light in a predefined manner.

We process color separation of the color scene for red, green, and blue components using computer graphics. The pixel resolution of the picture is  $512 \times 512$ , then three holograms which separately record the information of red, green, and blue components of the color scene are developed by IFTA, and the information is stored in the corresponding matrix— $r(m, n)$ ,  $g(m, n)$ , and  $b(m, n)$ . In the iterative process, we set the frequency domain amplitude  $A = 1$ , take the iterations 100 times. With the increase of the iteration number, the absolute error decreases, and we can see the error curve in Fig. 6. The horizontal axis represents the iteration number, and the vertical axis represents the error value  $e$ . When the iteration number is greater than 60, the error value remains to be constant. Then, the synthetic hologram is generated according to Eqs. (4)–(6), where the information is stored in the matrix— $c(m, n)$ .

White LED light can improve its spatial coherence through a pinhole. Load the synthetic hologram on the SLM. We choose three original objects, as shown in Fig. 7. The reconstructed images by our method are shown in Fig. 8(a). At the same time we contrast another way—spatial division method. We scale the object to one third of the original, then three color holograms are generated and each color scene occupies one third area of the SLM. A full-color flat image can be formed because of color mixing. We get the reconstruction image by computer simulation as shown in Fig. 8(b). Figure 9 shows the peak signal-to-noise ratio (PSNR) between the original objects (Fig. 7) and reconstructed images by our method and spatial division method. The green and red charts are the PSNR values of reconstructed images using our method and spatial division method, respectively. From the picture, we can see that the PSNR values by our method are higher. Using one third of the information, the quality of the reconstruction image is decreased, while the propose method satisfies the law of sampling, which ensures the information on the hologram, and the result shows that the proposed method has certain advantages.

Besides, compared with the method of pixel by pixel, the proposed method does not need to treat each pixel as

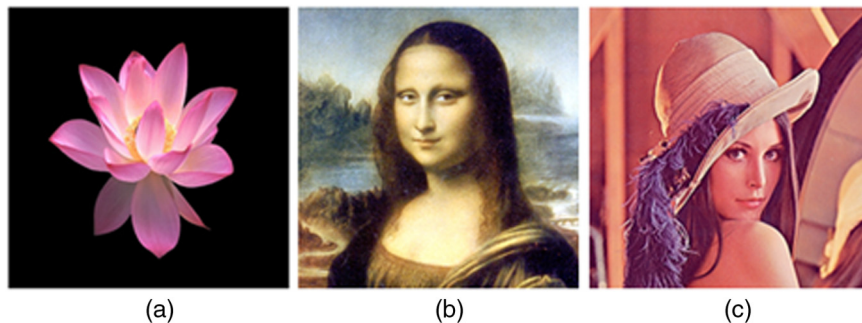
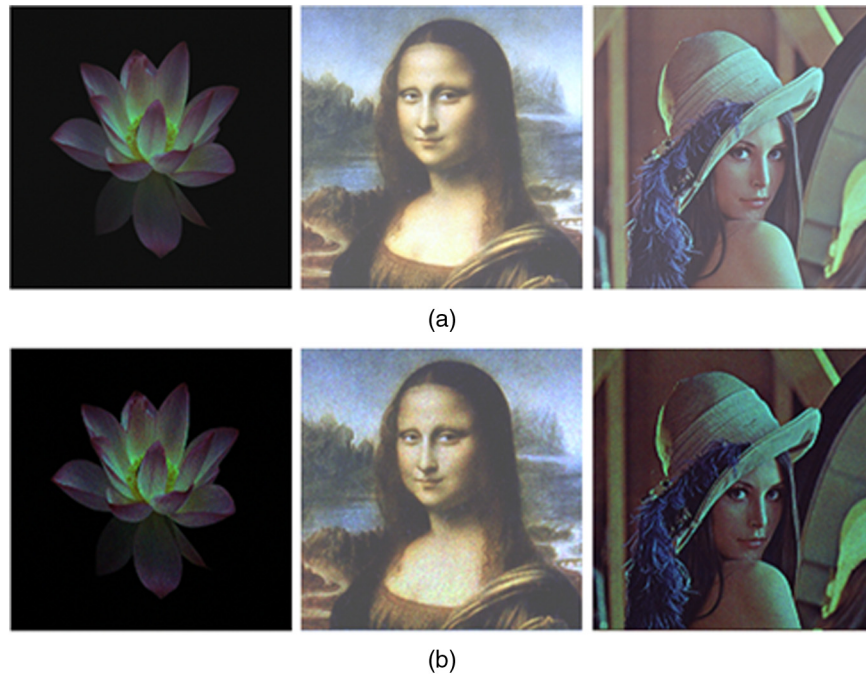
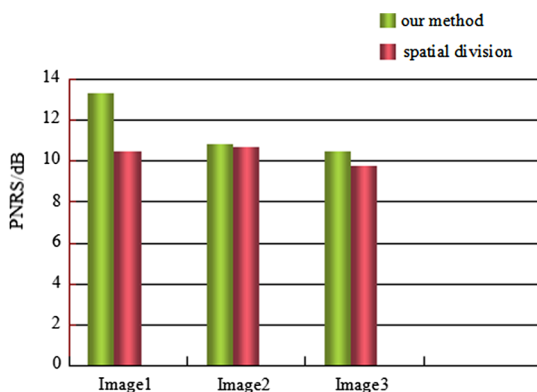


Fig. 7 Original object. (a) Object 1. (b) Object 2. (c) Object 3.



**Fig. 8** Reconstructed images by the (a) proposed method and (b) spatial division.



**Fig. 9** Peak signal-to-noise ratio (PSNR) values of the reconstructed images.

a sampling unit, which makes the process simpler. Unlike the method of time sequential color effect, which uses the synchronize control circuit to switch the hologram and the three reference lights in turns, our method designs a filter to realize the LED illumination. In short, the proposed method has certain advantages and potential applications.

#### 4 Conclusions

We propose a color holographic display method, which could record color information on one hologram. Compared with other methods, it only uses one SLM without synchronous control circuit, which can reduce the cost of the system. A filter owning pixel structure is designed so that laser illumination is replaced by LED illumination to assume safety for naked eye observation. In short, the proposed method makes the color holographic display simple and flexible, which makes it possible to realize the holographic TV.

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