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이진 위상 홀로그램을 이용한 천연색 영상의 구현

Full-color image generation by use of binary phase holograms

서 호형
한국전자통신연구원, 원천기술연구본부
hhsuh@ard.etri.re.kr

A binary phase hologram (BPH) is a computer generated hologram that is designed to get two-dimensional spot array of uniform or arbitrary intensity light as Fourier-Fraunhofer diffraction patterns$^{(1,2)}$. By illuminating the hologram with a collimated laser beam and using a Fourier transform lens located right after the hologram, the output image is obtained at the focal plane of the lens. Recently, the BPH has been researched in the fields of free space optical interconnections and optical parallel processing using opto-electronic devices$^{(3,4)}$. In this paper, we report the novel scheme of producing full-color image using binary phase holograms and three lasers of red, green, and blue. And the experimental results are also presented.

When a BPH is illuminated by a laser beam, the distance S between spots which constitute output image on the focal plane is given by

$$S = \frac{\lambda f}{P} \tag{1}$$

where, λ is the wavelength of the light, f is the focal length of the lens, and P is the period of the hologram. When we use laser beams of more than two colors or broadband source, we cannot get a clear image because of the color blurring. To solve this problem, we divide the hologram into three parts and design them with different periods, and let the laser beams of different color pass through the specific parts of the hologram.

The method of obtaining the color image using BHP is as follows. It comprises the steps of separating three color images having red, greed, and blue wavelengths of $\lambda(R)$, $\lambda(G)$, and $\lambda(B)$ from the objective color image; forming three holograms R, G, and B each having period of $P(R)$, $P(G)$, and $P(B)$; fabricating the three phase holograms adjacently on one plane with arbitrary gap; and reproducing the color image by the three lasers of R, G, and B.

In design three holograms R, G, and B, the periods $P(R)$, $P(G)$, and $P(B)$ of the three holograms should have different values to have the same spot spacing for three lasers of $\lambda(R)$, $\lambda(G)$, and $\lambda(B)$. That is, the periods should be proportional to the wavelengths as shown in the following equation.

$$S = \frac{\lambda(R) f}{P(R)} = \frac{\lambda(G) f}{P(G)} = \frac{\lambda(B) f}{P(B)} \tag{2}$$

Because the R, G, and B holograms are separated spatially, the specific laser beams can pass through the corresponding holograms independently.

Although three holograms are placed separately on a plane, the output images diffracted from each hologram construct the wanted color image without shifting laterally at the focal plane. This phenomenon is due to the shift-invariant property if Fourier transform.$^{(5)}$

Optically, the Fraunhofer diffraction has a property similar to Fourier transform and we can construct the optical Fourier-Fraunhofer diffraction pattern of an input pattern at the focal plane of a convex lens. According to the scalar diffraction theory, the intensity distribution for the transmission function of a hologram $g(x,y)$ is expressed as following:

$$I(\alpha,\beta) = \left(\frac{1}{\lambda f}\right)^2 \left| \iint g(x,y) \exp\left[-i\frac{2\pi}{\lambda f}(\alpha x + \beta y)\right] dxdy \right|^2 = \left(\frac{1}{\lambda f}\right)^2 \left| G\left(\frac{\alpha}{\lambda f}, \frac{\beta}{\lambda f}\right)\right|^2 \tag{3}$$

where, $G(\alpha,\beta)$ is the Fourier transform of $g(x,y)$.

When designing the BPH, all information in one period of each hologram is stored as phase values in $N \times N$ cells, and each cell has one of two fixed phases (0 or π). To get the desired output image using the hologram, we need to find an optimum configuration of the binary phases for all cells. This renders to the combinatorial optimization problem and it can be solved by an iterative algorithm$^{(4)}$. It starts from randomly chosen values of binary phase (0 or π) in the optimization. During a series of iterations, choose a cell and reverse its phase from 0 to π (or from π to 0), and this new phase is retained based on the its contribution to the cost function. The cost function is defined to have information such as diffraction efficiency and uniformity error. The optimization process continues in a way to reduce the cost function until both the diffraction efficiency and the uniformity error reach certain limits.

When the size of each phase cell is same, the period of the hologram is proportional to the number of cell N. And the number of cell should be proportional to the wavelengths. For example, the available wavelengths of commercialized lasers are $\lambda(R)$=632.8nm, $\lambda(G)$=543.5nm, and $\lambda(B)$=488nm.

We can obtain any integer ratio $N(R):N(G):N(B)$, which is the nearest values to the ratio $\lambda(R):\lambda(G):\lambda(B)$. Among cell numbers 100 to 300, the integer ratio becomes 262:225:202.

We chose a ring pattern as the objective color image. The pattern is composed of six colors (red, green, blue, cyan, magenta, yellow). The designed R hologram for red image is composed of 262x262 phase cells, the G hologram for green image is composed of 225x225 phase cells, and the B hologram for blue image is composed of 202x202 phase cells. The cyan, magenta, and yellow color are obtained by combining green and blue, blue and red, and red and green at the output plane, respectively.

Micro photo-lithographic technique is used in the fabrication of the holograms. The computer generated hologram pattern is plotted in chrome coated quartz mask as the amplitude only pattern by electron bean lithography. Then the amplitude pattern on chrome mask is transferred into optical surface-relief phase only pattern on the photoresist film by contact photolithography. The size of each phase cell is 2μm so the period of *R* hologram is 524μmx524μm, the period of *G* hologram is 450μmx450μm, and the period of *B* hologram is 404μmx404μm,

Figure 1 represents the optical setup of reproducing color image with the fabricated binary phase hologram. The three laser beams of red, green, and blue are illuminated on three different parts of the hologram by two prism beam splitters. The diffracted beams from the hologram make the output color image at the focal plane of the lens. This output image is detected and it is sent to the monitor by a CCD camera and a frame grabber connected to a PC. Figure 2 shows the experimental result using the proposed system. We note that the wanted color image could be obtained. The spot spacing is about 360μm. The reason why the image is symmetrical centering around the origin is that the phase of the hologram is binary. This symmetrical image can be suppressed using holograms of multiple phase more than 4 phases (0, $\pi/2$, π, and $3\pi/2$).(4)

In conclusion, we demonstrated the full-color image generation using BPH. Although the target pattern used in this paper is composed of six colors, the images having arbitrary colors can be produced without increasing the number of lasers in the proposed system by suitable mixing R, G, and B images in the output plane.

References

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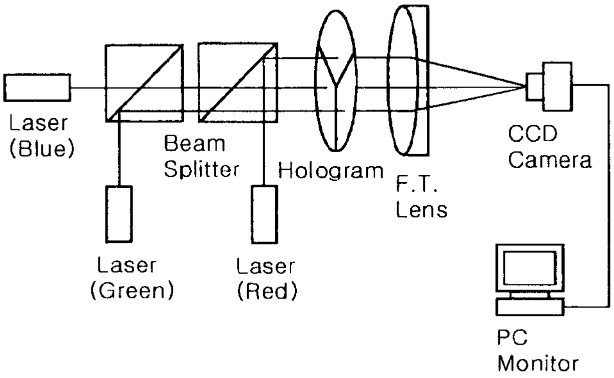

Figure. 1. Optical setup for producing color image with the fabricated binary phase hologram and three laser beams.

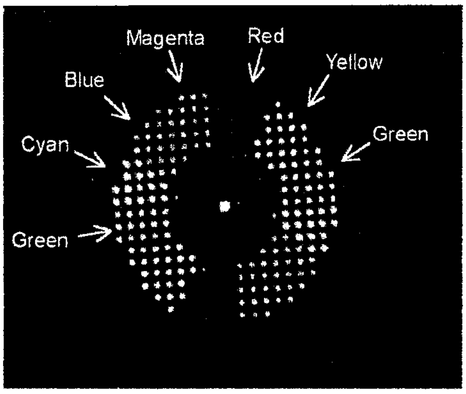

Figure 2. The experimental result of the output color image.