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Method for compensation of transverse dispersion in electro-holography

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ABSTRACT

In the process of optoelectronic reconstruction of color holograms, the reconstructed images of three colors can't be overlap properly because transverse dispersion caused by different wavelengths of three laser beams of R, G, B colors. In this paper, a novel method is proposed to compress or expand the number of discrete pixels of three component color images for eliminating transverse dispersion in the process of computing holograms. Holograms computed by the iterative Fourier transverse algorithm (IFTA) were loaded on reflective liquid crystal spatial light modulator (LC-SLM) for optoelectronic reconstruction. The experimental result shows that the method is effective.

Key words: Computer generated hologram; Optoelectronic reconstruction; Transverse dispersion; pixel number scaling

1. INTRODUCTION

The technique of optoelectronic holograms reconstruction based on SLM has been developed since the 1980's, and it can realize dynamic holographic reconstruction. Many researchers are researching phase holograms based on LC-SLM^[1-3] because of its high diffraction efficiency^[4-7]. In terms of color holography, the traditional rainbow holography can reconstruct color images, but it can't provide a real-time animated holography^[8-10]. In recent, digital color holography has been developed which mainly dedicate to solve the problem of overlapping reconstructed R, G, B images with use of three laser beams illuminating on the color holograms^[11-12]. For example, J. Zhao *et al* have achieved recording and reconstructing monochromatic holographic images (Red, Green, Blue), and also resolved the problem of color dispersion of R, G, B holographic images^[13]. K. Sato *et al* develop a holographic system with a high-resolution color CCD and a LCD panel for simultaneously recording the R, G, B holograms of the practical object using phase-shifting method, and fine color images of the practical object are reconstructed. But the system is complex and requires high precision for adjusting devices^[14-15]. The methods mentioned in references [13-15] adopt complex optical systems to record RGB holograms. Comparing with digital holograms extracted from CCD, the computer generated holograms are more flexible^[16]. In this paper, we get the influencing factors of transverse dispersion by analyzing reconstructed R, G, B monochromatic holographic images. We eliminate the transverse dispersion effectively by compressing or expanding the discrete pixels of R, G, B channels of color images in the process of computing the holograms and get better optoelectronic reconstructed images.

2. ANALYSIS OF OPTOELECTRONIC RECONSTRUCTION

The hologram optoelectronic reconstruction system consists of light source such as laser, SLM and other optical devices, which can reconstruct animated holograms in real-time. Fig. 1 shows the schematic of a system of optoelectronic reconstruction. The coherent light from semiconductor laser is expanded by micro objective(MO) and passes through the Fourier lens(FL) which is used to control the angle of laser beam, then light go to the SLM which is used for modulating light wave. After modulated by the SLM, it is reflected by a mirror and reaches the screen.

The optoelectronic reconstructed images of holograms can be displayed by 2D screen or 3D scattering material. As result

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of diffraction characteristic of 2D grating of SLM, we can see the same four images on the screen, as shown in Fig. 2. The coordinate center “O” is the 0-order diffraction. The red points are high order diffraction which decides the size of reconstructed images. X , Y is the width and height of reconstructed image. The top left corner of Fig. 2 is part of magnified image. Δx , Δy denote the horizontal and vertical pixel pitch, respectively.

Fig. 1 Scheme of optoelectronic reconstruction system

Fig. 2 Reconstructed images on screen(color on line)

From Bragg equation, we can easily get:

$$X = \frac{\lambda d}{\Delta \xi}, \quad Y = \frac{\lambda d}{\Delta \eta}, \quad \Delta x = \frac{\lambda d}{m \cdot \Delta \xi}, \quad \Delta y = \frac{\lambda d}{n \cdot \Delta \eta} \quad (1)$$

where, λ is a wavelength of reconstruction wave and d is the reconstruction distance which is the geometry distance between SLM and screen. m , n is the number of horizontal and vertical pixels of SLM, respectively. $\Delta \xi$ and $\Delta \eta$ denote the pixel pitches of the horizontal and vertical pixels.

The spatial light modulator used in our system is a kind of reflective liquid crystal spatial light modulator (LCR-2500) made by Holoeye corporation in Germany. Both of the horizontal and vertical pixel pitch are $19\mu\text{m}$, the number of pixels is 1024×768 . Fig. 3 illustrates the setup for optoelectronic reconstruction. We load high diffraction efficiency phase holograms of pentagram on the SLM, and reconstruct them with light whose wavelength is 633nm (red), 532nm (green), 473nm (blue), respectively. The reconstruction distance is 3800mm . The sizes of reconstructed images according to formula (1) are theoretically given by:

$$\begin{aligned} X_R = Y_R &= \frac{\lambda_R d_R}{\Delta x} = \frac{\lambda_R d_R}{\Delta y} = \frac{0.632\mu\text{m} \times 3800\text{mm}}{19\mu\text{m}} = 126.4\text{mm} \\ X_G = Y_G &= \frac{\lambda_G d_G}{\Delta x} = \frac{\lambda_G d_G}{\Delta y} = \frac{0.532\mu\text{m} \times 3800\text{mm}}{19\mu\text{m}} = 106.4\text{mm} \\ X_B = Y_B &= \frac{\lambda_B d_B}{\Delta x} = \frac{\lambda_B d_B}{\Delta y} = \frac{0.473\mu\text{m} \times 3800\text{mm}}{19\mu\text{m}} = 94.6\text{mm} \end{aligned} \quad (2)$$

In our experiment, we use three laser beams of R, G, B colors for reconstructing the R, G, B component holograms of pentagram, and record the R, G, B component reconstructed images respectively. The image shown in Fig. 4 are the superimposed result with the R, G, B component reconstructed images. There exists transverse dispersion for different wavelengths of R, G, B laser. The actual sizes of reconstructed images are $125\text{mm} \times 125\text{mm}$, $108\text{mm} \times 108\text{mm}$, $95\text{mm} \times 95\text{mm}$, respectively. They are in good agreement with the theoretical values.

Fig. 3 Optoelectronic reconstructed system

Fig. 4 Reconstructed images of CGHs

Assumed that the field angle of R, G, B images is α_r , α_g , α_b which is based the coordinate center “O”, then according the transverse dispersion definition of holography^[17], we can get the transverse dispersion of red and green reconstructed images by:

$$\begin{aligned}\Delta\alpha_g &= \frac{\alpha_g - \alpha_b}{\alpha_b} \% = 12.5\% \\ \Delta\alpha_r &= \frac{\alpha_r - \alpha_b}{\alpha_b} \% = 33.6\%\end{aligned}\quad (3)$$

Where $\alpha_r = \frac{X_R}{d_R}$, $\alpha_g = \frac{X_G}{d_G}$, $\alpha_b = \frac{X_B}{d_B}$ and $d_R = d_G = d_B$ in our system.

3. THE METHOD OF ELIMINATING THE TRANSVERSE DISPERSION

Formula (3) shows the transverse dispersion at the same reconstructed distance which is cause by different wavelengths of R, G, B. So we can get $X_B = X_G = X_R = X$ by adjusting the reconstruction distance for eliminating the transverse dispersion. Taking the “x” coordinate as an example, the reconstruction distance of three color laser should be meet the condition as follow:

$$d_R = \frac{X_R \cdot \Delta\xi}{\lambda_R}, \quad d_G = \frac{X_G \cdot \Delta\xi}{\lambda_G}, \quad d_B = \frac{X_B \cdot \Delta\xi}{\lambda_B} \quad (4)$$

We can get $d_R < d_G < d_B$ from formula (4). In this method, three SLMs should be used and the system is complex, also some precision adjusting devices are needed for adjusting the reconstruction distance. So it not only increases the cost but also brings problems for adjusting system. In this paper, we propose the method of compressing or expanding discrete pixels of R, G, B component images of original objects, and then generate the CGHs with method of IFTA. Transverse dispersion of R, G, B reconstructed images can be eliminated by holograms we made.

3.1 Elimination of the Transverse Dispersion

In optoelectronic reconstruction system based on one SLM, the reconstructed distance is equal. The number of pixels of reconstructed image is same as the pixels of SLM. The sizes of optoelectronic reconstructed images are decided by the product of lattices and pixel pitch of the reconstructed image^[18]. Taking the “x” coordinate as an example, the horizontal length of reconstruction R, G, B component images can be respectively expressed as follow formula:

$$\begin{aligned}
x_R &= m_R \Delta x_R = m_R \frac{\lambda_R d_R}{m \cdot \Delta \xi} \\
x_G &= m_G \Delta x_G = m_G \frac{\lambda_G d_G}{m \cdot \Delta \xi} \\
x_B &= m_B \Delta x_B = m_B \frac{\lambda_B d_B}{m \cdot \Delta \xi}
\end{aligned} \tag{5}$$

where, $d_R = d_G = d_B$, and m_R, m_G, m_B denote the number of the pixels of reconstructed image, respectively. $\lambda_R, \lambda_G, \lambda_B$ represent the wavelengths of R, G, B laser.

In the formula (5), if we want to get the same size of reconstructed image ($x_R = x_G = x_B$), the following condition should be met:

$$m_R : m_G : m_B = \frac{1}{\lambda_R} : \frac{1}{\lambda_G} : \frac{1}{\lambda_B} \tag{6}$$

Consider the condition of $\lambda_B < \lambda_G < \lambda_R$, we can conclude that the number of blue reconstructed image is the largest. So we take the blue image as the reference, the red and green images are scaled according to the formula (6). When the relationship of formula (6) is meet, the transverse dispersion of the reconstructed images of R, G, B components will be eliminated.

In this paper, the white pentagram was taken as an example. The number of pixels of original images and CGHs calculated by iterative Fourier transform algorithm (IFTA) are set as the same number of pixels of SLM. The R, G, B component original images have the same pixels of 1024×768 (equal to the pixel number of SLM), which are showed in the Fig. 5(a), 5(b) and 5(c), respectively. we assume that the size of blue image is 800×600 pixels (Fig. 5(c)), then the number of red and green original images should be 599×499 pixels Fig. 5(a) and 737×553 pixels (5(b)) respectively according to formula (6). If we take the R, G, B original images whose sizes are showed in Fig. 5 to make R, G, B CGHs, the transverse dispersion will be eliminated in optoelectronic reconstruction.

Fig. 5 Original information (a) for red (b) for green (c) for blue

3.2 Experimental Results

Fig. 6 illustrates the CGHs of original images shown in Fig. 5. Three images have the same size of 1024×768 pixels. The sub images of top right corners are the magnified R, G, B component CGHs.

Fig. 6 Computer generated holograms for red (a), green (b) and blue (c) component, respectively

System as shown in Fig. 3 was used to reconstruct hologram shown in Fig.6, and reconstructed images at the distance 3800mm were recorded. We get the reconstruction result shown in Fig. 7 by putting them into computer for superposition.

The transverse dispersion caused by different wavelengths of three laser beams of R, G, B colors has been eliminated in Fig. 8. But the color of pentagram is different with the ideal state. This phenomenon is called color aberration. It caused by the mismatch power of the R, G, B laser, the SLM's different modulation characteristic to R, G, B laser.

Fig. 7 Reconstructed image without transverse dispersion

4. CONCLUSION

By changing the number of pixels of R, G, B component images of original object and then generating CGHs respectively, we successfully eliminate the transverse dispersion based single SLM. In this paper, we test and verify this method mentioned above by reconstructing the R, G, B component CGHs which are computed using the IFTA. This method will promote the development of holographic display.

In this paper, we only give the method of eliminating transverse dispersion. But it is also applicable for solving the problem of longitudinal dispersion and position matching. Future works will be on them.

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