Analysis of complex modulation with layered spatial light modulators

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***Abstract*: The complex modulation hologram shows a very clear and accurate holographic image. The complex modulation which is composed of layered amplitude and phase only spatial light modulators is introduced. This structure allows us to improve the respective disadvantages of the amplitude only and phase only modulators. In this paper, we analysis and study the noise characteristics of the layered spatial light modulators depending on the interval and size of pixel.**

Keywords: Holographic display, Multilayers, Complex modulation.

I. INTRODUCTION

Recently, the research and development of holographic three-dimensional (3D) display technology have been very actively conducted. Stereoscopic display of 3D display used in movie theater causes confusion, because of vergence-accommodation mismatch. In principle, holographic 3D display is an ideal 3D display without any artificial defect [1]. Technology of the spatial light modulators (SLMs) to display hologram has been continuously developed. In particular, research on the complex modulation is an integral part [2, 3]. We usually use the amplitude only SLMs or phase only SLM to observe the holographic images. The problems occur in these devices when observing holographic image. DC noise and twin are occurred in amplitude SLM. Also unclean image is observed in phase only SLM and complicate the process for calculation computer generated hologram (CGH). By contrast, these problems do not occur in complex modulation. General CGH is represented by complex field. Thus, holographic images are most natural under the complex modulation. The complex modulation method using cascaded amplitude and phase only SLMs is analyzed. The ultimate objective of the proposed method overcomes the limitation of the amplitude and phase only modulated panels. It is expected to provide a clear hologram that improve the respective disadvantages of the two modulated panel previously used.

In this study, we address validity and effectiveness of complex modulation to reduce the respective noise of the amplitude and phase only modulated panels. Though there are many methods that can reduce noise in hologram [4], our approach would solve this problem by using multi-layered structure of amplitude and phase only modulated panels. Additionally, the analysis of the problem is caused by the distance between multilayers and size of pixel.

II. VALIDITY AND EFFECTIVENESS IN COMPLEX MODULATED PANEL

We propose complex modulated panel can be implemented as shown in Fig. 1. CGH pattern of amplitude and phase set on each of amplitude and phase panel with layered structure. Then, the system enters the hologram complex data into the eye through the lens of the plane wave transmitted through the amplitude only panel and phase only panel. This system overcomes the limitation of the amplitude and phase only modulated panel and provides a clear reconstructed holographic image that improve the respective disadvantages of the two modulated panel previously used because of we can observe complex data.

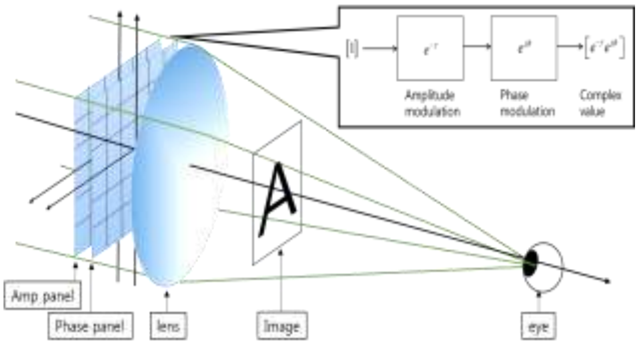

Figure 1. Complex modulated panel system schematic.

The reconstructed holographic image $F(x_2, y_2)$, is obtained by

$$F(x_2, y_2) = \frac{1}{(j\lambda d_1)(j\lambda d_2)} e^{j\frac{\pi}{\lambda d_2}(x_2^2+y_2^2)} \times \iint \left[e^{j\frac{\pi}{\lambda}\left(\frac{1}{d_1}+\frac{1}{d_2}-\frac{1}{f}\right)(u^2+v^2)} circ\left(\frac{u^2+v^2}{\rho^2}\right) \times A' \right] e^{-j\frac{2\pi}{\lambda d_2}(ux_2+vy_2)} du dv.$$

$$A' = \iint e^{j\frac{\pi}{\lambda}\left(\frac{1}{d_1}-\frac{1}{F}\right)(x_1^2+y_1^2)} G(x_1, y_1) e^{-j\frac{2\pi}{\lambda d_1}(x_1 u + y_1 v)} dx_1 dy_1 \quad (1)$$

where $G(x_1, y_1)$ is the CGH pattern before passing through the field lens, $circ\left(\left(u^2+v^2\right)/\rho^2\right)$ is the size of the pupil, d_1 is the distance between the pupil and the CGH, d_2 is the distance between the pupil and the retina, f is a focal length of the field lens and (u,v) is spatial domain in pupil. Here, $e^{j\frac{\pi}{\lambda}\left(\frac{1}{d_1}+\frac{1}{d_2}-\frac{1}{f}\right)(u^2+v^2)}$ is the key factor to make the accommodation effect in the system. Figure 2 illustrates reconstructed image of CGH by the function of Eq. (1). Because of DC and twin noise, reconstructed image of CGH by amplitude only modulation as shown in Fig. 2(b) has a lot of noise and brighter than other image. Result of phase only modulation in Fig. 2(c) is also difference from the original image as shown in Fig. 2(a). But complex modulation in Fig. 2(d) is almost similar to the original image and does not have the noise. Thus, we have confirmed the validity and effectiveness in complex modulation for improve the respective noise of the amplitude and phase only modulated panels.

(a) (b) (c) (d)

Figure 2. (a) Target image. Reconstructed image of CGH by (b) amplitude only modulation. (c) phase only modulation. (d) complex modulation.

III. Analysis of Reconstructed Image in Complex Modulation

In this section, the phenomenon with the interval and the size of pixel of complex modulation with layered SLM is analyzed. Figure 3 shows the accommodation effect of complex modulation when focal plane are alphabet ‘A’ and ‘B’ respectively. For the simulation setup, the pixel size is 8.5um, focal length is 0.5m, and ‘A’ and ‘B’ are separated from 0.1m. In this result, unlabored accommodation effect appear and focused alphabet of reconstructed image seem clear with any aliasing.

(a) (b)

Figure 3. Accommodation effect of reconstructed image in complex modulation with focus on alphabet (a) ‘A’ and (b) ‘B’.

In the next step, we observed the phenomenon in accordance with the interval of multilayers in the same pixel size. The reconstructed images in complex modulation are displayed according to distance difference between the multilayers illustrated in Fig. 4. When the distance between the multilayers is 0mm virtually as shown in Fig. 4(a), a uniform intensity and a clear image can be seen. However in actual case, we can see non-uniform intensity distribution of reconstructed image by increasing interval of the multilayers as shown in Fig. 4 (b) and (c). Because diffraction occurs in between the amplitude and phase panel. By increasing the interval of the multilayers, noise generates due to influence of different pixel other than a pixel.

(a) (b) (c)

Figure 4. Reconstructed image with interval of multilayers at (a) 0 mm. (b) 0.5 mm. (c) 1 mm.

Next, we analyzed the phenomenon of the pixel pitch in a fixed panel interval in the complex modulation. The reconstructed image according to the pixel size changes when the distance between the multilayers be the same do not show a significant difference. The set-up of Fig. 5 is the distance between the multilayers is 1 mm, a pixel size is 8.5 um, 11 um and 13.68 um. The smaller the pixel size occurs the noise at the periphery of the image and intensity of the alphabet ‘A’ image is different. This phenomenon is occurred because the pixel size becomes smaller the diffraction appear well. But the result was a finely largely unchanged. The image ‘B’ is observed a different common characteristic that the larger the pixel size is reduced accommodation effect.

(a) (b) (c)

Figure 5. Reconstructed image by size of pixel (a) 8 (b) 11(c) 13.68 um.

IV. Conclusion

In this paper, we addressed validity and effectiveness of complex modulation that is composed of the amplitude and phase only modulated panels. We found that little noise is generated with respect to the inter-layer distance. It is an interesting result. If more widely studied phenomenon in complex modulation and finding a solution, a very good modulation device will be able to emerge.

References

[1] J. Hong, Y. Kim, H.-J. Choi, J. Hahn, J.-H. Park, H. Kim, S.-W. Min, N. Chen, and B. Lee, “Three-dimensional display technologies of recent interest: principles, status, and issues,” Appl. Opt. **50**, H87–H115 (2011).

[2] J-P. Liu, W.-Y. Hsieh, T.-C. Poon, and P. Tsang, “Complex Fresnel Hologram Display using a Single SLM,” Appl. Opt. 50, H128-H135 (2011).

[3] L. Gonçalves Neto, D. Roberge, and Y. Sheng, “Full-range, continuous, complex modulation by the use of two coupled-mode liquid-crystal television,” Appl. Opt. 35, 4567-4576 (1996).

[4] E. Ulusoy, L. Onural, and H. M. Ozaktas, “Full-complex amplitude modulation with binary spatial light modulators,” J. Opt. Soc. Am. A 28, 2310-2321 (2011).