Reconstruct Holographic 3D Objects by Double Phase Hologram

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ABSTRACT

To develop a 3D display which can show true 3D images is very important and necessary. Holography has great potential to achieve the objective because holography can actually reconstruct the recorded object in space by reconstruction of wavefront. Further, computer generated hologram (CGH) is used to solve the major issue of conventional holography, which means the recoding process is quite complicated and needs the real objects. The reconstructed image, however, will be blurred and with the unexpected light if using only one phase-only spatial light modulator (PSLM). Although to use two PSLMs by dual-phase modulation method (DPMM) can modulate the phase and the amplitude information simultaneously to enhance the quality of the reconstructed image, it is hard to use in practical application because of the extremely high accurate calibration of the two PSLMs. Therefore, double phase hologram (DPH) was proposed to use only one PSLM to modulate the phase and the amplitude information simultaneously to make the reconstructed image be more focused and eliminate the unexpected light.

Keywords: True 3D Images, Holography, Computer Generated Hologram, Phase-only Spatial Light Modulator, Dual-phase Modulation Method, Double Phase Hologram

1. INTRODUCTION

Three-dimensional (3D) displays can provide the better watching experience than three-dimensional (2D) displays through showing 3D images with depth information. General 3D displays nowadays create 3D images by binocular disparity, which means 3D displays provide different images for observers' left and right eye individually and observers fuse these two images to be a 3D image. However, it will lead mismatch between accommodation and convergence and result in visual fatigue for observers [3]-[6]. Therefore, to develop and realize a 3D display which can show true 3D images is very important and more and more popular recently. Holography is regard as to have great potential to replace 3D displays by binocular disparity, for holography can actually reconstruct the information of recorded object in space to show true 3D images.

Interference is the main principle of holography [7]-[8]. For recording process of holography, one coherent beam called the object light directly propagates to the recorded object, and the other coherent beam is called the reference light to be used interference with the object light. The interference fringe pattern between abovementioned two beams is the hologram. When the hologram is illumined by another high coherent beam which is identical to the reference light, the wavefront of the recorded object will be reconstructed to let observers watch a reconstructed image of the recorded object. Reconstructed images by the hologram do not result in visual fatigue for obverses because the reconstructed images are true 3D images due to reconstruction of wavefront. The major issues of holography, nevertheless, are the recoding process is quite complicated and needs the real objects, so it is hard to use in real time application. Thus, computer generated hologram (CGH) has been widely used to solve these issues.

2. COMPUTER GENERATED HOLOGRAM (CGH)

CGH is based on using computers to calculate the interference fringe pattern to generate the hologram directly, so it does not need the real objects anymore for recording process. One of the fundamental methods of CGH calculation is the point light method [9]-[10]. The conception of the point light method is regard the recorded object's surface as point light sources, and the point light sources are considered spherical waves which propagate from the object plane to the hologram plane, as shown in Figure 1.

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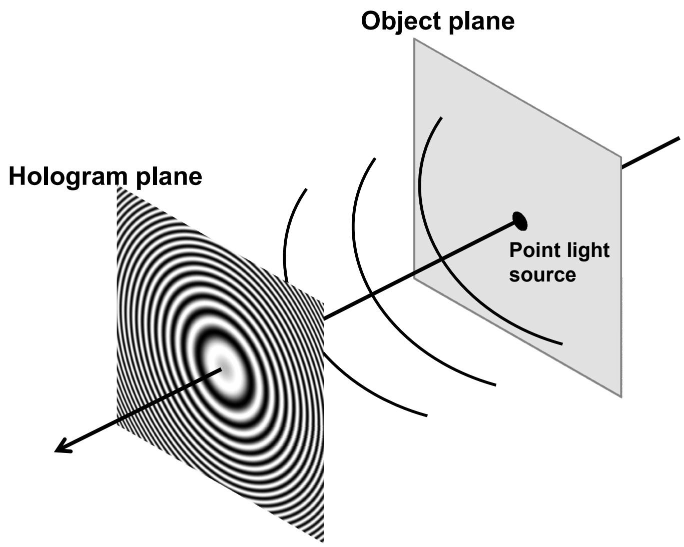

Figure 1. Principle of computer generated hologram by the point light method

For instance, there is a point light source, i, which makes up an object on the object plane with an amplitude of a_i and a phase of ϕ_i, and the coordinates of the point light source is (x_i,y_i,z_i). Then, the complex amplitude of the point source on hologram plane can be calculated from the following equation:

$$\boldsymbol{u_i(\alpha,\beta,\gamma) = \frac{a_i}{r_i} exp\{-j(kr_i + \emptyset_i)\}} \tag{1}$$

where r_i is distance between the point light source and the point on the hologram plane and defined as:

$$\boldsymbol{r_i = \sqrt{(\alpha - x_i)^2 + (\beta - y_i)^2 + (\gamma - z_i)^2}} \tag{2}$$

If the number of point sources is N, the complete interference patterns on hologram plane can be received by summarizing the complex amplitudes of all point sources, as shown in Eq. (3). Accordingly, if we use a phase-only spatial light modulator (PSLM) to display the complete interference patterns and illumine the PSLM by a high coherent and collimated light, the original object on the object plane will be reconstructed.

$$\boldsymbol{u(\alpha,\beta,\gamma) = \sum_{i=1}^{N} u_i(\alpha,\beta,\gamma)} \tag{3}$$

3. DOUBLE PHASE HOLOGRAM (DPH)

3.1 Dual-phase Modulation Method (DPMM)

The general PSLM, however, can only modulate the phase information but cannot adjust the amplitude information, so the reconstructed image will be blurred or with unexpected light. A. Shibukawa et al., proposed dual-phase modulation method (DPMM) to modulate the phase and the amplitude information simultaneously by using two PSLMs and a beam splitter (BS), as shown in Figure 2 [11]. If each PSLM only modulates the phase in the range [0, 2π] and the amplitudes keep the same values, the addition of two modulation curves can achieve all complex values in the complex plane. Nevertheless, the issues of DPMM are there are two PSLMs and the calibration of two PSLMs needs extremely high accuracy. It means DPMM by using two PSLMs is hard to use in practical application. Therefore, we propose double phase hologram (DPH) to achieve using only one PSLM to modulate the phase and the amplitude information at the same time for practical use. The algorithm of DPH will be described in detail in Section 3.2.

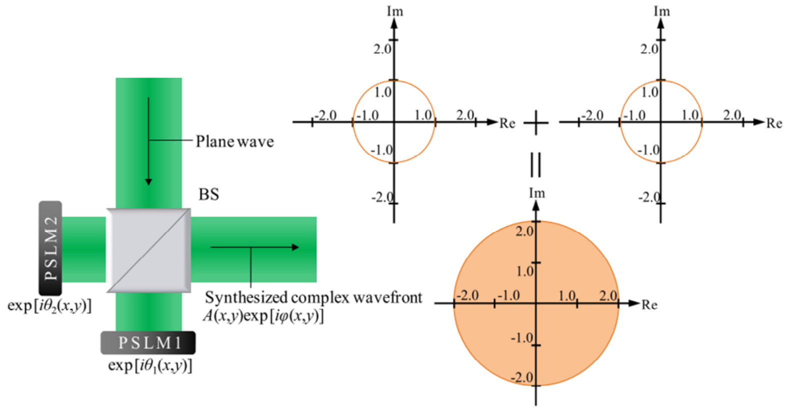

Figure 2. To modulate the phase and the information simultaneously by dual-phase modulation method

3.2 Algorithm

The algorithm of DPH is shown in Figure 3. First, as mentioned in Section 2, the complete interference fringe pattern from the object plane to the hologram plane is generated by the point light method, Ep. (3). Second, the phase one information, DP_1, and the phase two information, DP_2, are calculated by the following questions:

$$\boldsymbol{DP_1(x,y) = \emptyset(x,y) + cos^{-1}[\frac{A(x,y)}{2}]} \tag{4}$$

$$\boldsymbol{DP_2(x,y) = \emptyset(x,y) - cos^{-1}[\frac{A(x,y)}{2}]} \tag{5}$$

In Eq. (4) and Eq. (5), (x,y) denotes the coordinate of each pixel on the hologram plane; A is the amplitude of the fringe pattern; and ϕ is the phase information of the fringe pattern. Third, the interference fringe pattern of DPH is received by combining DP_1 and DP_2 with the arrangement shown in Figure 3.

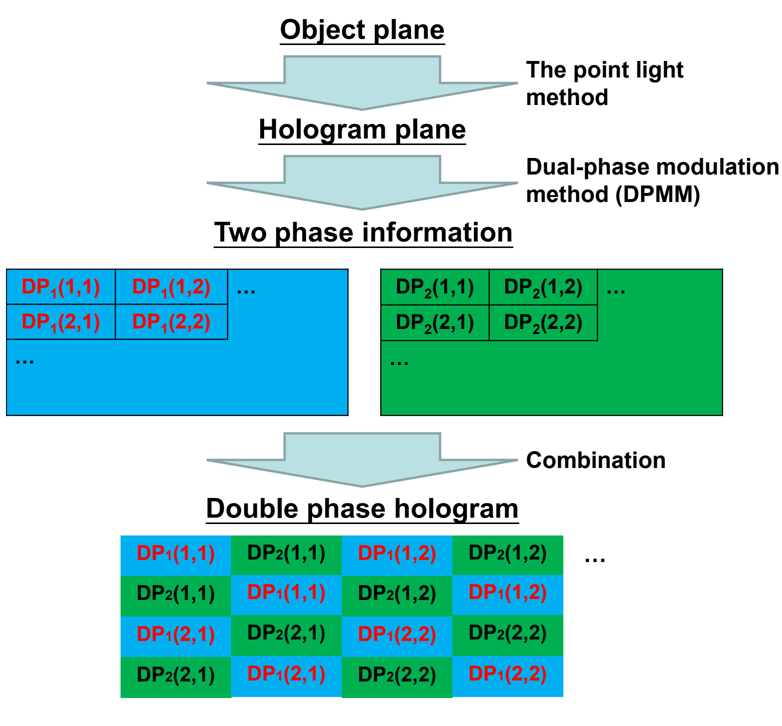

Figure 3. The algorithm and the arrangement of double phase hologram

4. EXPERIMENTAL SETUP AND RESULTS

4.1 Experimental Setup

The experimental setup is shown in Figure 4. The He-Ne laser of wavelength of 632.8nm, the objective lens, the lens, and the pinhole are used to generate a high coherent and collimated light. To decrease the intensity of the laser by the filter can protect the optical sensor of the camera, and the half-wave plate can change polarization of the laser. The notebook inputs the interference fringe pattern to the PLSM, and the beam splitter is used to separate the high coherent and collimated light. The size of the PSLM is 0.7 inch with a resolution of Full HD (1920x1080), so the pixel size is 8μm. Accordingly, we can use the camera to take pictures of reconstructed images.

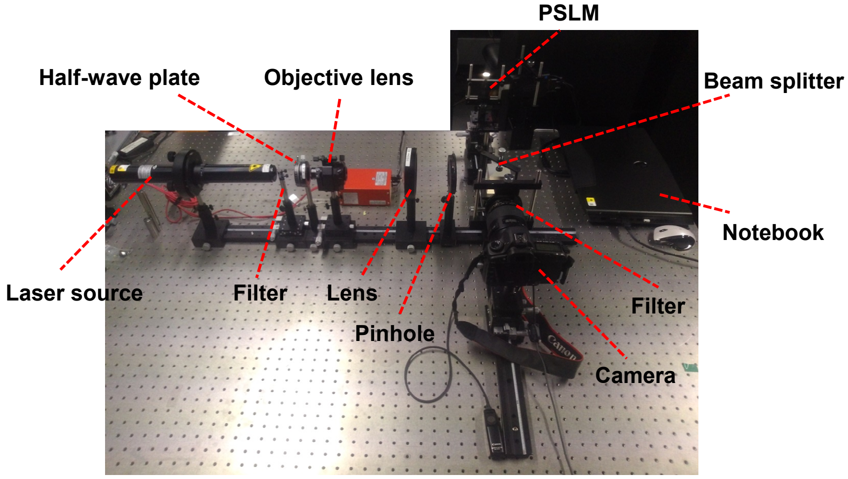

Figure 4. Experimental setup

4.2 Experimental Parameter

To confirm that DPH is applicable, we compare the reconstructed images by the interference fringe pattern of phase information only (PIO) and the fringe pattern of DPH. PIO means the fringe pattern is without the calculation of DPMM, which means the fringe patter on the hologram plane. In order to reduce the calculation time and clearly compare experimental results, we design there is only one point light source on the object plane. The distance between the object plane and the hologram plane, D, is assumed to be 30mm, 50mm, and 100mm. The fringe patterns of PIO and DPH of different distances are shown in Figure 5.

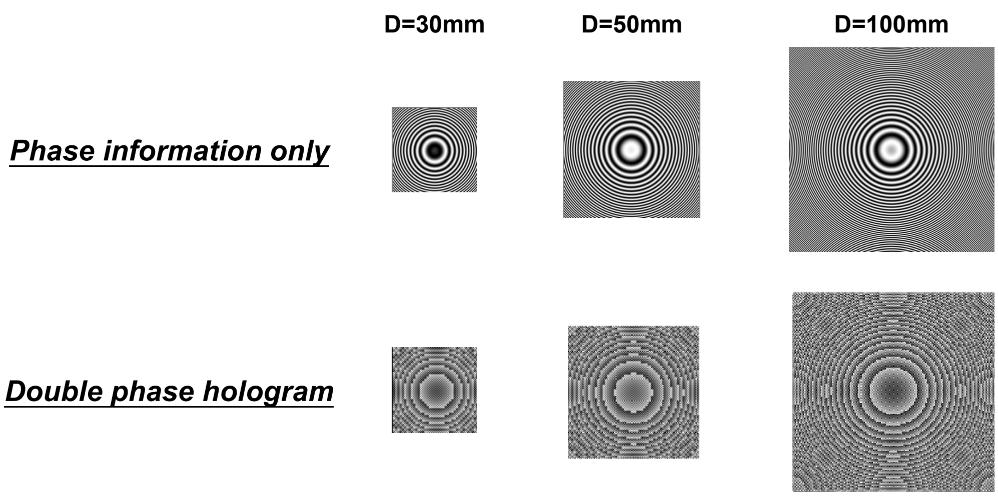

Figure 5. The fringe interference patterns of PIO and DPH of different distances

4.3 Experimental Result

The experimental results are shown in Figure 6. According to Figure 6, the reconstructed point light sources of different distances by the fringe pattern of DPH are more focused to compare with the reconstructed point light sources by the fringe pattern of PIO. More importantly, the reconstructed point light sources by the fringe pattern of PIO are surrounded by the unexpected light. Consequently, we realize to use only one PSLM to modulate the phase and the amplitude information simultaneously to make the reconstructed image be more focused and eliminate the unexpected light.

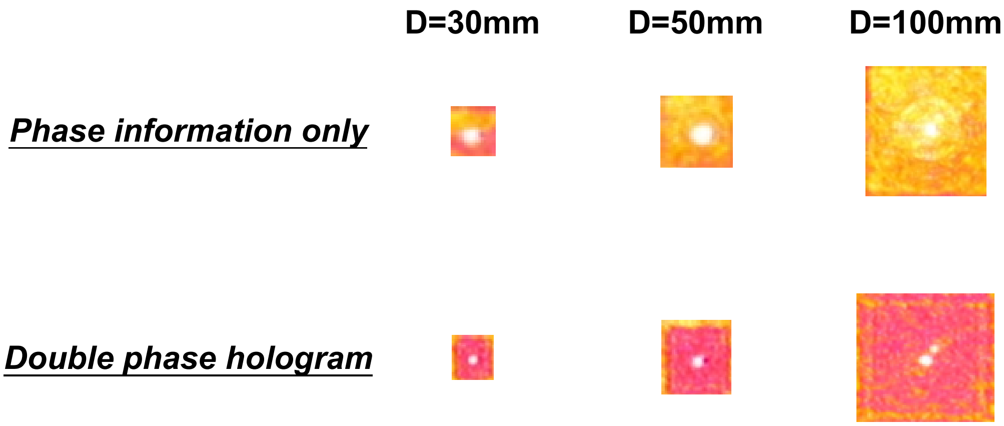

Figure 6. Experimental result of PIO and DPH of different distances

5. CONCLUSION AND DISCUSSION

3D displays nowadays create 3D images by binocular disparity to lead visual fatigue for observers, so it is very important and necessary to develop a 3D display which can show true 3D images to enhance the watching experience. Holography is regard as to have great potential to replace 3D displays by binocular disparity because holography actually reconstructs the recorded object in space by reconstruction of wavefront, which means the true 3D images. Use CGH can solve the major issue of conventional holography, which means the recoding process is quite complicated and needs the real objects, but reconstructed images are blurred and with the unexpected light if only using one PSLM because the phase and the amplitude information cannot be modulated at the same time. Therefore, DPH is proposed to use only one PSLM to modulate the phase and the amplitude information simultaneously by DPMM. According to experimental results, the reconstructed images by the fringe pattern of DPH are more focused and eliminate the unexpected light.

In this paper, only fundamental experiments have been done to confirm the concept of DPH. Next, the input image on the object plane will be change, for example, to increase the number of point light source or to input some geometrical figures. In addition, the arrangement of DP_1 and DP_2 will be discussed in the future, too.

6. ACKNOWLEDGMENT

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