Kinoform Generated Combined with the Error Diffusion Method and the Dynamic Random Phase

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Abstract. A computer generated kinoform combined with error diffusion and the dynamic random phase is presented. In order to compensate the error generated in the reconstructed image from the phase only hologram, the Floyd-Steinberg error diffusion technique is employed. The error can be diffused to the neighboring pixels in this method. And sequential kinoforms are generated by adding dynamic phase factor into the object domain to reduce the speckle noise. The results show that the kinoform can be achieved correctly and the representation quality of the reconstructed image can be improved compared with that obtained from the original kinoform.

Keywords: Kinoform · Error diffusion · Dynamic random phase

1 Introduction

In recent years, three-dimensional (3D) display attracts considerable attentions [1–5]. Among the three-dimensional display technologies, the digital holographic technology is recognized as the optimal and the most promising three-dimensional display technology, which can provide the most authentic 3D illusion to the naked eye. With the rapid development of digital computers, computer-generated hologram (CGH) [6–9] technology is recognized as a good way to provide content for digital holographic 3D display. Many approaches are proposed to generate CGH such as the point-based method [10], polygon-based method [11] and multiple viewpoint projection [12, 13].

Kinoform is a phase only hologram, which regards the amplitude of interference light as constant. Compared with amplitude-type holograms, the kinoform has several advantanges. It can be displayed with a phase-only device and results in higher optical diffraction efficiency as well as rejection of the conjugate image and the zero-order image. However, removing the amplitude component will result in substantial degradation on the reconstructed image. To solve this problem, some optimization approaches are presented such as the Gerberg-Saxton algorithm [14], the bidirectional error diffusion algorithm [15] and the iterative Fresnel transform method [16].

Inspired by the previous works [17, 18], kinoform generated combined with the error diffusion method and the dynamic random phase is proposed. The result show that the representation quality of the reconstructed image is improved significantly from the

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kinoform generated combined with error diffusion method and the random phase factor. The principle of the proposed method is demonstrated first and then the numerical simulation process is carried out. The quality of the reconstructed image are evaluated by the PSNR and the conclusions are given finally.

2 Principle

The complex amplitude $F(u, v)$ of the Fresnel hologram is generated from the object waves emitted from each point on an object in Eq. (1). Where $A(x, y)$ is the intensity of each point in the object scene. λ is the wavelength of the optical wave.$r_{x;y;u;v}$ indicates the distance between the object point and the hologram. $\varphi_t(x, y)$ represents the random phase factor, which is used to reduce the dynamic range of the object wave spectrum distribution.

$$F(u,v)\Bigg|_{\substack{0\le u\le X\\ 0\le v\le Y}} = \sum_{x=0}^{X-1}\sum_{y=0}^{Y-1}\frac{A(x,y)\exp(j2\pi r_{x,y;u,v}/\lambda)\exp[j\varphi_t(x,y)])}{r_{x,y;u,y}} \tag{1}$$

Then, the phase only hologram $F_p(u, v)$ can be obtained from the complex amplitude of the hologram from the Eq. (2), in which the magnitude of each pixel is set to be a value of unity.

$$\left|F_p(u,v)\right| = 1,\ \ and\ \ \arg(F_p(u,v)) = \arg(F(u,v)) \tag{2}$$

The reconstructed image of the phase only hologram generated with Eq. (2) is poor. The large amount of error in each hologram pixel $E(u_i, v_i)$ is caused after removing the magnitude information. The error can be given by setting the magnitude to unity as Eq. (3).

$$E(u_i,v_i) = F(u_i,v_i) - F_p(u_i,v_i) \tag{3}$$

To overcome the problem, the Floyd-Steinberg error diffusion technique [15, 17] is employed to compensate the error. Figure 1 shows the error diffusion process more intuitively.

The errors generated on the odd rows are diffused to the neighborhood pixels that have not been visited according to Eqs. (4–7), from which we know the pixel on the odd rows are scanned from left to right.

$$F(u_i, v_i+1) \leftarrow F(u_i, v_i+1) + a_1F(u_i,v_i), \tag{4}$$

$$F(u_i+1, v_i-1) \leftarrow F(u_i+1, v_i-1) + a_2F(u_i,v_i), \tag{5}$$

$$F(u_i+1, v_i) \leftarrow F(u_i+1, v_i) + a_3F(u_i,v_i), \tag{6}$$

$$F(u_i+1, v_i+1) \leftarrow F(u_i+1, v_i+1) + a_4F(u_i,v_i), \tag{7}$$

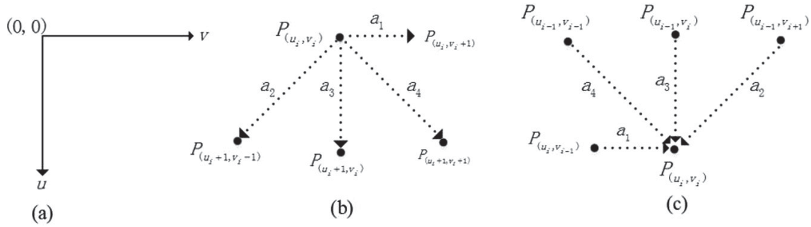

Fig. 1. a) The co-ordinate system with horizontal and vertical axes. (b) Error diffusion from the current pixel to its neighborhood, scanned from left to right. (c) An alternative representation of (a), showing the updating of a pixel from its neighborhood.

According to the Ref [17], a_1 to a_4 are set as Eq. (8).

$$a_1 = 7/16, a_2 = 3/16, a_3 = 5/16, a_4 = 1/16 \quad (8)$$

The sequential kinofroms can be obtained by setting the phase factor $\varphi_t(x, y)$ randomly assigned from $[0, 2\pi]$ in each calculation. Then the intensity information of each reconstructed image from sequential kinofroms is superimposed and normalized as the intensity information of the final reproduced image.

3 Simulation results

The numerical reconstruction image is obtained by using the convolution method. Figure 2(c) shows the image reconstructed from the original kinoform. The severe attenuation appears in the reconstructed image, which is caused by removing the magnitude information of the hologram.

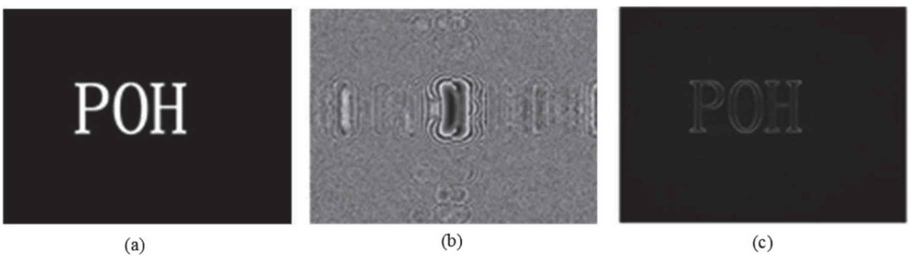

Fig. 2. a) The object plane (b) The original kinoform (c) The image reconstructed from the original kinoform

Figure 3(c) shows the image reconstructed from the error diffusion kinoform described in part 2. From which we can see the brightness of the reconstructed image is increased. However, the distortion also appears in the image.

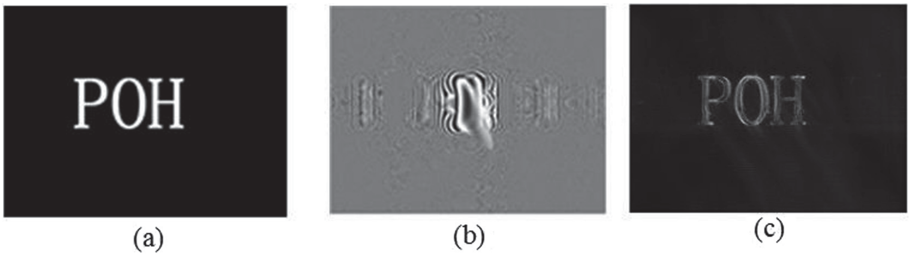

Fig. 3. a) The object plane (b) The error diffusion kinoform (c) The image reconstructed from the error diffusion kinoform

Then, based on the error diffusion method, the random phase factor is added in Eq. (1) to achieve the kinoform. Figure 4(c) represents the image reconstructed from the kinoform generated when the random phase is added only. The reconstructed image in Fig. 4(d) is obtained from the kinoform generated combined with error diffusion and the random phase factor. The results show that the representation quality of the reconstructed image is improved significantly from the kinoform generated combined with error diffusion method and the random phase factor.

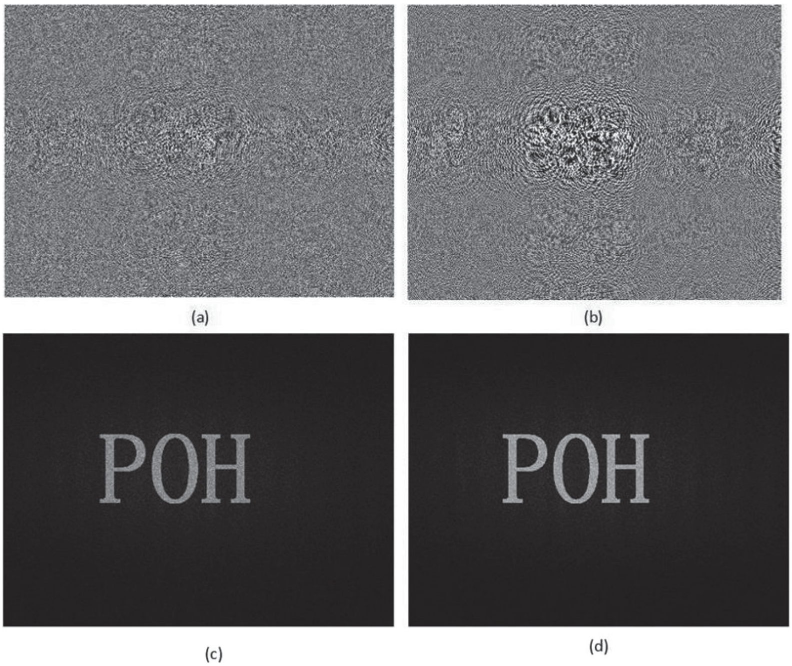

Fig. 4. a) The kinoform generated when the random phase is added only; (b) The kinoform generated by using the error diffusion method and the dynamic random phase; (c) The image reconstructed from (a); (d) The image reconstructed from (b).

Figure 5(a) shows the images reconstructed from the kinoforms using the dynamic random phase method with the 5th, 10th and 20th iteration numbers. And Fig. 5(b) represents the images reconstructed from the kinoforms generated combined with error diffusion method and the dynamic random phase with the same iteration numbers.

Peak signal to noise ratio (PSNR) is used to evaluate the quality of the reconstruction images. The results are shown in Table 1, from which we can see that the reconstruction results from the kinoforms generated combined with error diffusion and the dynamic random phase are superior to that kinoforms generated with the dynamic random phase only.

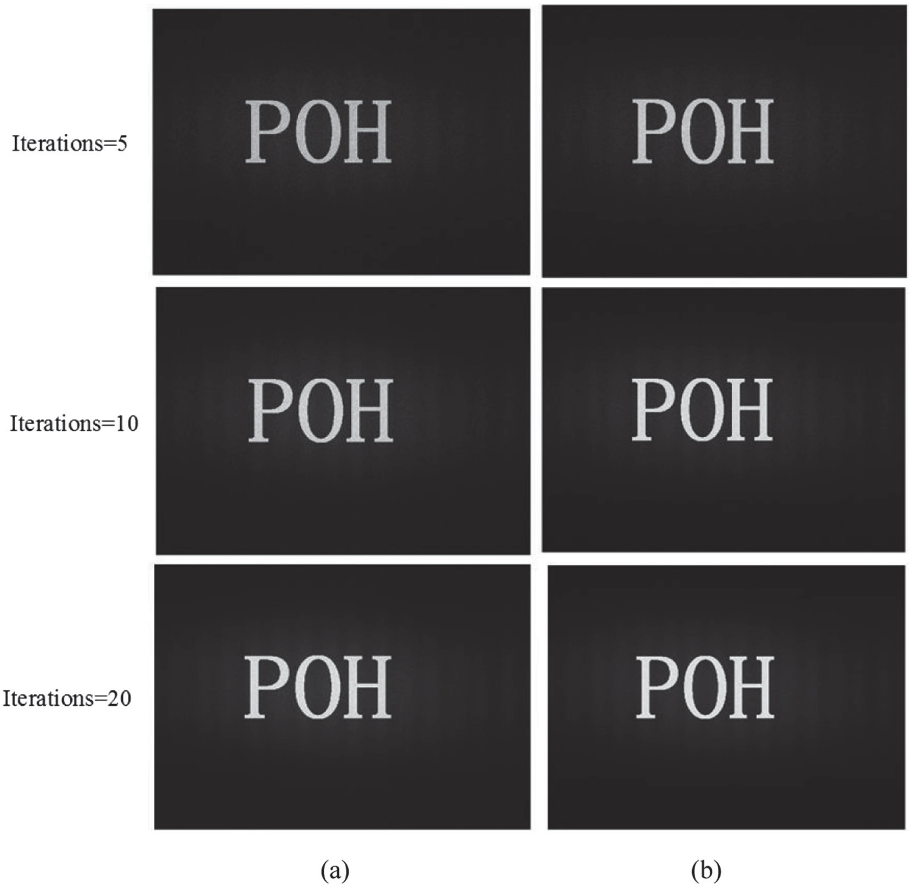

Fig. 5. a) The images reconstructed from the kinoforms using the dynamic random phase method with the 5th, 10th and 20th iteration numbers (b) The images reconstructed from the kinoforms generated combined with error diffusion and the dynamic random phase.

Table 1. PSNRs of the reconstructed images

Iteration numbers	PSNR (dB)	
	The dynamic random phase method	The method combined with the error diffusion and the dynamic random phase
0	21.6543	23.8054
5	23.3231	25.2590
10	25.5781	28.0231
20	26.9221	30.1241

4 Conclusions

In conclusion, a computer generated kinoform combined with error diffusion and the dynamic random phase is presented. The error diffusion approach is used to compensate the error caused by removing the magnitude information of the phase only hologram. And sequential kinoforms are obtained by adding dynamic phase factor into the object domain to reduce the speckle noise. The results demonstrates that the representation quality of the reconstructed image can be improved compared with that obtained from the original kinoform.

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