Paper

Iterative Dummy Area Method with Flexible Dummy Area Size for the Design of Kinoform

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Abstract: As an algorithm that generates a kinoform which is a kind of phase-type computer-generated hologram, there is an iterative dummy area method. However, this algorithm produces the error in dummy area, because it reduces the error in the original image space using the degree of freedom in the dummy area. It is undesirable for an error to occur in the dummy area in use efficiency of the light. In this study, we aim to reduce the error in the dummy area. In the computer generated hologram, the reconstructed image is modulated by a sinc function in both the horizontal direction, vertical direction. Therefore, the peripheral part of reconstructed image darkens in comparison with center. Considering the optical reconstruction, we can ignore the error that exists in the peripheral part of reconstructed image. From this, we use only a peripheral part at the start as a dummy area and widen a range to gradually use as a dummy area. We call the area that newly added flexible dummy area. By this method, we can collect errors in the peripheral part.

Keywords: Kinoform, iterative dummy area method.

1. Introduction

Kinoform is a hologram that records only the phase information of the object wave. In the kinoform, use efficiency of the light is high and use efficiency of 100% is theoretically possible, because the unnecessary diffracted wave does not occur during reconstruction. Furthermore, we can give an original image any phase because the kinoform reconstructing a two-dimensional image is strength reconstruction. Therefore, we use random phase for the phase of reconstructed image because extremely wide dynamic range is necessary for remarkable spikes-formed distribution by Fourier transform

In addition, we must make amplitude distribution regularity, because the kinoform has not recorded amplitude information. However, an error occurs in the reconstructed image by making amplitude distribution regularity. As algorithm to reduce an error of this time, we use iterative dummy area method.

2. Iterative dummy area method

We show the flow of iterative dummy area method in Fig. 1. In the iterative dummy area method, we add a dummy area of initial value 0 around an original image and we transpose this image to input image. The reduction of the error is en-

Figure 1: Iterative dummy area method.

Figure 2: Dummy area.

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abled by using degrees of freedom of phase and amplitude in this dummy area. We define the size of an original image as $sN_x \times sN_y$ [pixel], and define size when a dummy area is added to an original image as $N_x \times N_y$ [pixel]. We show the

image after adding dummy area in Fig. 2. If we define initial distribution of the original image as $f(x, y)$, initial input signal $g_0(x, y)$ is as follows.

$$g_0(x, y) = |g_0(x, y)| \exp\{j\varphi(x, y)\} = \begin{cases} |f(x, y)| \exp\{j\varphi_0(x, y)\} & : -\frac{sN_x}{2} \leq x \leq \frac{sN_x}{2} - 1, \\ & -\frac{sN_y}{2} \leq y \leq \frac{sN_y}{2} - 1 \\ 0 & : \text{otherwise} \end{cases} \quad (1)$$

Where, $\varphi(x, y)$ is the random phase.

$$G_0(u, v) = \frac{1}{\sqrt{N_x N_y}} \sum \sum g_0(x, y) \cdot \exp\left\{j2\pi\left(\frac{ux}{N_x} + \frac{vy}{N_y}\right)\right\} = |G_0(u, v)| \exp\{j\varphi_0(u, v)\} \quad (2)$$

$G_0(u, v)$ is the inverse Fourier transform of Eq. (2).

Next, as a restriction condition on the hologram side, we perform amplitude regularity and band limiting. Signal after having performed a restriction condition becomes Eq (3), if we replace the amplitude with constant value A.

$$G'_0(u, v) = \begin{cases} A \exp\{j\varphi_0(u, v)\} & : -\frac{tN_x}{2} \leq x \leq \frac{tN_x}{2} - 1, \\ & -\frac{tN_y}{2} \leq y \leq \frac{tN_y}{2} - 1 \\ 0 & : \text{otherwise} \end{cases} \quad (3)$$

By doing Fourier transform to $G'_0(u, v)$ obtained here, reconstructed image $g'_0(x, y)$ can be obtained.

$$g'_0(x, y) = |g'_0(x, y)| \exp\{j\varphi'_0(x, y)\} \quad (4)$$

In addition, we perform the following substitution as a restriction condition on the reconstructed image side.

$$g_1(x, y) = \begin{cases} |f(x, y)| \exp\{j\varphi'_0(x, y)\} & : -\frac{sN_x}{2} \leq x \leq \frac{sN_x}{2} - 1, \\ & -\frac{sN_y}{2} \leq y \leq \frac{sN_y}{2} - 1 \\ a_0 g'_0(x, y) & : \text{otherwise} \end{cases} \quad (5)$$

$g_1(x, y)$ is the signal after the substitution, and a_0 is Eq (6).

$$a_0 = \frac{\sum \sum |f(x, y)|^2 |g'_0(x, y)|^2}{\sum \sum |g'_0(x, y)|^4} \quad (6)$$

The algorithm called iterative dummy area method is to repeat the procedure described above using Eq (5) as a new input. It becomes Eq (7) and Eq. (8), if we define input of the $(k + 1)^{th}$ iteration as .

$$g_{k+1}(x, y) = \begin{cases} |f(x, y)| \exp\{j\varphi'_k(x, y)\} & : -\frac{sN_x}{2} \leq x \leq \frac{sN_x}{2} - 1, \\ & -\frac{sN_y}{2} \leq y \leq \frac{sN_y}{2} - 1 \\ a_k g'_k(x, y) & : \text{otherwise} \end{cases} \quad (7)$$

Figure 3: Phase difference restrictions.

$$a_k = \frac{\sum \sum |f(x, y)|^2 |g'_k(x, y)|^2}{\sum \sum |g'_k(x, y)|^4} \quad (8)$$

However, the speckle may occur because of using a random phase to the reconstructed image. Speckle is the noise appearing in the hologram technology in general, and occurs because of using coherent light such as laser light to reconstruct or record[1]. Due to give a big influence on the reconstructed image, it is necessary to remove the speckle. Therefore in order to remove the speckle, we limit the phase difference to the range shown in Fig. 3. Here, the phase difference is the difference of phase at each point in the reconstructed image. In this study, we call this speckle elimination method phase difference constraint method. we add phase difference constraint to restriction condition on the reconstructed image side of the iterative dummy area method.

3. Iterative variable dummy area method

The Fig. 4 shows the result of using an iterative dummy area method. The original image is Fig. 5. However, the result image has been adjusted that luminance value of the maximum is maximum value of the amplitude. A similar process has been performed to all the images in this study.

Figure 4: Result.

Figure 5: Original image.

Figure 6: Variable area.

From Fig. 4, it can be seen that a large number of errors are occurring in dummy area. Considering the optical reconstruction, it is undesirable for an error to occur in the

(a) The result including the dummy area.

(b) The result of the original image area only.

(c) Brightness value is max value in original area.

Figure 7: Result(Dummy area:128).

(a) The result including the dummy area.

(b) The result of the original image area only.

(c) Brightness value is max value in original area.

Figure 8: Result(Dummy area:128).

dummy area in use efficiency of the light. Therefore, we utilize the characteristic that the reconstructed image is modulated by a sinc function in both the horizontal direction and vertical direction when reconstructing the computer generated hologram. In the optical reconstruction, we can ignore the error that exists in the peripheral part of reconstructed image. Therefore, we increase the error occurs in peripheral part of reconstructed image instead of decreasing the error occurs in around the original image.

First, we will add the flexible area separate from the dummy area around the original image. We use the area comprising this flexible area as new original area, and perform the iterative dummy area method. We will reduce gradually the flexible area as repetition progresses. In the flexible area, max value is the range of dummy area, minimum is the range of original image area.

4. Simulation and results

The simulation was performed under the following conditions.

- Images: with 64×64 pixel shown in Fig. 5
- Initial phase: Random phase
- Dummy area: 256×256 [pixel]
- Band limiting: 1/2
- Irritation times: 1000 times

Reconstructed image error rate is performed by the following equation.

$$a_0 = 10 \cdot \log \frac{\sum \sum |f(x, y)|^2 |g'_k(x, y)|^2}{\sum \sum |g'_k(x, y)|^4} \quad (9)$$

We show the results of simulation in Fig. 7, Fig. 8. Figure 7(b) and Fig. 8(b) are results of taken out only original image area in Fig. 7(a) and Fig. 8(a). In addition, the value of dummy area's amplitude more than the value of original image area's maximum value has been adjusted to original image area's maximum value.

From Fig. 7 and Fig. 8, we found that the error occurs in peripheral part of reconstructed image but the error does not occur in around the original image. Further, the reconstructed image error is 29.3[dB] and -34.5[dB] respectively. In addition, the reconstructed image error reduction comparable is possible even when compared with the conventional iterative dummy area method.

5. Conclusion

Iterative dummy area method reduces the error of the original image area by using the degree of freedom in the dummy area. But, it is undesirable for the use efficiency of the light to occur error in the dummy area. Therefore, we utilize the characteristic that the reconstructed image is modulated by a sinc function when reconstructing the computer generated hologram. It was possible to reduce the error in around the original image by providing a flexible area in this study. Further, the reconstructed image error reduction comparable was possible even when compared with the conventional iterative dummy area method.

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