Dependence Initial Phase Distribution for Kinoform Speckle Elimination

Akihiro Ito^{a,*}, Takayuki Yokoyama^a, Shiyuan Yang^a

^aKyushu Institute of Technology, 1-1 Sensui-cho Tobata-ku Kitakyushu-shi Fukuoka-ken, 804-8550, Japan

*Corresponding Author: ito.serikawa@gmail.com

Abstract

In recent years, the holographic technology has advanced, and it has been drawing attention in various fields. Holographic technology can be classified into two types: optical holography and Computer-generated holography. Optical holography is a method in which a hologram is produced by irradiating a real object with light such as a laser. However, in this case, there is a problem that a hologram can not be produced for an object that does not actually exist or an object that is difficult to irradiate laser. On the other hand, since Computer-generated holography calculates the hologram creation process on a computer, it is possible to produce a hologram even for a fantasy object or an object difficult to irradiate laser. In this research, we focus on Kinoform which is a type of Computer-generated hologram. Kinoform is a phase type Computer-generated hologram that uses only phase information without using amplitude information, and is known for its extremely high light utilization efficiency. However, since the amplitude information is eliminated, the problem is that the error is large. One of the factors of the error is noise called speckle. In order to remove this speckle, there is a method called speckle elimination. However, this method has a problem that the effect may not be sufficient depending on the position of the original image in the reconstructed image area. In this research, we improved this problem by changing the initial phase of the original image.

Keywords: Computer-generated Hologram, Kinoform, Speckle elimination.

1. Introduction

In recent years, the holographic technology has advanced, and it has been drawing attention in various fields. Holography is a technology of wave-front recording and reproduction. Also, the hologram is a stereo image recorded

using diffraction and interference of light. Holographic technology is classified into two types, optical holography and Computer-generated holography. Generally, the technology of making a hologram using a real object and a laser is called optical holography, and the hologram produced by this technology is called an optical hologram. However, there is a problem that a hologram cannot be produced in the case where an object to be reproduced does not exist or when it is difficult to irradiate a laser. On the other hand, in the technology called Computer-generated holography, all calculations in the hologram creation process are performed on a computer, so that it is possible to produce holograms of objects that cannot be reproduced by optical holography and even for fantasy objects. Since light is generally represented by a complex number, a hologram produced by optical holography contains complex amplitude information. However, in Computer-generated holography, it is difficult to record both amplitude information and phase information on the same medium, so either one is recorded. Therefore, Computer-generated holograms are classified into two types, amplitude type Computer-generated hologram recording amplitude information only and phase type Computer-generated hologram recording phase information only. In this research, we use Kinoform which is one type of phase type Computer-generated hologram. An advantage of the Kinoform is that the utilization efficiency of light is remarkably higher than that of an amplitude type. However, Kinoform excludes amplitude information, so that large errors are generated in the reconstructed image. One of the factors of the error is that speckle appears in the reconstructed image. Speckle appears due to the use of coherent light such as laser, and it is noise generated in hologram technology in general. As a method of eliminating this speckle, there is a method called a speckle elimination, and by using this method, speckle can be completely removed. By the way, when the speckle elimination is used, a dummy area having no amplitude information and phase

information is given around the original image. At this time, the position of the original image can be freely arranged within the dummy area. In this way, it is possible to easily change the position of the reconstructed image by changing the content of the program without changing the position of the real hologram. This is useful in technology such as laser marking and laser surface processing. The reproduction that original image is arranged at the center of the dummy is called on-axis reproduction, and the reproduction that the original image is placed outside the center of the dummy area is called off-axis reproduction. There is a problem that the effect of the speckle elimination is sufficient in the case of on-axis reproduction, but in the case of off-axis reproduction, the effect of the speckle elimination may be insufficient depending on the position of the original image. What is considered as a cause of this problem is that when the position of the original image is changed, the phase distribution of the reproduced image also changes, therefore a phase distribution of a reconstructed image in which speckle elimination cannot be used appears. So the purpose of this research is that speckle elimination can be used regardless of the position of the original image to change the initial phase distribution of the original image.

2. Error reduction method of Kinoform

2.1 Fourier transform type Computer-generated Hologram

Figure 1 shows a simple hologram reproduction model. Coherent light is irradiated to the hologram and the light wave passes through the lens. As a result, a reproduced image can be obtained on the screen. There is a relationship of a Fourier transform pair between the hologram and the screen. A reconstructed image can be obtained by Fourier transformation of the hologram, and a hologram can be obtained by inverse Fourier transformation of the

Fig. 1. Fourier transform type hologram.

reconstructed image. Fourier transform type Computer-generated Hologram is making a hologram by considering the original image as a reconstructed image and performing inverse Fourier transformation on it.

2.2 Phase type Computer-generated Hologram

In the Computer-generated hologram, it is difficult to record both the amplitude information and the phase information on the same medium, so either information is recorded when making the hologram. The hologram in which only the amplitude information is recorded is called an amplitude type Computer-generated hologram, and the hologram in which only phase information is recorded is called a phase type Computer-generated hologram. A phase type Computer-generated hologram is often called a Kinoform. Kinoform has much higher light utilization efficiency than amplitude type. However, the amplitude information is missing, so the error of the reproduced image becomes large. Next section, I will describe the error reduction method of Kinoform.

2.3 Repetitive dummy area method

There is a method called a repetitive dummy area method as an algorithm for error reduction of Kinoform. In this method, it is possible to utilize the amplitude and phase freedom of the dummy area by addition of the dummy area that initial value is zero around the original image. Next, explain the concrete flow of repetition. First, making a hologram by performing inverse Fourier transformation on the original image plus the dummy area. After, on the hologram side, making the amplitude constant and applying band limitation. Band limitation is to set the amplitude and phase values outside the designated band to zero. By doing this, we can satisfy the sampling theorem and prevent aliasing. After these operations are completed, performing a Fourier transform on the hologram to create a reconstructed image. Finally, replacing only the original image area with the original image, and returning that image to the beginning of repetition as an input image. By repeating this operation, error can be reduced by the repetitive algorithm.

2.4 Speckle elimination

When preparing a hologram with Kinoform, noise called speckle appears in the reconstructed image by using a random phase as the initial phase. This noise cannot be removed by the repetitive dummy area method, so the

Fig. 2. Phase distribution model

speckle elimination is used to eliminate this noise. First, the generation mechanism of speckle will be described. Figure 2 is the four neighboring sample points. The phase difference between sample points is defined as follows.

$$\Delta\varphi_0(x, y) = \varphi(x-1, y-1) - \varphi(x, y-1) \quad (1)$$

$$\Delta\varphi_1(x, y) = \varphi(x, y-1) - \varphi(x, y) \quad (2)$$

$$\Delta\varphi_2(x, y) = \varphi(x, y) - \varphi(x-1, y) \quad (3)$$

$$\Delta\varphi_3(x, y) = \varphi(x-1, y) - \varphi(x-1, y-1) \quad (4)$$

Where $-\pi \leq \varphi \leq \pi$, $-2\pi \leq \Delta\varphi_i \leq 2\pi$

In this case, function (5) is obvious.

$$\sum_{i=0}^3 \Delta\varphi_i = 0 \quad (5)$$

However, when $-\pi \leq \Delta\varphi_i \leq \pi$, function (5) becomes function (6).

$$\sum_{i=0}^3 \Delta\hat{\varphi}_i = 0, \pm 2\pi, -4\pi \quad (6)$$

Therefore, speckle appears when the sum of phase differences becomes $\pm 2\pi, -4\pi$. Secondly, a concrete procedure of the speckle elimination will be described. First, in the original image area, examining the sum of the phase differences with respect to a point where the amplitude is not zero. When the sum of the phase differences has a value that is not zero, adding an appropriate phase such that the sum of the phase differences becomes 0. However, changing the phase of one of the four adjacent points, therefore it affects another adjacent four points. This problem is to solve by deciding sample points for changing the phase in advance and sequentially searching the original image area from one direction. This algorithm is a speckle elimination. In the repetitive dummy area method, incorporating the speckle elimination as a constraint condition on the reconstructed image side. As a result, it is possible to reduce the occurrence

Fig. 3. Reconstructed image

of speckle in the reconstructed image.

In Figure 3, creating reproduction images under the following conditions.

- Image size is 64×64 pixel
- Dummy area size is 512×512 pixel
- Number of repetition is 10000 times
- Band limiting is $1/2$
- Original image is Figure 3(a)

It is found that the reproduced image by the speckle elimination has the smallest error from Figure 3.

2.5 Effect of original image position

In the repetitive dummy area method and the speckle elimination, errors are reduced by using dummy area. The size of the dummy area can be arbitrarily set, and within the dummy area, the position of the original image can be freely arranged. In this way, it is possible to easily change the position of the reconstructed image by changing the content of the program without changing the position of the real hologram. This is useful in technology such as laser marking and laser surface processing. The reproduction that original image is arranged at the center of the dummy is called on-axis reproduction, and the reproduction that the original image is placed outside the center of the dummy area is called off-axis reproduction. However, in the course of the research, there is a problem that the effect of the speckle elimination might not appear sufficiently in the case of off-axis reproduction. In order to solve this problem, we propose the method of the next chapter. Therefore, the phase distribution of the reconstructed image has changed to a

phase distribution where the speckle elimination cannot be applied.

3. Dependence initial phase distribution for Kinoform speckle elimination

It is thought that the reason why the effect of the speckle elimination is not sufficiency by off-axis reproduction is that the phase distribution of the reconstructed image changed due to the change of the position of the original image. The speckle elimination acts on the phase distribution of the reconstructed image side during repetition. To solve this problem, we propose to change the initial phase of the original image. When the initial phase of the original image changes, the phase distribution of the reconstructed image also changes. Therefore, we thought that it is possible to generate the phase distribution to which the speckle elimination can be applied would by changing it in several patterns. Figure 4 shows the position of the original image in the dummy area. Reconstructed images created by changing the position of the original image by 3 patterns, changing the initial random phase by 4 patterns, and applying the speckle elimination are shown in Figure 5 to 7.

Fig. 4. Position of the original image

Fig. 5. Original image is Position 1

Fig. 6. Original image is Position 2

Fig. 7. Original image is Position 3

Figures 5 to 7 reproduced image are all created under the following conditions.

- Image size is 64×64 pixel
- Dummy area size is 512×512 pixel
- Number of repetition is 10000 times
- Band limiting is $1/2$
- Original image is Figure 3(a)

From Figure 5, in the case of the original image is at position 1, the speckle elimination can be applied when initial phase is patterns 1 and 3.

From Figure 6, in the case of the original image is at position 2, the speckle elimination can be applied when initial phase is patterns 2.

From Figure 7, in the case of the original image is at position 3, the speckle elimination can be applied when initial phase is patterns 2.

Therefore, it has been shown that the speckle elimination can be applied by changing the initial phase regardless of the original image position.

4. Conclusions

In this research, we showed that speckle elimination can be applied by changing the initial phase of original image no matter where the position of the original image is placed in the dummy area. As a future problem, when reproducing a hologram created by speckle elimination, observation is possible on simulation, but observation becomes difficult with actual optical reproduction. Therefore, we aim to make

holograms created by speckle elimination observable even by optical reproducing for future research.

References

- (1) Takayuki Yokoyama, Yosuke Koga, and Shiyuan Yang :
“Error Reduction Algorithm for the Generation of a
Kinoform with Laser Diode Array”, Proceedings of the
3rd International Conference on Industrial Application
Engineering, 2015
- (2) Joseph W. Goodman : “Introduction to Fourier Optics”,
Morikita Publishing Corporation, 287-293, 340-345,
2012
- (3) P.Hariharan : “Basics of Holography”, OPTRONICS
company, 9-11, 2004
- (4) George B.Arffen and Hans J.Weber, : “Mathematical
Methods for Physicists”, KODANSHA, 54-63,2009
- (5) Yatagai Toyohiko : “Light and Fourier Transform”,
Asakura Publishing Corporation, 12-24,1992