Generation of Pseudo Random Phase Distribution of Laser Light

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Abstract

In most cases, the distribution of an object can be calculated by measuring its Fourier transform distribution. When a general laser wave plane is used, the measurement of Fourier transform distribution has a large error because of the digitizing of Fourier amplitude. In this study, we suggest a method to generate a laser light distribution with pseudo random phase that can reduce the error of Fourier amplitude.

Keywords : random phase, diffuser, Fourier transform.

1. Introduction

When measuring objective form or surface reflectance, an object is irradiated with laser light and its intensity distribution can be calculated by measuring its Fourier transform distribution. However, the measuring error of Fourier transform distribution is very large when using a general laser wave plane⁽¹⁻⁴⁾. A dynamic range is a size of the amplitude of the Fourier spectrum. In order to make this dynamic range small, a random phase is used and generated by a digital phase diffuser irradiated with the laser light of a general laser wave plane. The general random phase usually leads to the happening of speckles in the distribution of laser wave plane. In this paper, we propose a method to generate laser wave plane without speckles by using the speckle reduction algorithm⁽⁵⁾. The generated phase distribution becomes a pseudo random distribution.

2. Review of Fourier Spectrum Measurement

In the measurement of Fourier spectrum, an illuminating wave plane is irradiated to an object shown in Fig. 1(a). The Fourier spectrum concentrates at the center of optical axis. This leads to a large quantization error of Fourier amplitude

so that a large error exists in the calculation of the object. In addition, the information of high spatial frequency region loses caused by quantization so that a large error exists in the calculation of the object. When using a random diffuser as shown in Fig. 1(b), the dynamic range can be reduced so that the problem described above can be avoided. In general, a random phase diffuser leads to speckles in the laser wave plane. And it is difficult to avoid these speckles such as using general diffusers. Instead of the conventional phase diffuser, digital diffuser and double diffraction optical systems are available for this the purpose speckle reduction.

Fig. 1. Fourier spectrum measurement.

3. Speckle Reduction Using Double Diffraction Optical System

Figure 2 shows the optical system of double diffraction Fourier transform. The relationship between the input and the output is

$$g(x',y') = f(x,y), \quad (1)$$

where $x' = -x, y' = -y$.

Fig. 2. Optical system of double diffraction Fourier transform.

This system has the merit that the same distribution to the input can be obtained at the plane with distance $4f$. In fact, the extent of Fourier lens is finite so that Eq. (1) becomes

$$g(x',y') \approx f(x,y). \quad (2)$$

This means the finite extent of Fourier plane corresponds to the band limitation of Fourier transform.

To generate a random phase distribution at the output plane, a spatial light modulator can be used and we use a phase modulator to modulate the general laser wave plane. For convenience, we suppose the laser light as a plane wave. Because of Eq. (2), the error must be caused by band limitation. So we use the general Fourier repetition algorithm to reduce the error and use the phase reduction algorithm to avoid the generation of speckles at output⁽⁵⁾. Figure 3 shows the diagram of the above method.

Fig. 3. Iterative Fourier repetition algorithm.

4. Simulations and Results

In the simulations, we use two types of speckle reduction method. One is to select the phase of input randomly with phase difference constraint (Method A), another is the iterative phase difference constraint algorithm (Method B). For details of the phase difference constraint and the iterative phase difference constraint algorithm, see Ref. (5).

4.1 Generation of Laser Light Distribution with Pseudo Random Phase

We first show the simulation on the generation of laser light distribution. Suppose the desired intensity distribution of the generated laser light be a uniform squared one with 128×128 sampled pixels and the phase be random. The size of the input distribution is 256×256 sampled pixels and the center 128×128 pixels which use distribution of the output corresponding to a phase modulator. The irradiated laser light is a plane wave. The initial phase distribution is random generated. In the iterations of the Fourier repetition algorithm described in Sect. 3, the input phase distribution is restricted with Method A and Method B and the Fourier transform distribution is limited into 128×128 pixels. The number of iteration is 10000. Figure 4(a) and (b) show the output intensity with methods A and B, respectively. It can be observed that uniform squared distributions are obtained.

(a) Method A

(b) Method B

(c) Constant phase

(d) General random phase

Fig. 4. Output intensity distribution.

To compare with the general methods, Fig. 4(c) shows the output intensity with a constant phase distribution and Fig. 4(d) shows the general random phase case. The case of constant phase can be also generate a uniform squared distribution but the phase is not random. For the case of a general random phase, it can be observed speckles occur from Fig. 4(d). Figure 5 shows the phase histogram of output with methods same to Fig. 4. It can be observed that the phase distribution using method A is similar to that with general random phase. For the case of method B the phase distribution is a little different to a random one because the condition of iterative phase difference constraint algorithm is strict. For the constant phase, the phase distribution concentrates near a constant value. Table 1 shows the maximum of Fourier amplitude with different types of phase. It can be observed that the maximum of Fourier

Fig. 5. Output phase distribution.

Table 1. Maximum of Fourier amplitude with different types of phase.

Type of phase	Maximum of Fourier amplitude
Restricted by method A	13.8
Restricted by method B	17.8
Constant phase	63.2
General random phase	1.5

amplitude becomes small when method A or Method B is used. So we can say methods A and B can generate pseudo random phase distribution that has smaller Fourier amplitude dynamic range than that with a constant phase.

4.2 Measurement of a Test Image with the Generated Pseudo Random Phase Laser Light

We show a test of the measurement with Fourier spectrum using a test image shown in Fig. 6. The test image has the same size to the uniform squared laser light in the previous section. The test image is illuminated with the four types of laser light shown in Sect. 4.1. The reconstructed images from the measurement of Fourier spectrum are shown in Fig. 7. From Fig. 7(d), it can be observed that speckles exist when the general random phase is used. The reconstructed images using methods A and B (Figs. 7(a) and (b)) do not have any speckles that are similar to the reconstruction using a constant phase illuminating laser light (Fig. 7(c)). So we can say the proposed methods A and B are suitable for the measurement of Fourier spectrum.

Fig. 6. Test image.

Fig. 7. Reconstructed images.

5. Conclusions

In this study, we proposed two methods to generate pseudo random phase distribution for reducing the Fourier amplitude dynamic range. These methods do not have any speckles in the laser light distribution and we may say it is suitable as an illumination laser light for Fourier spectrum measurement.

References

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