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Phase Extraction Technology Based on the Unequal-Step Phase Shift Method

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Abstract

In recent years, the rapid development of science and technology to promote industrial high-speed forward, optical three-dimensional measurement technology gradually forming, and applied to multi-industry multi-field. The use of optical projection of the three-dimensional measurement technology can achieve zero contact and high-speed and efficient measurement, recovery error is also small, high precision, so more experts and scholars will be put into its research. When the sine grating is projected onto the object to be measured, the light changes by the height of the points of the object to be measured, the deformed gratings are obtained. Phase measurement profiling use these deformed gratings which have the phase information to extract phase, then use the phase - height relationship to restore the three - dimensional surface of the object. The work of this paper is to study the phase extraction technique of three-step unequal phase shift method and five-step unequal step phase shift method. Firstly, the model and the deformed grating stripe modulated by the measured object and the measured object are established, and the phase is extracted by the three-step and five-step inequality algorithm to obtain the phase, and then the phase of each object to be measured is reconstructed by the phase-height relationship. Height information to restore the shape of the object being measured.

Keywords

Optical three-dimensional measurement, structured light projection, phase measurement profilometry, unequal step phase shift method.

1. INTRODUCTION

The phase shift method can be considered as the earliest phase calculation method, and it is also a commonly used method to obtain relative phase values. It not only utilizes the deformed grating stripe obtained by modulating the sinusoidal grating through the object to be measured, but also uses the phase shift method to combine the two to obtain the three-dimensional information features of the object to be measured. It subtracts the phase of the object and the phase of the reference plane after being placed on the object to obtain the difference between the two phases, and uses the difference to perform three-dimensional reconstruction of the object to obtain three-dimensional information of the object. Phase measurement profilometry is the most complete technique in the phase measurement method. It requires a simple measurement environment and configuration, and high precision. As the number of phase shift steps increases, the phase shift will become smaller and smaller, and the measurement time will be longer and longer. Therefore, the commonly used phase shift method is mainly three-step phase shift method, four-step phase shift method and five-step phase shift method.

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2. PRINCIPLE OF PHASE EXTRACTION TECHNOLOGY

2.1. The Basic Principle and Implementation Method of Three-Step Unequal Step Phase Shift Method

A sinusoidal grating stripe is irradiated onto the surface of the object to be measured, and any phase shift is performed in the range of $(-\pi, \pi)$, and δ_n is the phase shift of the nth (n=0, 1, 2) frame sine fringe pattern to obtain three-frame distortion. The grating stripe can be expressed as:

$$I_n = R\{A + B\cos(\varphi + \delta_n)\} \quad (1)$$

Where δ_{n} is an arbitrary quantity and δ_0 =0, which is as follows:

$$I_1 - I_0 = RB[\cos(\varphi + \delta_1) - \cos\varphi] \quad (2)$$

$$I_2 - I_0 = RB[\cos(\varphi + \delta_2) - \cos\varphi] \quad (3)$$

Equation (3) is the obtained phase principal value, and then the phase of the height modulated by the object after being placed on the object is subtracted from the phase value of the reference plane to obtain the difference between the two phases.Then according to the height mapping formula, the three-dimensional shape of the object can be recovered.

2.2. The Basic Principle and Implementation Method of Five-Step Unequal Step Phase Shift Method

A sinusoidal grating stripe is irradiated onto the surface of the object to be measured, and any phase shift is performed in the range of $(-\pi, \pi)$, and the five-frame deformed grating stripe can be expressed as:

$$I_n = R\{A + B\cos(\varphi + \delta_n)\} \quad (4)$$

Where δ_{n} is an arbitrary quantity and δ_{n} =0, which is obtained by the formula (4):

$$I_3 - I_1 = RB[\cos(\varphi + \delta_3) - \cos(\varphi + \delta_1)] \quad (5)$$

$$I_4 + I_2 - 2I_0 = RB[\cos(\varphi + \delta_4) + \cos(\varphi + \delta_2) - 2\cos\varphi] \quad (6)$$

Let $X = I_4 + I_2 - 2I_0, Y = I_3 - I_1$=1, be obtained by (6)/ (5):

$$\frac{X}{Y} = \frac{\cos(\varphi + \delta_4) + \cos(\varphi + \delta_2) - 2\cos\varphi}{\cos(\varphi + \delta_3) - \cos(\varphi + \delta_1)} \quad (7)$$

Solve the above formula:

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$$\varphi = \arctan \frac{X\cos\delta_3 - Y\cos\delta_1 - Y\cos\delta_4 - Y\cos\delta_2 + 2Y}{X\sin\delta_3 - X\sin\delta_4 - Y\sin\delta_1 - Y\sin\delta_2} \tag{8}$$

The equation (8) is the obtained phase main value, and then the phase of the height modulated by the object after being placed on the object is subtracted from the phase value of the reference plane to obtain the difference between the two phases, and then the height mapping formula can be recovered. The three-dimensional shape of the object.

3. SIMULATION

In order to prove the accuracy and superiority of the technique of extracting phase by the non-equal phase shift method in three-dimensional measurement, computer simulation and error analysis are a high-efficiency and low-cost test analysis method. Firstly, a sinusoidal distribution fringe pattern with a modulation grating period of 8 pixels is generated, and then a three-dimensional object model is generated. Finally, a sinusoidal grating stripe pattern is modulated by a three-dimensional object to simulate a deformed modulated raster image, and the deformed modulated raster image is subjected to a three-dimensional phase shift algorithm. Refactoring to recover the corresponding 3D object.

3.1. Three-Step Unequal Step Phase Shift Simulation

First, the code is generated to generate a fringe pattern, and then three three-dimensional object models are generated, and the modulated modulation grating maps of the objects are simulated respectively. The three-step unequal phase shift algorithm is used to reconstruct the three-dimensional reconstruction of the deformed raster image to restore the corresponding The shape of the three-dimensional object.

3.1.1 Model 1: Three-dimensional shape reconstruction of peaks function model

Model 1:

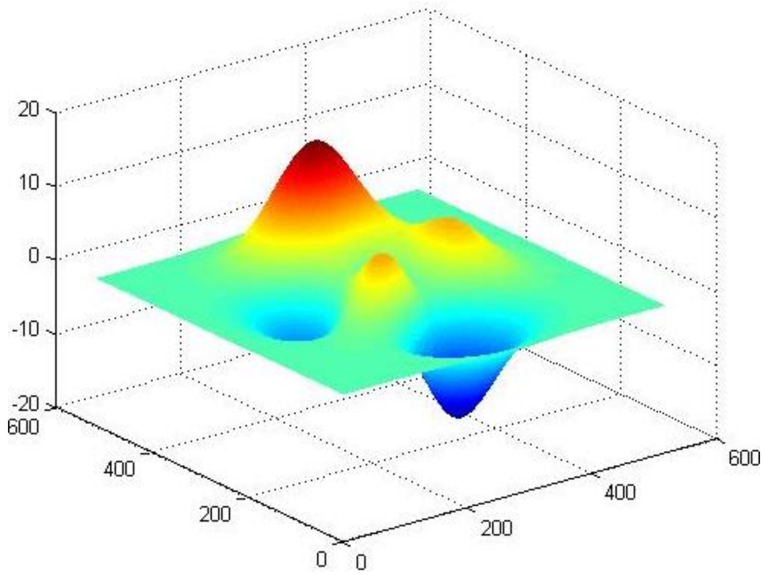

Fig 1. Model 1 original image

Display of all rasters projected to model one without noise and all rasters with random noise (0.5*rand (512)):

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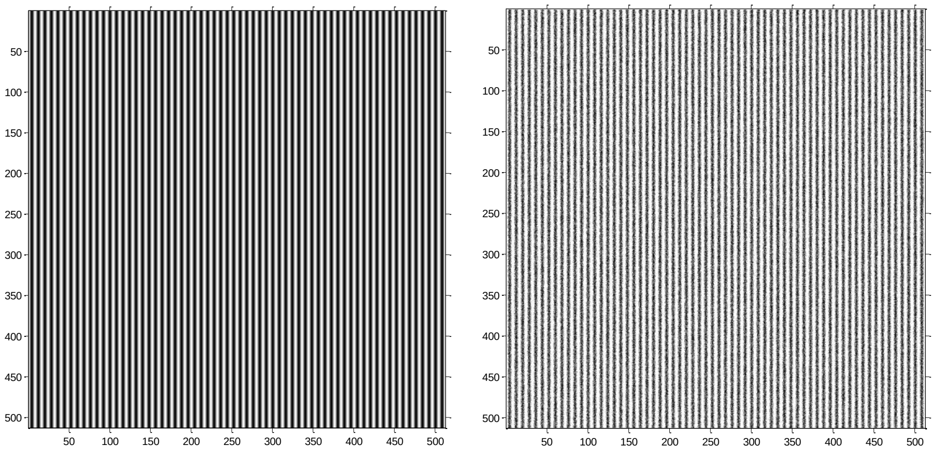
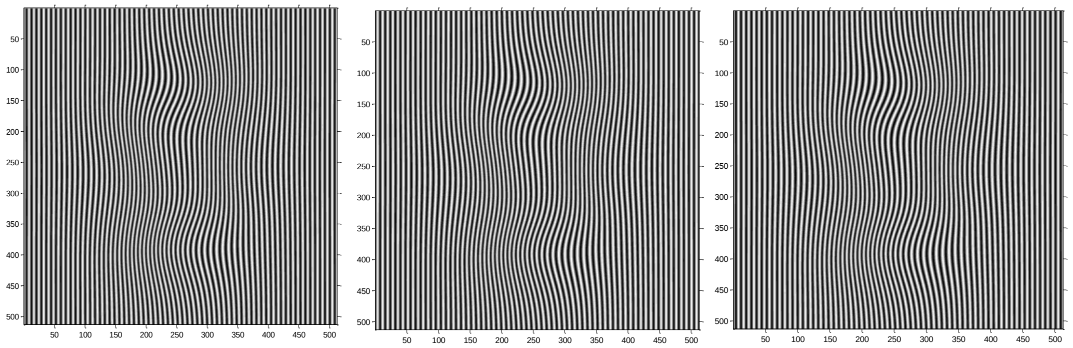
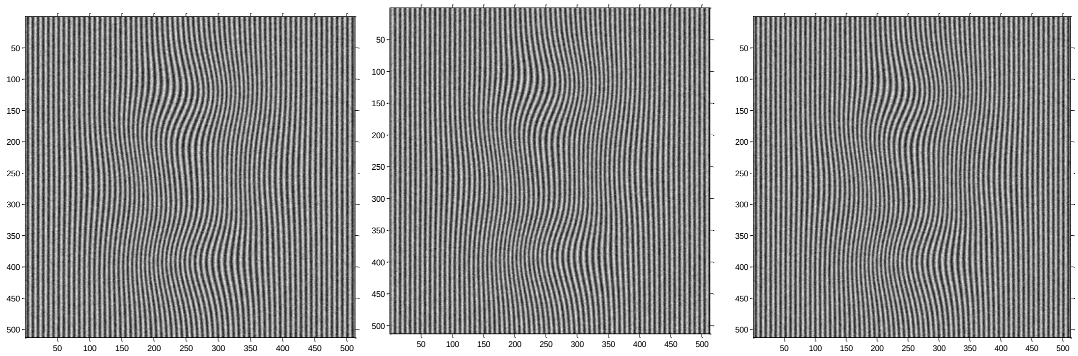


(a) Reference grating



$delta = 2/3\pi$ $delta = 2\pi - 0.2$ $delta = 2\pi - 0.1$

(b) Deformed grating without noise



$delta = 2/3\pi$ $delta = 2\pi - 0.$ $delta = 2\pi - 0.1$

(c) Deformed grating after noise addition

Fig 2. Deformed grating

It can be seen from Fig. 2 that the reference grating stripe with no noise is clear, neat and orderly, and is a vertical stripe between light and dark; while the approximate shape of the reference grating after noise is added, the stripe outline is obviously blurred. And the streak color is not as clear as before. Deformed gratings undergo different degrees of deformation with different phase shift amounts, and the difference between the shape variables before and after noise addition is not obvious, but the stripe contour is blurred.

When no noise is added, the reconstructed model one and the error map show:

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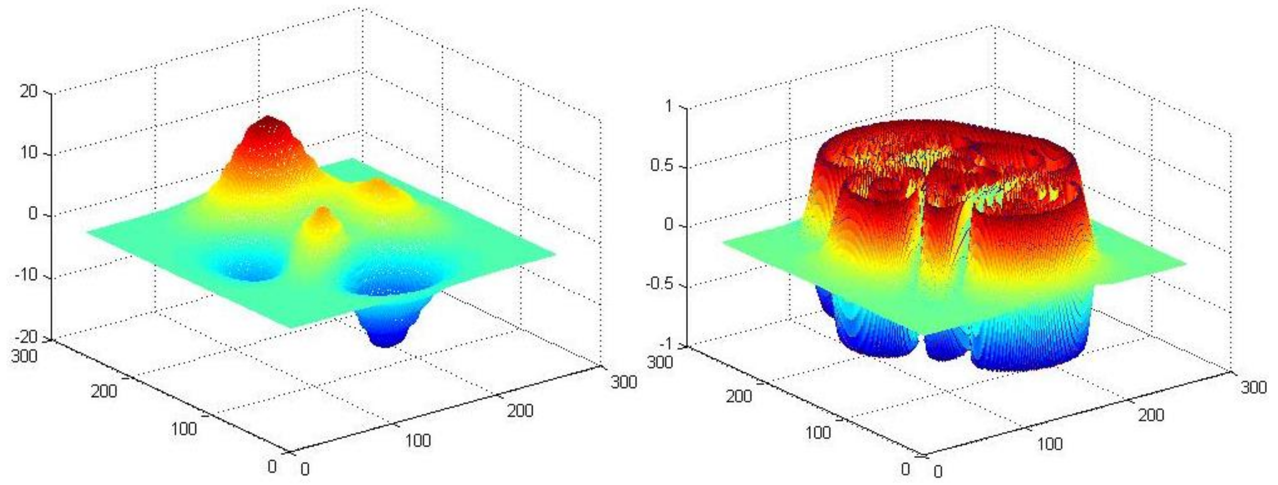
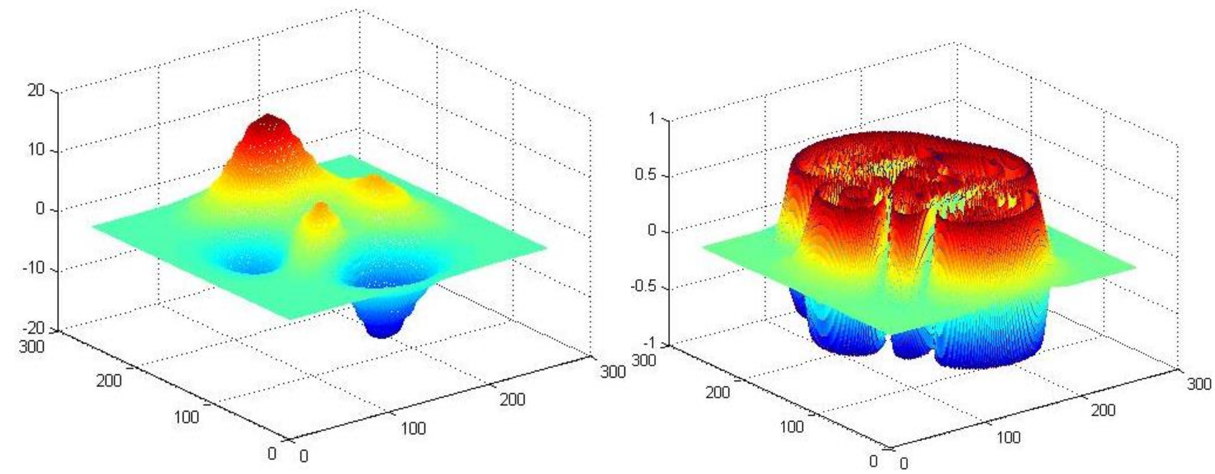


(a) Recovery graphics (b) Error graph

Figure 3. Recovery and error plots without noise

It can be seen from the figure that when no noise is added, the three-dimensional object pattern recovered by the three-step unequal phase shift algorithm is more consistent with the original image, except that the surface is slightly matte and the error is between -1 and 1.

After adding 0.5*rand (512) of random noise, the reconstructed model and error plots show:



(a) Recovery graphics (b) Error graph

Figure 4. Recovery and error map after adding noise

It can be seen from the figure that after adding noise, the three-dimensional object pattern recovered by the three-step unequal phase shift algorithm is more consistent with the original image, and the surface is slightly matte, and the error is also between -1 and 1. The difference is not obvious compared to the recovery map when no noise is added.

3.1.2 Model 2: Three-dimensional reconstruction of the straw hat model

Model 2:

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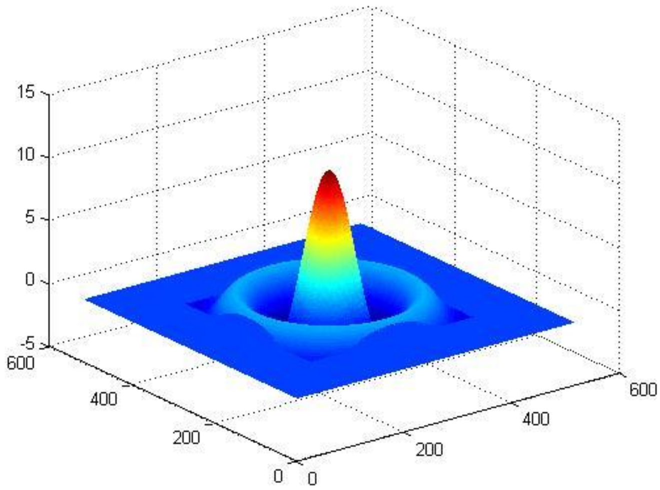
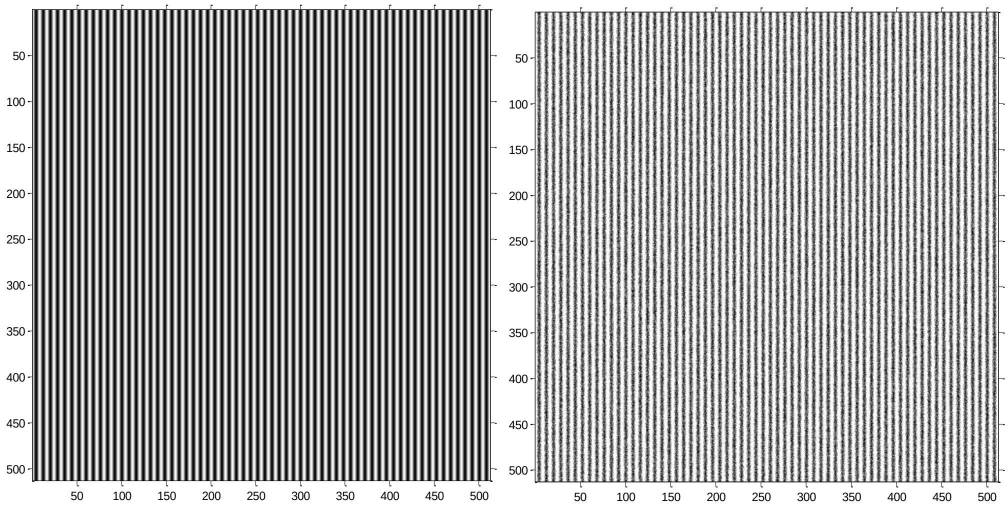
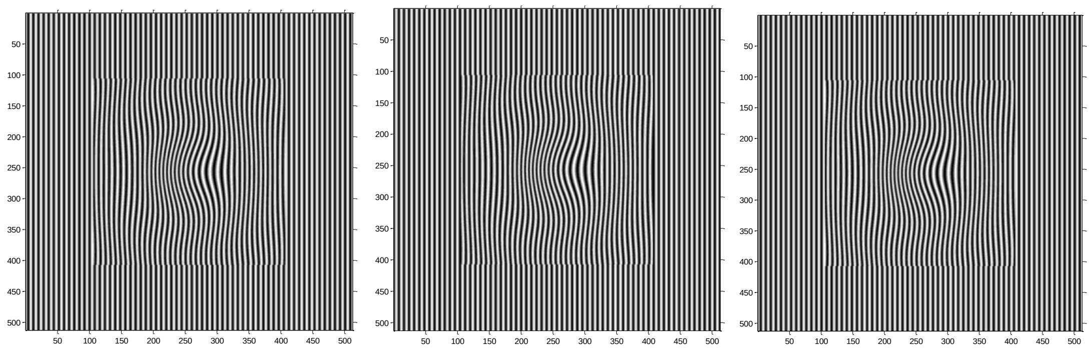


Figure 5. Model three original graphics

Display of all gratings projected to model three without noise and all gratings with random noise (0.5*rand (512)):



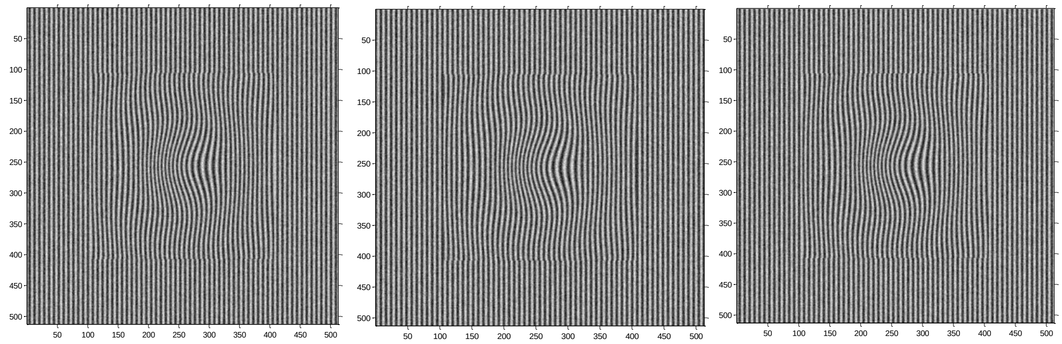
(a) Reference grating



$delta = 2/3\pi$ $delta = 4/3\pi$ $delta = 2\pi - 0.$

(b) Deformed grating without noise

ISSN: 2472-3703 DOI: 10.6911/WSRJ.201908_5(8).0001



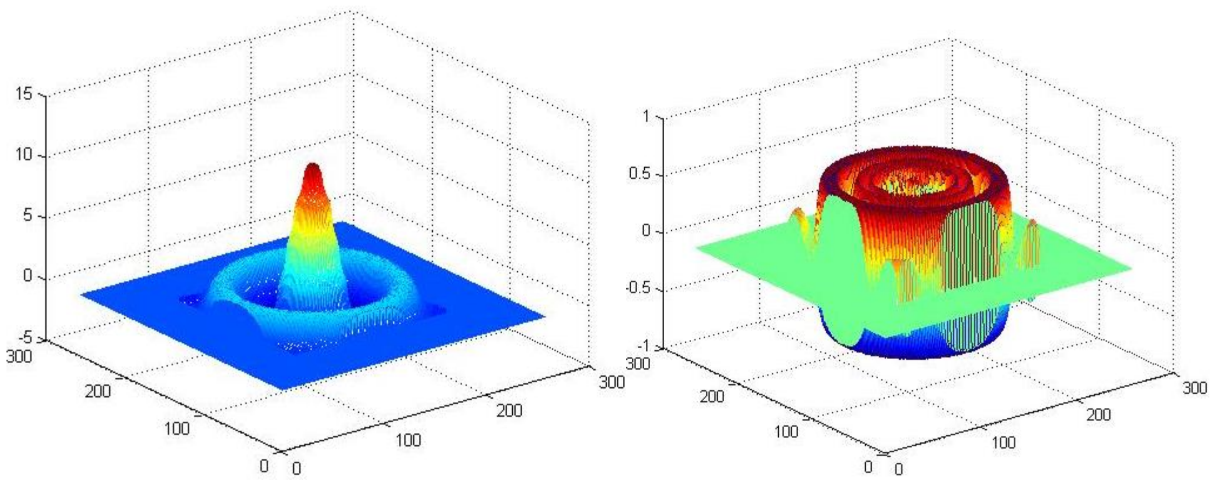
$delta = 2/3\pi$ $delta = 4/3\pi$ $delta = 2\pi - 0.1$

(c) Deformed grating after noise addition

Figure 6. Deformed grating

It can be seen from Fig. 4 that the reference grating stripe without noise is clear and neatly arranged, which is a vertical stripe between light and dark. However, although the approximate shape of the reference grating after noise is added, the stripe outline is obviously blurred. And the streak color is not as clear as before. In addition to the above differences, the deformed gratings before and after the addition of noise have different degrees of deformation with different phase shift amounts.

Model 3 and error graphs for reconstruction without noise:

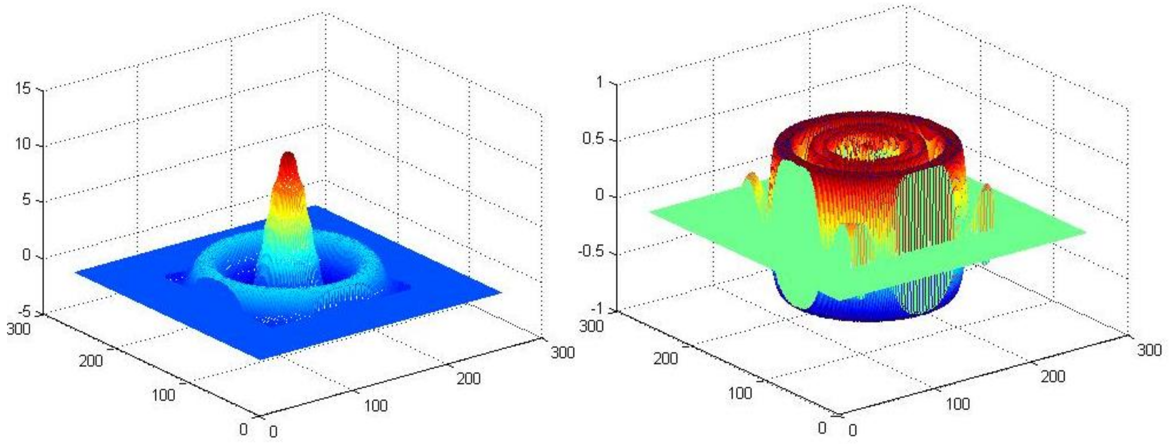


(a) recovery graphics (b) Error graph

Figure 7. Recovery and error plots without noise

It can be seen from the figure that when no noise is added, the three-dimensional object pattern of the model three recovered by the three-step unequal phase shift algorithm is consistent with the original image, and the surface is slightly uneven, and its error map shows an error of -1. Between 1 and 1.

The reconstructed model three and error plots after adding 0.5*rand(512) of random noise show:



(a) recovery graphics (b) Error graph

Figure 8. Recovery and error map after adding noise

It can be seen from Fig. 6 that after adding noise, the three-dimensional object pattern of the model three recovered by the three-step unequal phase shift algorithm is consistent with the original image, the surface is slightly uneven, and the image recovered when no noise is added. The difference is not large, and the display error is between -1 and 1 in the original image.

Through the three-dimensional object reconstruction of the three models, we can see that the phase extraction technique of the three-step unequal phase shift method has higher precision, and the recovered model is not much different from the original image. The difference is not obvious. At the same time, we can see from the results of the comparison of the three models that the three-step unequal phase shift algorithm is roughly the same in accuracy for the different models, because from the error analysis diagram, the three models The error analysis graph has hardly changed much. Moreover, for the same model, the effect of adding noise or not adding noise is not very large.

3.2. Five-Step Unequal Step Phase Shift Simulation

The first is to generate a fringe pattern in the MATLAB development environment, and then generate three three-dimensional object models, respectively simulate the modulated modulation raster map of these objects, and use the five-step unequal step phase shift algorithm for the deformed raster image. Reconstruction, restore the corresponding three-dimensional object shape.

3.2.1 Model 1: Three-dimensional shape reconstruction of peaks function model

Model 1:

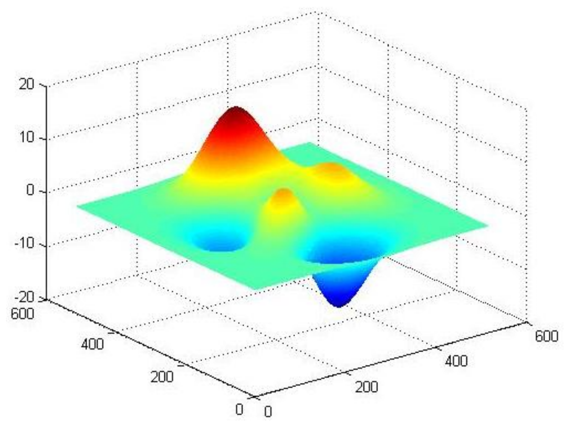
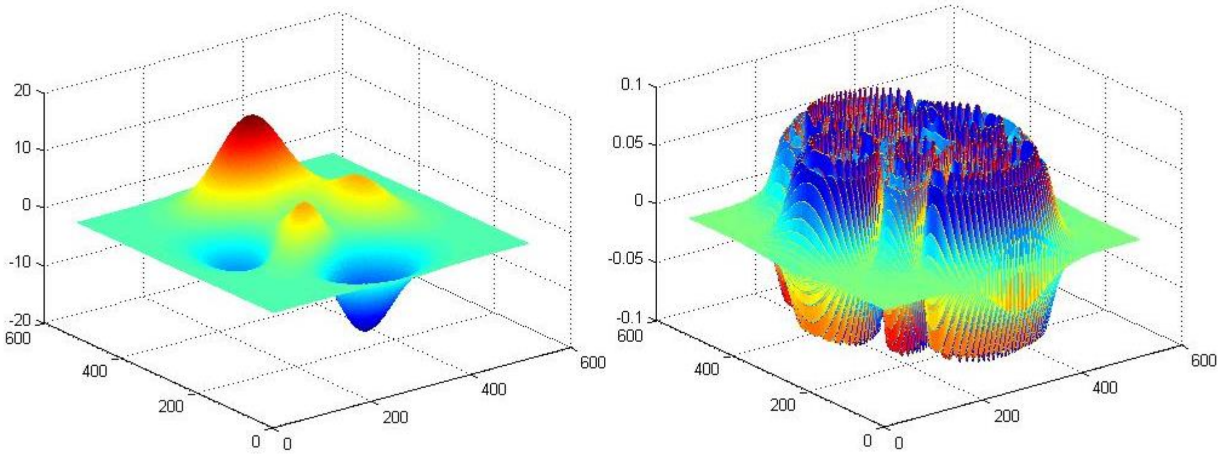


Figure 9. Model 1 original image

ISSN: 2472-3703 DOI: 10.6911/WSRJ.201908_5(8).0001

When no noise is added, the reconstructed model one and the error map show:

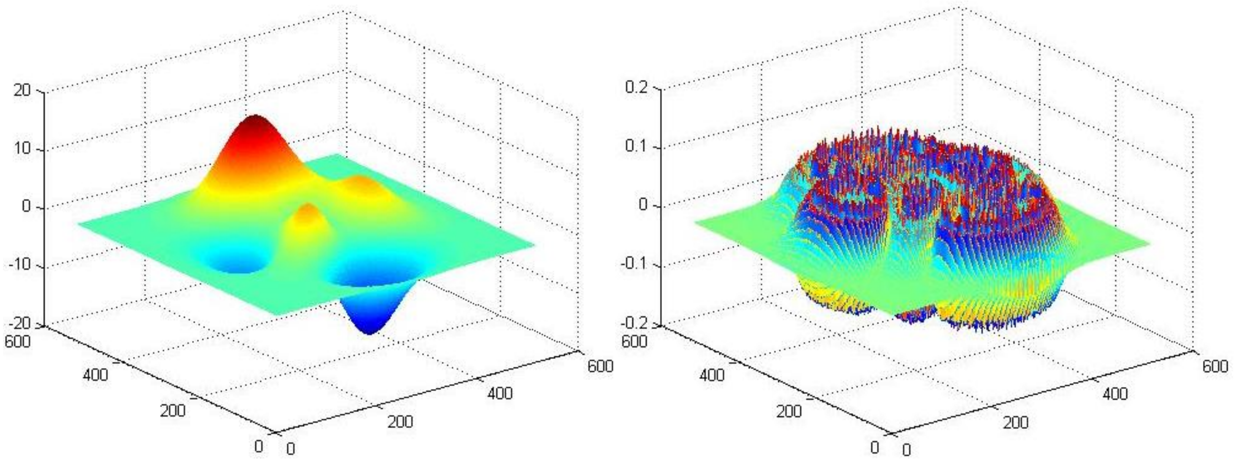


(a) recovery graphics (b) Error graph

Figure 10. Recovery and error plots without noise

It can be seen from Fig. 3.15 that when no noise is added, the three-dimensional object pattern of the model one recovered by the five-step unequal phase shift algorithm is more consistent with the original image, and is more reconstructed than the three-step unequal phase shift method. Smooth, more reductive, its error plot shows an error between -0.1 and 0.1.

The reconstructed model 1 and error plots after adding 0.5*rand (512) of random noise show:



(a) recovery graphics (b) Error graph

Figure 11. Recovery and error map after adding noise

It can be seen from Figure 11 that after adding random noise, the recovered graphics have a good effect, which is not much different from the original image, and the error is between -0.2 and 0.2.

It can be seen that the phase extraction technique of the five-step unequal phase shift method has higher precision, and the recovered model has little difference from the original image. The error of the model reconstructed before and after adding random noise is 0.1 higher than that without noise.

3.2.2 Model 2: Three-dimensional reconstruction of the straw hat model

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Model 2:

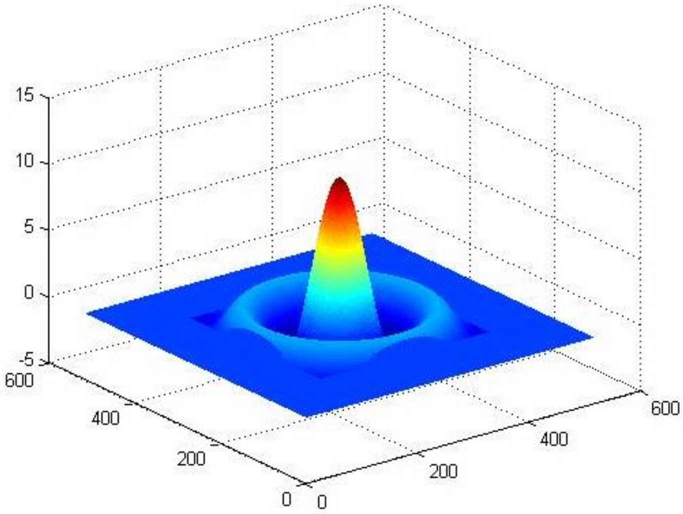
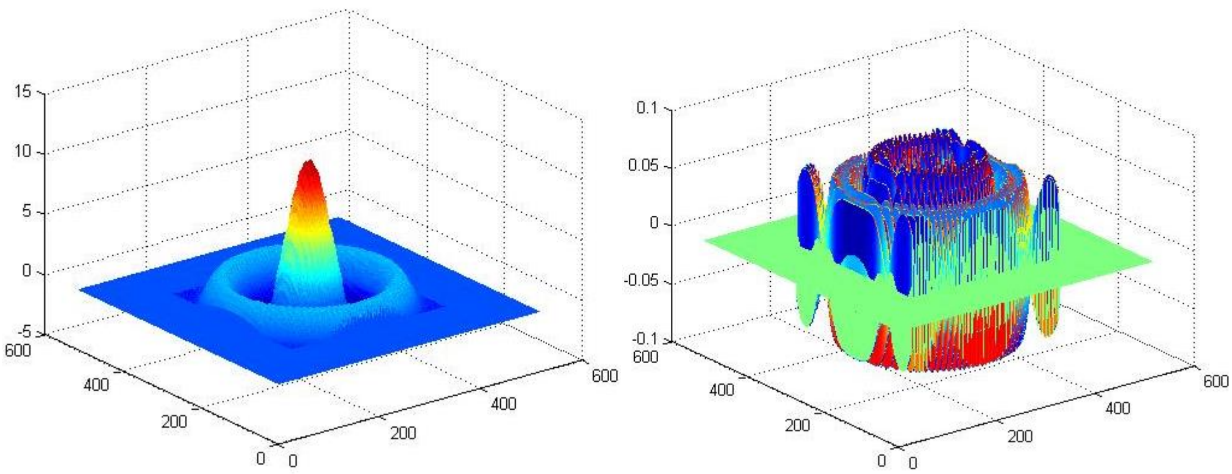


Figure 12. Model 3 original image

Reconstructed model three and error maps when no noise is added:



(a) recovery graphics (b) Error graph

Figure 13. Recovery and error plots without noise

It can be seen from the figure that when no noise is added, the three-dimensional object pattern of the model three recovered by the five-step unequal phase shift algorithm is more consistent with the original image, and is smoother than the three-step unequal phase shift method. The reductiveness is better, and its error graph shows that the error is also between -0.1 and 0.1.

The reconstructed model three and error plots after adding 0.5*rand (512) of random noise show:

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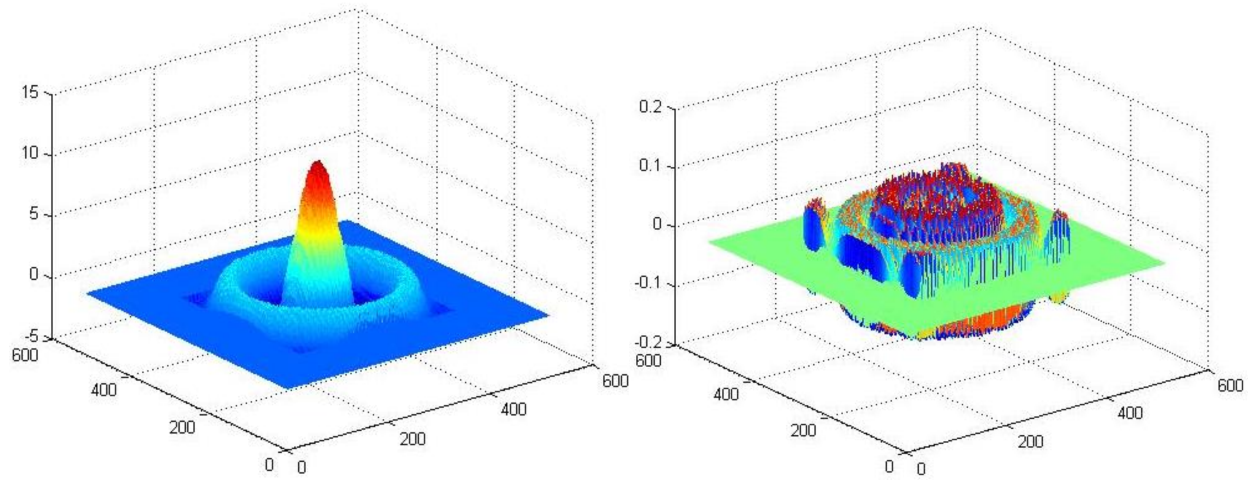

(a) recovery graphics (b) Error graph

Figure 14. Recovery and error map after adding noise

It can be seen that the phase extraction technique of the five-step unequal phase shift method has higher precision, and the recovered model three is not much different from the original image. The error of the model reconstructed before and after adding random noise is 0.1 higher than that without noise. .

4. CONCLUSION

Through the comparison of the above three models under the five-step unequal phase shift algorithm, it can be seen that the accuracy of the recovered images between the different models is not much different, and the errors are kept within the same range. However, for the same model, the error when adding noise is higher than that when no noise is added, but it is not a big influence.

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