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A new method based on neural network to solve the wrapped phase map from 2-fringe

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Abstract: The phase shift method of fringe projection technique has attracted much attention for its high-precision, high-speed, and flexible measurement capabilities. But the increase of the phase shift step also means that the measurement is more time-consuming. Compared with at least three steps phase shift method, the two-step phase shift method is important to coordinate measurement speed and accuracy. This paper proposes a new method based on neural network to solve the wrapped phase map. The simulation results show that this method is an accurate and efficient two-step phase shifting phase solution method.

1. Introduction

Structured light profilometry (SLP) is an optical three-dimensional scanning technology. It uses pre-defined spatial intensity patterns that will change relative to the original pattern due to surface contours. By analyzing the intensity distribution of fringe after deformation, the measured shape can be reconstructed. Digital fringe projection (DFP) technique has been widely used in industries, medical, entertainment and other fields due to its advantages of high spatial resolution, fast speed, and high dot density [1].

Extracting the phase from the deformed fringe pattern is a essential process of fringe projection profilometry. At present, Fourier profilometry [2] and phase shift profilometry [3] are the two most important methods in DFP. Fourier transform profilometry only needs one fringe image, and the phase can be demodulated through frequency domain information. Therefore, it has been widely used in dynamic measurement [2]. However, the filtering window, noise and even boundary defects have a great influence on its accuracy. The traditional phase-shifting method requires at least three images with a known phase shift [3], but the number of steps is proportional to once measurement time. In addition, the object is required to remain stationary during the measurement. When the object moves, corresponding phase error will occur. In order to balance the measurement time and accuracy, the two-step phase shift method should be a good compromise method.

In recent years, in order to meet the requirements of fast measurement, while ensuring high measurement accuracy, while reducing the number of images that need to be collected as much as possible, a variety of two-step phase shifting algorithms have been proposed [4-5]. Although some methods are more flexible or accuracy, it still takes a long time compared with the traditional algorithm.

In order to efficiently measure and calculate in a time-saving manner, this paper uses a neural network [6-7] to solve the two-step phase shift phase to obtain accurate phase information. The method proposed in this paper has high application value in the field of rapid measurement.

2. Two-step phase shift

The fringe projection method uses a certain angle between the projector and the camera's optical axis to construct a triangular relationship, and obtains the three-dimensional profile of the measured object through phase and height mapping. In this paper, different gray values are regarded as different heights of three-dimensional objects, and the mapping relationship between phase and gray value of two-dimensional images is constructed.

The fringe projection method generally uses cameras and projectors as the main measurement tools. The projector is responsible for projecting a specific pattern of fringe pattern on the surface of the object to be measured, and the camera is responsible for collecting the pattern of fringe pattern on the surface of the projected object. If necessary, a plane will be added after the object to be measured as the carrier plane. However, even if it is not added, a virtual plane will be introduced after the object to be measured to facilitate the calculation, so it does not affect the measurement of the system.

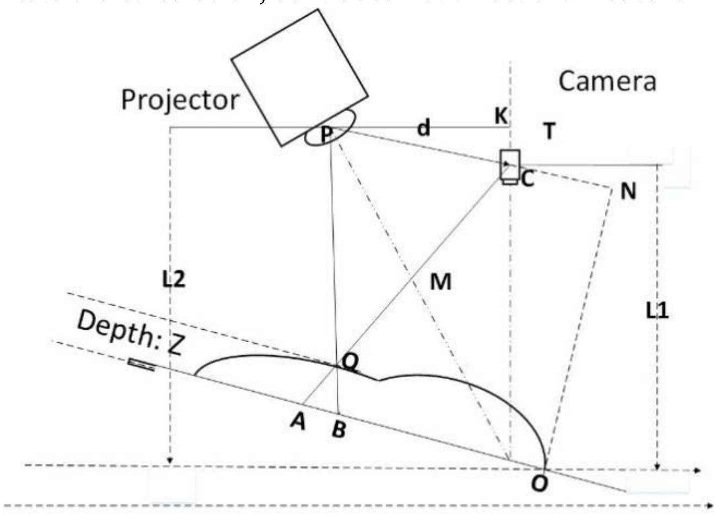

Figure 1: Optical path diagram of raster projection technology

The optical path diagram of the system is shown in Figure 1. Where P is the optical center of the projector and C is the optical center of the camera. O is the intersection of the optical axis of the camera and the optical axis of the projector, and the horizontal plane passing through point O is the reference X-axis in the calculation. $L1$ and $L2$ are the distance from the camera optical center and the projector optical center to the X-axis, and d is the distance from the camera optical center to the projector optical center along the X-axis. PO is assumed to intersect AC at point M, and the $A-B-O$ plane is a hypothetical imaginary plane and parallel to the connection PC between the optical center of the projector and the optical center of the camera.

Since $\overline{AB}$ is much smaller than $\sqrt{(L2-L1)^2+d^2}$ in actual measurement, its existence can be ignored, and the above formula is simplified as follows:

$$Z(x,y) \approx \frac{d \cdot L1 \cdot \overline{AB}}{(L2-L1)^2+d^2} = \frac{d \cdot L1}{(L2-L1)^2+d^2} \cdot \overline{AB} \tag{1}$$

If the fringe pattern projected by the projector has a fixed period, since the projection from the plane (ideal DLP micromirror array) to the plane is a linear mapping, the pattern mapping on the virtual plane also has a fixed period.

For the N-step phase shift method, the phase shift of each step is different from the projected phase of the previous step by $\frac{2\pi}{N}$, that is, the following equations:

$$I_i(x,y) = A(x,y) + B(x,y)\cos\left[\frac{2\pi}{N}\cdot(i-1)+\varphi(x,y)\right] \tag{2}$$

Where $i = 0,1,2,\ldots,N-2,N-1$. Use the PEAKS function in Matlab and set the height to -6. A two-step phase shift method is used, and noise with a mean value of 0 and a variance of 1 gray level is added to the figure. The corresponding two images collected are shown in Figure 2.

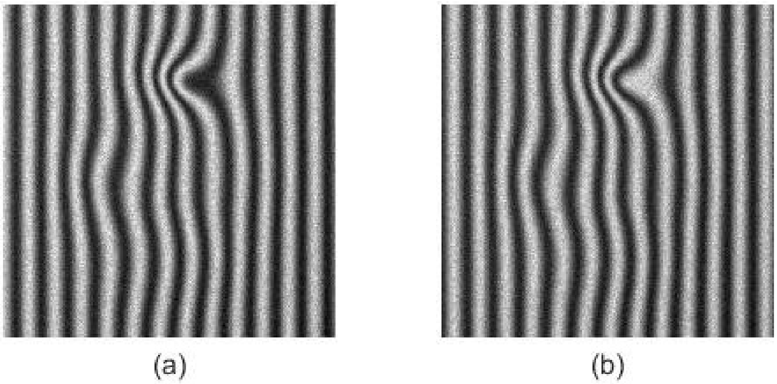

Figure 2: Two-step phase shift image. (a) Phase shift angle; (b) Phase shift angle π

The equation system has N equations and three unknowns. In principle, it can be solved when $N \geq 3$. But for the two-step phase shift method, there are only two equations, so it needs a special method to solve it.

3. Neural network method

First the training set is collected. This paper builds a random height shape generator. After the distribution matrix is generated by the PEAKS function i*n Matlab, the following random* distribution is used to obtain the corresponding indicated height.

$$H = r_h \cdot (H_0)^{r_g} \tag{3}$$

Where r_h is a highly random parameter uniformly distributed in $[-5,5]$, and r_g is a gradient random parameter uniformly distributed in $[1/2,2]$.

In summary, the fringe image we get (take the initial phase image of each group of samples as an example) is as follows:

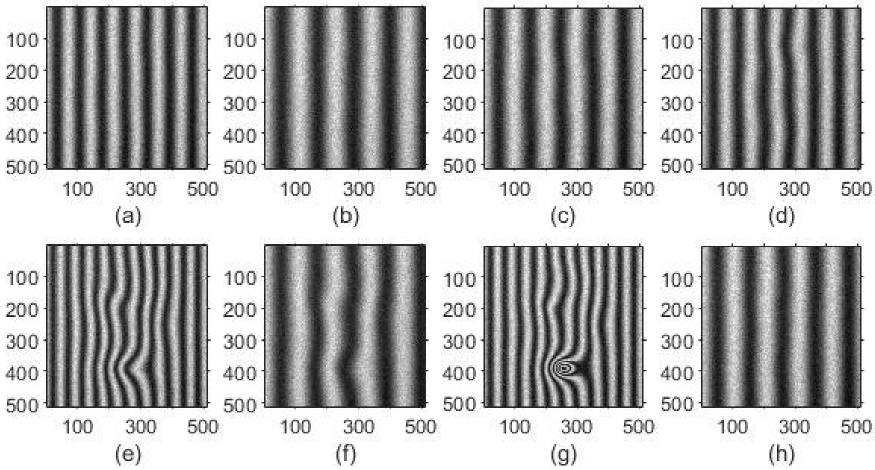

Figure 3: The initial phase fringe diagram corresponding to the random surface generator

From the theory of the two-step phase shift method, we know that the phase cannot be solved by the two data of a single pixel, so we choose the window data as input, where $L > 1$. In order to ensure the stability of the solution process, generally take $L \geq 3$. At this time, the input data is 6 and the output value is the phase value.

4. Simulation

In this paper, the neural network is trained by using randomly generated height model and grid pattern, and a stable solver is obtained. The number of hidden layers of neural network is 10, and each layer contains 120 neurons. The transfer function of each neuron is sigma. The final training result is obtained through 5000 iterations.

In order to verify the phase solving ability of our method, we generate a surface independently by random surface generator for testing. In this test diagram, we try to make it have the ability of external reasoning, that is, the maximum gradient beyond the training set. The test surface is solved by using the trained neural network. The final result is shown in Figure 4.

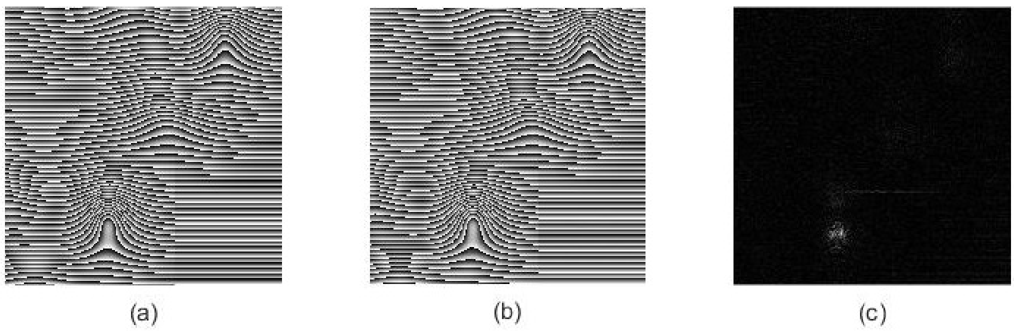

Figure 4: Result. (a) Real phase map; (b) Phase map by neural network; (c) Phase error.

The average absolute error of phase is only 0.012 rad. Compared with the 0.1 rad of other methods, its accuracy can be improved by one order of magnitude. But at the same time, it should be noted that the larger error of this method also appears in the region with larger gradient. But compared with other methods, the scale of error is much smaller.

5. Conclusion

In this paper, the neural network is used to solve the two-step phase-shifting problem, and the phase information is obtained. The method proposed in this paper has a high effect in the field of high-speed measurement. The simulation results show the excellent performance of our method. Compared with other methods, its accuracy has an overwhelming advantage of order of magnitude.

But on the other hand, our method can obtain high precision measurement results for the region with large gradient change, but it does not solve this problem perfectly. This will be the direction of our efforts in the future.

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