EPH - International Journal of Science And Engineering

ISSN (Online): 2454 2016
Volume 06 Issue 01 January 2020

DOI: https://doi.org/10.53555/eijse.v6i1.10

3-D SHAPE MEASUREMENT BASED ON DITHERING TECHNIQUE

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Abstract:-

Projector defocusing technique can eliminate projector nonlinearity in real-time three-dimensional shape measurement. However, the high-frequency harmonics brought by defocusing technique weakens the sinusoidal feature of the defocused fringe patterns, which will bring obvious measurement errors. The dithering algorithm is proposed to generate binary fringe, the projector is defocused properly to achieve approximate sinusoidal fringes. This method improves the sinusoidal property of the defocused fringe patterns. Absolute phase is retrieved by applying this method and phase-shifting algorithm. Simulations and experiments are carried out to verify the proposed method, and results show that phase quality has been improved greatly. Compared with existing methods, the proposed method achieves higher precision and can generate fringe patterns more sinusoidal, which is more proper for projector defocusing technique.

Keywords: - *Measurement; dithering algorithm; fringe projection; defocusing technique; fringe analysis.*

1. INTRODUCTION

Three-dimensional measurement based on digital sinusoidal fringe-projection techniques has been widely used because of the advantages such as non-contact, low-cost and high-precision, etc.[1~3]. The traditional fringe projection technique uses a projector to project the sinusoidal gratings on the referenced plane and the object, the modulated raster images got by the camera are sent to the computer by using the image acquisition card, calculating the corresponding relation between phase and the surface height, the threedimensional information of the object can be got by using the calibration parameters of the system. However, sinusoidal fringe needs 8-bits, measurement speed will be under restrictions because of the maximum frame rate of the projector. Moreover, most of the projector has its own nonlinear, which leads to that the projected fringe is no longer satisfied the standard sinusoidal distribution, which directly affects the phase quality and accuracy of measurement.

In recent years, S. Y. Lei and S .Zhang proposed a technique that if the projector is defocused, the binary structured pattern can become ideal sinusoidal. A large number of results had proved that this technique could overcome the nonlinear gamma effect of the projector, and the camera and projector could not require a high degree of synchronization [4-5]. However, this technique has proved to be successful when the fringe stripes are narrow, yet failed when fringe stripes are wide, and the high-frequency harmonics appeared in the measurement affects the quality of the gratings greatly [6].
In order to solve the problems brought by projecting the binary fringe directly, Ayubi et al. come up with using pulse width modulation technology to generate binary fringe [7]. Wang and Zhang draw the way of electronic system eliminating harmonic power and put forward the optimized pulse modulation method [8-12]. This method can eliminate specific order harmonics, high-quality sinusoidal fringe can be obtained by defocusing technique, which has been greatly improved in terms of measurement accuracy. However, this modulation is optimized on the one-dimensional direction, and the effect is poor when grating period is large.

Dithering technique have been successfully used in printing technology to represent grayscale images with binary structured images. Dithering algorithm contains random jitter [13], ordered dithering [14] and error diffusion dithering [15], etc. Considering that the error diffusion dithering technique can reserve the detail of the image best, this article will use error diffusion dithering technique to jitter sinusoidal gratings into a binary raster, and then becomes sinusoidal gratings through the appropriate defocused, Simulation and experimental results both show that grating generated by the dithering algorithm conducting three-dimensional measurement can get a better measurement accuracy and when grating period is large it also can obtain good measurement accuracy.

2. THE PRINCIPLE OF3-D SHAPE MEASUREMENT BASED ON DEFOCUSING TECHNIQUE

Defocusing technique uses projector to put the 1bit binary raster into sinusoidal gratings through the appropriate defocusing, then the sinusoidal fringes are projected on the reference plane and the object, modulated fringes got by CCD are sent to the computer for processing by the image acquisition card, calculating the corresponding relation between phase and the surface height, the three-dimensional information of the object can be got by the calibration parameters of the system.
Phase shift method is a more mature algorithm to solve the phase of the principal value, which possesses high accuracy and speed of operation and other advantages. To achieve high-speed 3-D shape measurement, a four-step phase-shifting algorithm with a phase shift of is used. Four fringe imaged can be described as:

$$I_1(x,y)=I'(x,y)+I''(x,y)\cos[\theta(x,y)] \quad (1)$$

$$I_2(x,y)=I'(x,y)+I''(x,y)\cos[\theta(x,y)+\pi/2] \quad (2)$$

$$I_3(x,y)=I'(x,y)+I''(x,y)\cos[\theta(x,y)+\pi] \quad (3)$$

$$I_4(x,y)=I'(x,y)+I''(x,y)\cos[\theta(x,y)+3\pi/2] \quad (4)$$

Where $n = 0,1,2,3$, $I'(x, y)$is the average intensity, $I'(x, y)$is the intensity modulation, $\theta(x, y)$is the phase to be solved for. According to (1-4), the phase can be obtained
as:

$$\phi(x,y)=\arctan\left[\frac{I_4-I_2}{I_1-I_3}\right] \quad (5)$$

The range of $\phi(x, y)$is $[-\pi,+\pi)$. Continuous, complete phase value should be:

$$\theta(x,y)=\phi(x,y)+2k(x,y)\pi \quad (6)$$

Where k (x y) is an integer which represents the order of the grating at the point (x y)Phase unwrapping method includes time domain method and space domain method, generally, time-domain method is higher than the accuracy of space domain method, this article uses gray code method to expand the phase.

2.1. Error Diffusion Dithering Algorithm

In this method, the pixels are quantized in a specific order, and the error of quantization for the current pixel is propagated forward to local unprocessed pixels. By this method, the local average of the converted image is close to the original one. Equation (7) shows the principle of error diffusion:

$$\tilde{I}(i,j) = I(i,j) + \sum_{m,n \in S} h(m,n) e(i-k, j-l) \qquad (7)$$

Where, *I* (*i*, *j*)is the original image, *I*%(*i*, *j*)is the grayvalue of (*i*, *j*)at the original image plus quantization errordiffusion of surrounding pixels, quantization error *e*(*i*, *j*)ofthe pixel (*i*, *j*)spreads to several adjacent pixels by a twodimensional weight function *h*(*m*, \`*n*), *h*(*m,n*)is alsoknown as error diffusion kernel function.

Next, the technique is to convert *I*%(*i*, *j*)to 1-bit binary pattern based on the threshold value and obtain the final output jitter image pixel *D*(*i*, *j*):

$$D(i,j) = \begin{cases} 255, & \tilde{I}(i,j) \geq T \\ 0, & \tilde{I}(i,j) < T \end{cases} \qquad (8)$$

Where, threshold k is usually taken 128

The quantization error *e*(*i*, *j*)in the equation (7) is the difference between the gray value of the output pixel *D*(*i*, *j*)and the *I*%(*i*, *j*):

$$e(i,j) = \tilde{I}(i,j) - D(i,j) \qquad (9)$$

Repeat the above steps, progressive processing, and ultimately to obtain a binary image Kernel *h(m,n)* is the most critical parameter in the error diffusion, selecting different kernel corresponds to different error diffusion dithering algorithm.

For Floyd-Steinberg dithering algorithm, its kernel is:

$$h(m,n) = \frac{1}{16} \begin{bmatrix} - & x & 7 \\ 3 & 5 & 1 \end{bmatrix} \qquad (10)$$

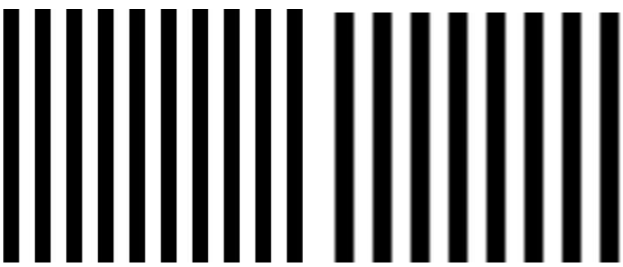
Where, “-” represents the previously processed pixels， represents the pixel currently being processed.

3. SIMULATION AND ANALYSIS

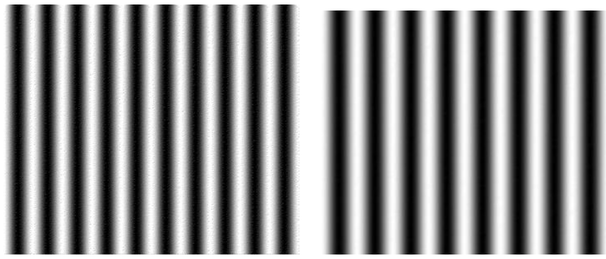
3.1. Sinusoidal of the Defocused Fringe and Error Analysis

Figure 1 shows the intuitive comparison of the fringes between defocused binary fringe and defocused dithering fringe. Figure(b)shows the defocused binary fringe. Figure (d) shows the defocused dithering fringe.

Figure 2 is unwrapping diagram and phase error after defocusing raster in figure 1. The figure (a) is unwrapping diagram, the lines can be seen clearly. Figure (c) is the jitter unwrapping diagram, which is obviously much better than binary raster. Figure (b) is the phase error measured after the binary grating defocusing (-0.4~0.4). Figure (d) is the phase error measured after the jitter grating defocusing (0.005~0.03), which is better than figure (b). It shows the fringes are close to standard fringes and the accuracy is higher by using dithering algorithm. However, we found that the phase error is cyclical, this could be the result of the simulation filter, these errors may not appear in the actual experiment.



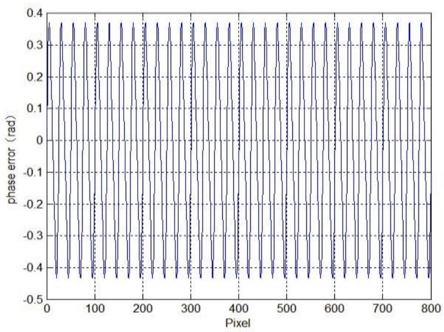
(a) Binary raster **(b) Defocus grating.**



(c) Jitter binary raster (d) Defocus grating

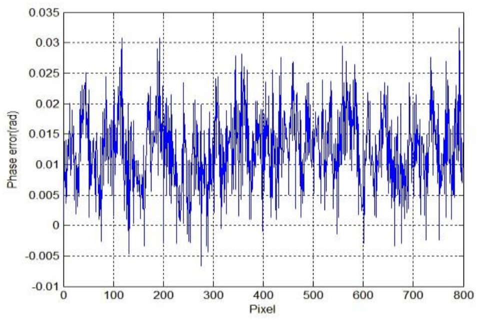
Fig. 1. The intuitive comparison of binary patterns and dithering patterns.

(a) System Binary raster defocus solution package diagram.



(b) Phase error.

(c) Jitter raster defocus solution package diagram.

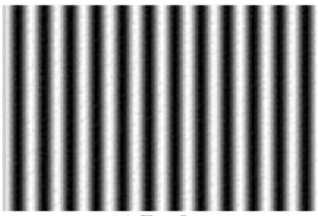


(d) Phase error.

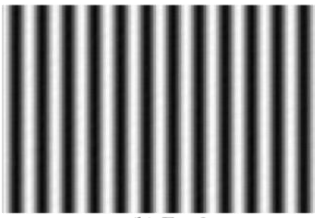
Fig. 2. The comparison of binary patterns and dithering patterns after simulation

3.2. Simulation Analysis of the Applicability of Dithering Algorithm

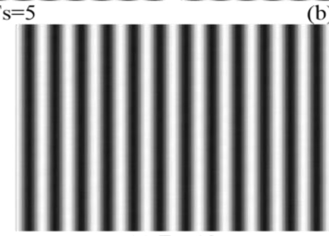
Figure 3 show the simulation experiments on T = 25 and T=100, figure（a-c）show three fringe patterns of different degree of defocusing on T=25, figure（d-f）show three fringe patterns of different degree of defocusing on T=100, you can observe its sinusoidal is getting better. It can be seen from figure (g), with the degree of defocusing increasing, the error is getting smaller, but when the degree of defocusing is too large, it is not conducive to measure, results show that dithering algorithm is suitable for small-period fringes, and the error using dithering method for large-period fringes is smaller than the existing methods.



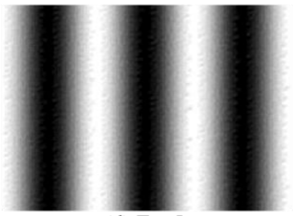
(a) Fs=5



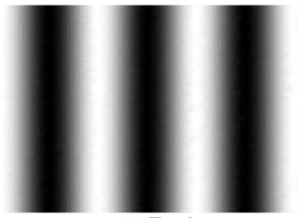
(b) Fs=9



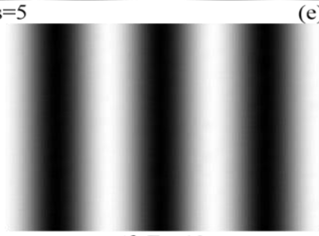
(c) Fs=13



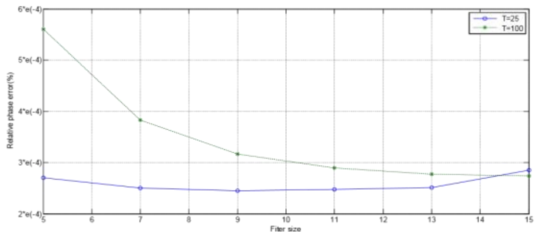
(d) Fs=5



(e) Fs=9



(f) Fs=13

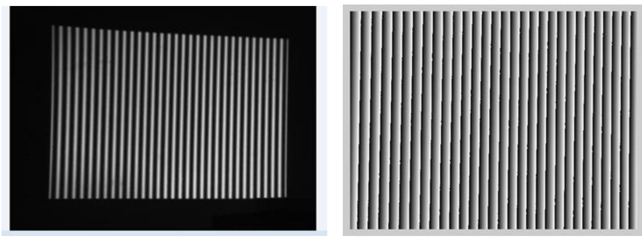


(g) The RMSE of T = 25 and T = 100 at different levels of defocus

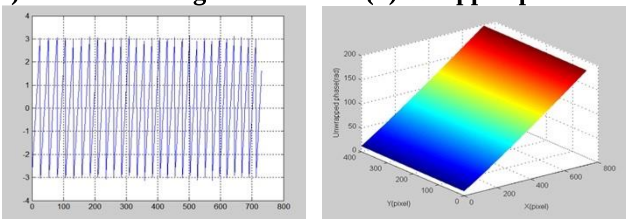
Fig. 3. Relative phase error of dithering with different fringe period.

4. Experiments

To verity the performance of this proposed algorithm, a flat white broad is measured. The camera (Basler acA2000340km) used among the experiments is focusing, DLP projector (PHYLINA PD-L800) is at a state of lower degree of defocusing. Figure 4(a) is the error diffusion dithering defocused raster image of the period 25 collected by camera, figure 4(b) is the wrapped phase map, figure 4(c) shows the cross section of the figure4(b). Figure 4(d) is then unwrapped by applying a spatial phase-unwrapping algorithm.’



(a) Defocused fringe **(b) Wrapped phase map**



(c) Defocused fringe **(d) Wrapped phase map**

Fig. 4. Measurement with dithered fringe pattern.

In the case of the low degree of defocusing of the projector, we calculated the phase errors based on using different period fringes, as shown in figure 5. It can be seen that the error diffusion dithering algorithm not only can obtain high quality phase when the fringe period is relatively small, when the cycle is larger, it also can maintain lower phase error, which indicates that it has strong adaptability. The experimental results are consistent with the simulation results.

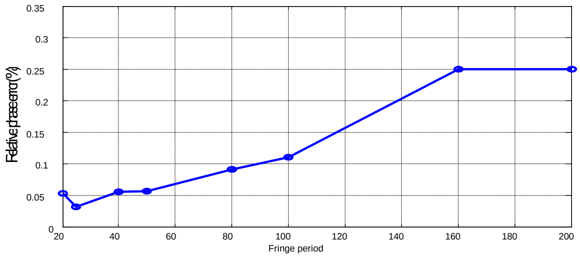
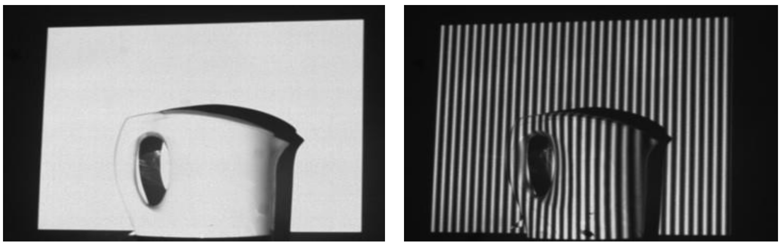
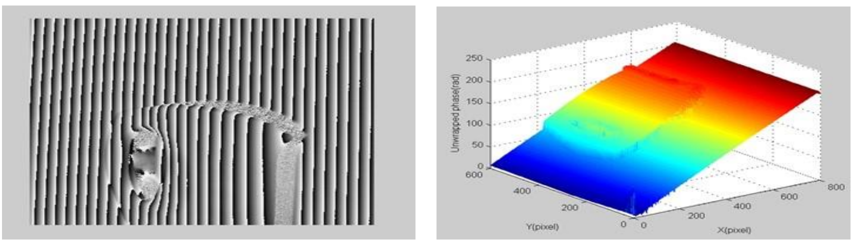


Fig. 5. Relative phase error of dithering with different fringe period.

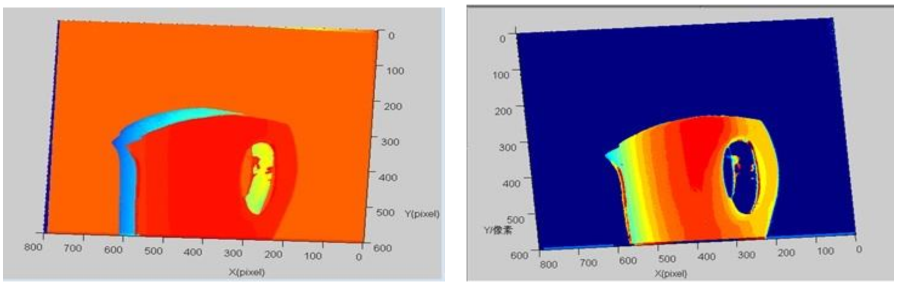
To verity the performance of this proposed algorithm, a kettle sitting in front of the flat white broad, as shown in 6 (a). Figure 6 (b) is a four-step phase shift raster image, figure 6 (c) is the wrapped phase map obtained by four-step phaseshift method, figure 6 (d) is the unwrapped phase map, and t the 3-D image is obtained as shown in 6(e) and 6(f). Visibly, error diffusion jitter grating meets the measurement requirements and the phase quality is relatively high when it is used to the actual measurement.



(a) Measurement object **(b) A four-step phase shift diagram**



(c)Wrapped phase map for the object **(d) Unwrapped phase map p**



(e)The final phase of the measured object (f) The final phase of the measured object after correction

Fig. 6. Measurement of an object with dithered fringe pattern.

5. Conclusions

Projector defocusing technique is used in high-speed and real-time three-dimensional measurement systems increasingly, image dithering technology has proved that it can solve a series of problems in defocusing method, such as reducing the impact of higher harmonics, overcoming the projectors nonlinear problems. This paper proposes to use the dithering algorithm to generate the projection grating, it significantly improves the quality of the jitter grating and the sinusoidal jitter grating becomes better. When the projector defocusing level is low, the dithering algorithm can significantly improve the quality of the grating and reduce the phase error greatly, thus it can enhance the overall accuracy of the system. Simulation and experimental results have demonstrated the advantages of dithering algorithm.

Conflict of interest

The author confirms that this article content has no conflict of interest.

Acknowledgements

This work was financially supported by National Natural Science Foundation of China (61503161) ..

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