

Research on identifying the order of fringe pattern traces using angular scan and zone search method

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A method for automatically identifying the order of fringe pattern traces is presented. It uses the simplified Otsu algorithm for obtaining the threshold, the angular scan in the range of 45° for searching the trace positions, and the zone search technique for identifying different traces. Experimental results show that the proposed method may reliably obtain the order of fringe pattern traces orientating from almost 45° to 90° .

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Interferogram contains the profile information of the measured object, which may help us to understand the comprehensive profile of the object in some applications, such as machine manufacture and inspection of optical components^[1,2]. To obtain the information, identifying the interference fringes is necessary^[3]. Manual graphical methods are utilized to meet the requirement of applications. However, the manual graphical methods are tedious and sometimes introduce errors. Applying computer to realize manual graphical methods is one of the promising ways to obtain better profile information. In the method, the image is firstly filtered and thresholded to obtain a binary gray-level image, then scanned to obtain the midpoints that consist of the traces. Finally, the method of scan is utilized to determine the order of the fringe pattern traces^[4-7]. In practice, it is found that the method of scan sometimes fails when different arrangements and shapes of fringe pattern traces exist in the interferogram or broken trace exists in the fringe pattern traces.

In this paper, a new method is proposed which utilizes the angular scan and zone search technique to overcome these disadvantages. The method automatically positions the trace location and marks the trace with different number to obtain the order of fringe pattern traces. By processing various interferograms, detailed analysis is given.

In our experiment, a Fizeau interferometer equipped with two different complementary metal-oxide semiconductor (CMOS) cameras is utilized. Before the imaging beam having the profile information of the test and reference surfaces reaches the eyepiece of the interferometer, it is divided into two beams by a beam splitter. One beam reaches the eyepiece for observation, and the other beam passes through an imaging lens to form an appropriate image received by a CMOS camera. These two cameras obtain two different sizes of interferograms. After the interferogram is digitized and calculated, a two-dimensional (2D) gray-level array $G_1(u, v)$ that has u rows and v columns is acquired. Then noise filtering is performed by using the spin filter that has a window of 5×5 pixels^[8]. When the image is filtered, it is necessary to binarize the image. Otsu algorithm is widely employed

to automatically obtain the threshold and acquire a binary image in interferogram processing applications, but the amount of calculation is great^[9]. In this experiment, a simplified Otsu algorithm that can achieve less amount of calculation is implemented. Let w_0 be the ratio of the number of dots in the foreground to the size of the image, u_0 be the average gray level of the foreground, w_1 be the ratio of the number of dots in the background to the size of the image, and u_1 be the average gray level of the background, then we can get

$$T = w_0 \times w_1 \times (u_0 - u_1)^2. \quad (1)$$

The algorithm searches the maximum value of T by using Eq. (1). When the maximum is found, the value of the expected threshold is obtained. The binary image in the selected circular zone can be obtained by the value of the expected threshold. Then the horizontal scan is utilized to obtain the midpoints of dark fringes in the binary image and the angular scan and zone search technique are implemented in the selected circular zone.

Let R be the radius of the angular scan, R_1 be the radius of the selected circular zone, and R_c be the distance between the origin of coordinates and the center of the selected circular zone, then we can get

$$R = R_c - R_1. \quad (2)$$

Let i and j be integers in the range $[1, u]$ and $[1, v]$ respectively defining the pixel locations, $\text{Temp}R_1$ and $\text{Temp}R_2$ be the functions of i and j , and k_1 and k_2 be the parameters of $\text{Temp}R_1$ and $\text{Temp}R_2$, respectively, we can get

$$\text{Temp}R_1 = k_1 \times \sqrt{i^2 + j^2}, \quad (3)$$

$$\text{Temp}R_2 = k_2 \times \sqrt{i^2 + j^2}. \quad (4)$$

Considering the reliability of the angular scan, we can select k_1 and k_2 be 0.9 and 1.1, respectively. We have

$$\text{Temp}R_2 > R \geq \text{Temp}R_1. \quad (5)$$

When Eq. (5) is met and the midpoint on a trace is found, we assign the midpoint a number and implement the zone search technique to search its neighborhood midpoints and identify different traces along the traces.

A computer with Intel CPU 2.4 GHz and RAM 512 MB is used to implement the method that was written with VB6.0. The flow chart of the angular scan and zone search technique is shown in Fig. 1.

Figures 2(a), 3(a) and 4(a) show the interferograms obtained from our experiment. The size of Fig. 2(a) is 391×295 pixels, while the size of Figs. 3(a) and 4(a) is 320×240 pixels. The value of the threshold found in the selected circular zone in Fig. 2(b) is 171, while the value of the threshold found in the selected circular zones in Figs. 3(a) and 4(a) is 173. Figures 2(b), 3(b) and 4(b) show the threshold and filtered results of the selected circular zones in Figs. 2(a), 3(a) and 4(a), respectively. It is seen that much noise in the zones is cleared.

Figures 5 and 6 show the results obtained by using the horizontal scan. It is seen that the traces include the

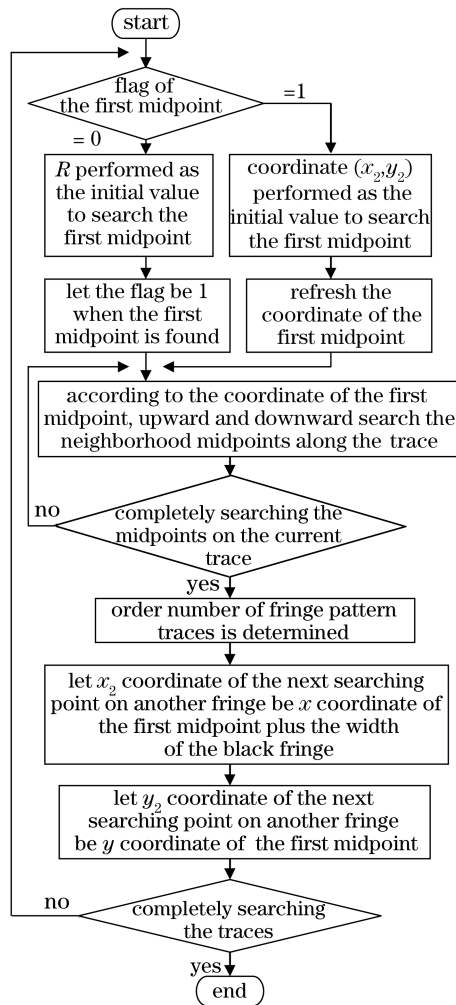


Fig. 1. Flow chart of the angular scan and zone search technique.

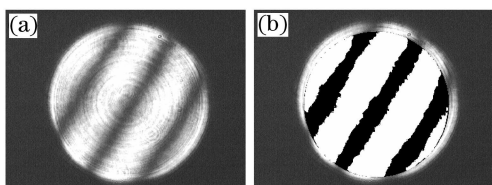


Fig. 2. (a) Interferogram with slope fringes captured by CMOS camera; (b) binary image of Fig. 2(a).

information of the fringes.

To make the discussion of identifying the order of the traces easier, we let mode 1 denote the case in which row line scans from the top of the interferogram to the bottom, mode 2 denote the case in which row line scans from the bottom of the interferogram to the top, mode 3 denote the case in which row line scans almost from the middle of the interferogram, and mode 4 denote the case in which diagonal line scans from the top of the interferogram to the bottom. Three fringe pattern traces of the selected circular zone in the binary image are regarded as No. 1 – 3 from left to right.

The experiments for testing the effect of using row line and diagonal line were implemented and it is found that row line and diagonal line working in these modes may yield wrong order of the traces. In Fig. 5(a), when row line is utilized to search the midpoints on the traces in mode 1, the midpoints on the middle trace found first are marked as No. 1. Then the left midpoints of the middle trace are found and marked as No. 2. Finally, the right midpoints of the middle trace are found and marked as No. 3. In Fig. 6(a), when row line is utilized in mode 3, the scan line would pass through the broken trace and the middle trace is found first. After the middle trace is

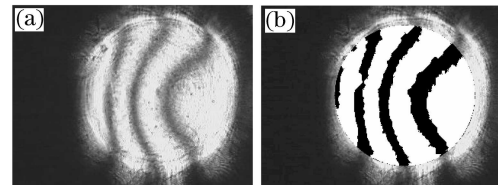


Fig. 3. (a) Interferogram with winding fringes captured by CMOS camera; (b) binary image of Fig. 3(a).

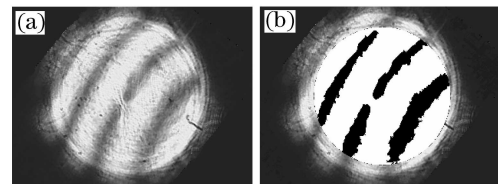


Fig. 4. (a) Interferogram with broken fringes captured by CMOS camera; (b) binary image of Fig. 4(a).

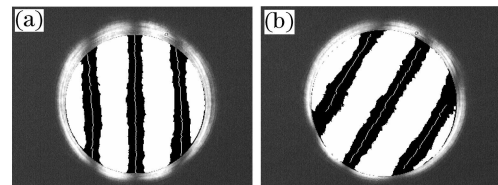


Fig. 5. (a) Vertical fringe pattern traces; (b) slope fringe pattern traces.

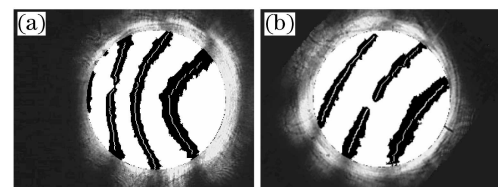


Fig. 6. (a) Winding fringe pattern traces; (b) fringe pattern traces with broken trace.

Table 1. Experimental Orders of Fringe Pattern Traces from Left to Right

	Fig. 5(a) (No.)	Fig. 5(b) (No.)	Fig. 6(a) (No.)	Fig. 6(b) (No.)	Ratio of Correctness
Mode 1	2-1-3	1-2-3	2-1-3	1-2-3	50%
Mode 2	2-1-3	3-1-2	3-1-2	3-1-2	0
Mode 3	1-2-3	1-2-3	3-1-2	1-3-2	50%
Mode 4	1-2-3	1-2-3	3-1-2	1-3-2	50%

marked as No. 1, a wrong order of fringe pattern traces happens. In Fig. 6(b), when diagonal line is utilized in mode 4, the scan line would pass through the broken trace and the right trace is found first. Then the middle trace would be marked as No. 3, which also results in a wrong order of fringe pattern traces. The experimental orders of fringe pattern traces are shown in Table 1.

From Table 1, it can be seen that the ratio of correctness is low. When the scan works in mode 2, the ratio of correctness is the lowest, because the length of the middle trace is the longest and this trace is found first.

In the experiment using the proposed method, traces A, B, C and D correspond to No. 1-4 traces respectively. Three fringe pattern traces of the selected circular zones in Figs. 7(a), 7(b), 8(b) and 9 are respectively regarded as No. 1-3 from left to right. Four fringe pattern traces of the selected circular zone in Fig. 8(a) are regarded as No. 1-4 from left to right. The following test results are given by implementing the angular scan and zone search technique.

Figure 7(a) shows that No. 1-3 vertical fringe pattern traces are identified as traces A, B and C. The ring zone is recorded to indicate that the angular scan works at the first times. Two quasi-triangular scan zones that are

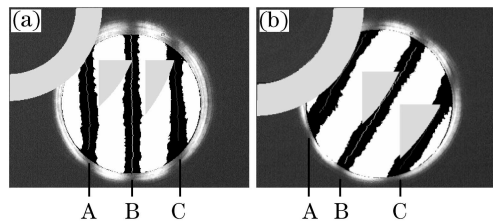


Fig. 7. (a) Identifying the order of vertical fringe pattern traces and (b) the order of three slope fringe pattern traces.

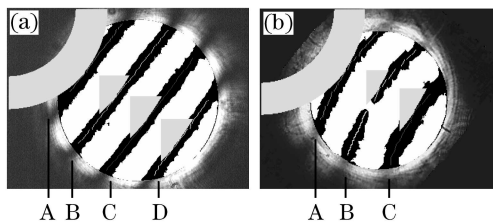


Fig. 8. (a) Identifying the order of four slope fringe pattern traces and (b) the order of three slope fringe pattern traces with broken trace.

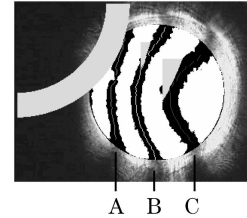


Fig. 9. Identifying the order of winding fringe pattern traces with broken trace.

horizontally arranged indicate the other times of scan. Figure 7(b) shows that three slope fringe pattern traces considered as No. 1-3 traces are identified as traces A, B and C. The ring zone of Fig. 7(b) is greater than that of Fig. 7(a), because the distance between the origin of coordinate and the first midpoint is greater. Figure 8(a) shows that No. 1-4 slope fringe pattern traces are identified as traces A, B, C and D. Three quasi-triangular scan zones are arranged along the traces. Figure 8(b) shows that No. 1-3 slope fringe pattern traces with broken trace are identified as traces A, B and C. The sizes of two quasi-triangular scan zones are different because of the curved traces. Figure 9 shows that No. 1-3 winding fringe pattern traces with broken trace are identified as traces A, B and C. The length of the ring zone is the longest, because the distance between the origin of coordinate and the center of the selected circular zone is the farthest. The sizes of two quasi-triangular scan zones are greatly different because of the irregular arrangement of the traces. It is seen that the ring zone and the quasi-triangular scan zones function in the range of 45° , which indicates that the angular scan searching the midpoints in a zone can avoid the influence of the broken trace. Additionally, it can be seen that the scanning zones automatically alter with the arrangements and shapes of fringe pattern traces. When the coordinate (x, y) of the first midpoint on a fringe is found by the angular scan, let the coordinate (x_2, y_2) be the initial value to search the first midpoint on another fringe. The value of x and the width of the black fringe equal the value of x_2 , and the value of y_2 equals the value of y . The procedure is processed until determining the order of the fringe pattern traces is accomplished.

The proposed method obtains the experimental orders of the fringe pattern traces from left to right, which are shown in Table 2.

Table 2. Experimental Orders of Fringe Pattern Traces from Left to Right Using the Proposed Method

	Fig. 7(a)	Fig. 7(b)	Fig. 8(a)	Fig. 8(b)	Fig. 9	Ratio of Correctness
Proposed Method	A-B-C	A-B-C	A-B-C-D	A-B-C	A-B-C	100%

From Table 2, it can be seen that the ratio of correctness of the angular scan and zone search technique is 100%. It indicates that the proposed method can process different fringe pattern traces including the broken trace and winding trace. Identifying the order of the traces benefits from the adjustment.

In conclusion, a method for identifying the order of fringe pattern traces has been developed in this paper. After the interferogram is firstly filtered by the spin filter with a window of 5×5 pixels effectively, the computer employs the simplified Otsu algorithm for thresholding, the angular scan for searching the trace positions, and the zone search algorithm for identifying different traces along the traces. Although different arrangements and shapes of fringe pattern traces or broken trace exist in the interferogram, experimental results show that the proposed method can be applicable to identify the order of the fringe pattern traces from almost 45° to 90° . In addition, the proposed method functioning in the range of 45° can be reliable for computer to realize manual graphical methods.

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