New Method of Automatic Extracting and Ordering Fringes of Interferograms with Closed Loop Fringe Pattern

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Abstract

An automatic fringe analysis method for interferograms with arbitrary closed loop fringe pattern is developed, using an automatic fringe extracting and coding technique in the parallel pseudo-contour tracing form. The principle and procedures have been discussed in detail. It is proved that this method is very easy and convenient for using in practice.

1. Introduction

Interferograms have been extensively used in various fields of optical measurements, such as measurements of profiles, shapes, strains, fluid properties and so on. In many applications, the fringes, may be loops. Determination of fringe orders of interferograms with closed loop fringes is very difficult because it is possible for such interferograms to have more than one fringe peak along the same scan line with the same fringe order but different coordinates. Several fringe analysis methods of interferograms in the form of loops have been reported. These methods, except for the Newton's ring type fringe patterns consisting of concentric circular finges [1], are interactive. Yatagai et al. developed a semiautomatic fringe analysis system for all kinds of fringes, in which the fringe orders are determined by operator with a light pen[2]. A highly interactive fringe tracing and pseudo color coding algorithm. was proposed, in which the operator directs the fringe tracing and codes each fringe according to its order to help computer to identify fringe order[3].

This paper presents an efficient method for automatic extracting and numbering fringes with closed loop fringe pattern, which uses an automatic fringe extracting and coding technique in the form of parallel pseudo-contour tracing.

2. Principle and Method

In order to achieve automatic extracting and numbering fringes of interferograms with closed loop fringe pattern, we develop an automatic parallel peak detecting, pseudo-contour tracing and coding technique. The basic procedures consists of: (1) extracting and coding fringe peaks; (2) linking the interrupted gaps and eliminating noise curves; (3) establishing a 1-1 corresponding relation between fringe order and its pseudo-contour value. All the procedures are automatically performed.

1. Extraction of Fringe Segments

The fringe segment extraction includes four steps: (1) noise reduction; (2) fringe peak detection; (3) pseudo-contour coding; (4) interrupted point recordation.

(1). Diminishing noise by local unweight average:

Because of the contributions in interferograms of optical noise, parasitic interference and electronic noise, it is very important to diminish the influence of noise before the task of extracting fringe peaks by the gray level comparing method. One of the most efficient method of improving signal-to-noise ratio is local gray averaging. A 3×3 local unweight averaging operator is employed. The gray level at eaoh point (i, j) of the output pattern is the average of the gray levels in the input pattern within a 3×3 neighboring point matrix of point (i, j), as shown in Fig. 1 (a), including point (i, j) itself, namely;

$$g_{ij} = \frac{g_{i-1j-1} + g_{ij-1} + g_{i+1j-1} + g_{i-1j} + g_{ij} + g_{i+1j} + g_{i-1j+1} + g_{ij+1} + g_{i+1j+1}}{9}$$

$g_{i-1,j-1}$	$g_{i,j-1}$	$g_{i+1,j-1}$
$g_{i-1,j}$	$g_{i,j}$	$g_{i+1,j}$
$g_{i-1,j+1}$	$g_{i,j+1}$	$g_{i+1,j+1}$

(*a*)

$g_{i-1,j-2}$	$g_{i-1,j-2}$	$g_{i,j-2}$	$g_{i+1,j-2}$	$g_{i+2,j-2}$
$g_{i-2,j-1}$	$g_{i-1,j-1}$	$g_{i,j-1}$	$g_{i+1,j-1}$	$g_{i+2,j-1}$
$g_{i-2,j}$	$g_{i-1,j}$	$g_{i,j}$	$g_{i+1,j}$	$g_{i+2,j}$
$g_{i-2,j+1}$	$g_{i-1,j+1}$	g_{i-j+1}	$g_{i+1,j+1}$	$g_{i+2,j+1}$
$g_{i-2,j+2}$	$g_{i-1,j+2}$	$g_{i,j+2}$	$g_{i+1,j+2}$	$g_{i+2,j+2}$

(*b*)

Fig. 1 3×3 (*a*) and 5×5 (*b*) point matrixes

(2). Detecting fringe peaks by gray level comparing method:

Detection of fringe peaks is executed after above preprocessing. The method we used bases on the comparison among the local gray levels. In the method, a two-dimensional peak detection is performed within a 5×5 point matrix, as shown in Fig. 1 (b). The peak conditions, with respect to the four directions shown in Fig. 2, are defined as follows:

$$(g_{ij} - g_{i-2j})(g_{ij} - g_{i+2j}) > 0$$

for the x-direction,

$$(g_{ij} - g_{i,j-2})(g_{ij} - g_{ij+2}) > 0$$

for the y-direction,

$$(g_{ij} - g_{i-2j-2})(g_{ij} - g_{i+2j+2}) > 0$$

for the xy-direction,

$$(g_{ij} - g_{i-2j+2})(g_{ij} - g_{i+2j-2}) > 0$$

for the -xy-direction. When the peak conditions are satisfied for any of two or more directions, the point under detection is taken to be a fringe peak.

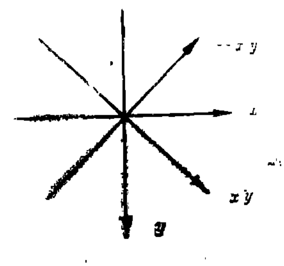

Fig. 2 Directions for fringe peak detectino

According to the peak detecting conditions developed above, points in the analyzed area are detected by horizontal scanning right across the full width of the interferogram, which is repeated down until all the points are detected.

(3). Coding points by pseudo-contour code rule:

At the same time, the gray level at the point under detection is coded according to a pseudo-contour code rule. This code rule can be expressed as follows: If the point under detection isn't a peak, it is numbered by zero. Otherwise, it is numbered by a positive integer determined according to its connective property to its 4-neighboring points. Namely, If it is connective to its 4-neighboring points, it is numbered by the same positive integer with its connective points for they are on the same segment. If not so, it is numbered by a new positive integer assigned on the assumption of a linear unit increase with the find of a new segment.

The 4-neighboring points of point (i, j) are defined as one left adjacent to it on the same line and three immediately above it on the previous, as shown in Fig. 3. They are scanned. Provided there is one or more peaks among the 4-neighboring points, then point (i, j) is connective to its 4-neighboring points, namely, they are on the same segment. Otherwise, point (i, j) isn't connective to its 4-neighboring points, in other word, a new segment is detected.

(4). Recording interrupted points:

Because of the continuity of fringes, it is impossible that any interrupted points such as starting or ending points of fringes can exist in

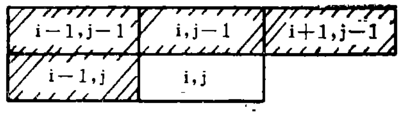

Fig. 3 4-neighboring points of point (i, j)

an interferogram. These interrupted points belong to either interrupted fringe gaps or noise curves. In order to link up the interrupted gaps and eliminate noise curves, the messages of the interrupted points are recorded.

2. Extraction of Fringes

This procedure is composed of two steps: (1) linking interrupted gapes; (2) eliminating noise curves.

(1) Linking interrupted gapes:

At the first step, an interrupted point (x_i, y_i) is taken out and the data on the same segment with it are fitted to a quadratic polynomials

$$f(x) = a_0 + a_1 \cdot x + a_2 \cdot x^2$$

The coefficients a_0, a_1 and a_2 are determined by the least square method. Substitute an interrupted point (x_j, y_j) into the above equation and calculate the absolute error between f (x_j) and y_j:

$$AE(j) = |f(x_j) - y_j| = |a_0 + a_1 \cdot x_j + a_2 \cdot x_j^2 - y_j|$$

If min (AE(j))<L, where L is the tolerant error, (x_j, y_j) is taken as the correspondiug interrupted point of point (x_i, y_i) to the interrupted gap. The derivatives at these two interrupted points are calculated and instituted with their x- and y-coordinates into function

$$g(x) = b_0 + b_1 \cdot x + b_2 \cdot x^2$$

The coefficients b_0, b_1 and b_2 are obtained. The interrupted gap is interpolated by g(x) and numbered by the value equal to the minor pseudo-contour value of these two interrupted points. After that, the segment coding with a major pseudo-contour value is recoded by the minor. This process is repeated until no interrupted point can be linked.

(2). Eliminating noise curves:

For the same reason mentioned above, all the residual segments with interrupted points in the analyzed area are eliminated as noise curves.

Up to now, fringes are automatically extracted and coded by different pseudo-contour values. Obviously, the fringes extracted by use of the code rule and linking algorithm has the following properties: i) each fringe corresponds to only one pseudo-contour value; ii) different fringes corresponds to different pseudo-contour values. Therefore, a 1-1 corresponding relation can be established between fringe order and fringe pseudo-contour value.

3. Determination of Fringe Orders

In order to set up a 1-1 corresponding relation, it is required to determine the center area of the closed loop fringe pattern at first and then the numbering direction in which the 1-1 corresponding relation is set up.

(1). Determining center area of closed loop fringe pattern:

The pseudo-contour values of any two points are equal to each other, provided they are on the same fringe. Then, if a point lies in the center area of closed loop fringe pattern, the first pseudo-contour values crossed with any radial vector radiating from this point are equal to each other, as shown in Fig. 4(a). Therefore, the determination sequence of the center area shown in Fig. 4 (b) is as follows:

(i). scan in horizontal direction across the full width of the interferogram. Compare the pseudo-contour values of the adjacent peaks.

(ii). repeat at intervals down the image until adjacent peaks with the same pseudo-contour value are found.

(iii). scan in vertical direction with the y_c position determined by the previous and the x_c determined by the midvalue of the x-coordinates of the adjacent peaks. If the pseudo-contour values of the adjacent peaks on the two sides of point (x_c, y_c) are equal to each other, point (x_c, y_c) lies in the center area of the closed loop fringe pattern. Otherwise, repeat until the center area is found.

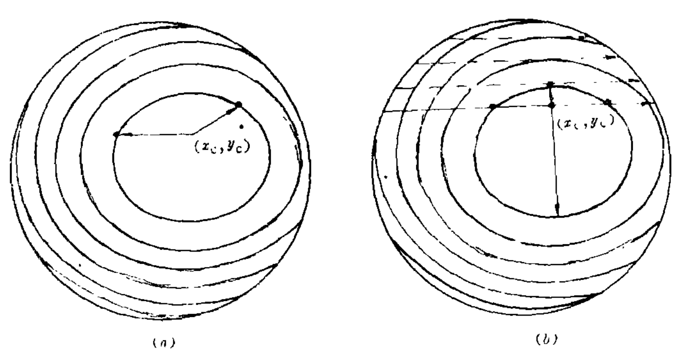

Fig. 4 Property (*a*) and determination (*b*) of the center area

(2). Determining the numbering direction:

After above procedure, the numbers of fringe peaks along a series of radial vectors starting at (x_c, y_c) and ending at the boundary are calculated. The vector angle is varied 30 degrees in increment over a range of 360 degrees, and the vector giving the largest number of fringe peaks is taken as the numbering direction, as shown in Fig. 5.

(3). Establishing 1-1 corresponding relation:

On the assumption of a linear nuit increase (or decrease) in fringe number along the numbering direction determined above, a 1-1 corresponding relation between fringe order and fringe pseudo-contour value is established. According to this 1-1 corresponding relation, a computer can automatically distinguish fringe orders by the corresponding pseudo-contour values of fringes.

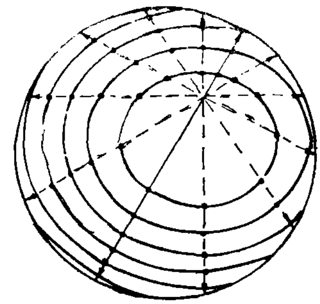

Fig. 5 Determination of the numbering direction

3. Conclusion

By using the method presented above, automatic fringe analysis of interferograms with closed loop fringe pattern is achieved. This code technique is very simple and necessary for automatic fringe order determination of interferograms with closed loop fringe pattern. This method also can be used in other simple and complicated fringe patterns.

References

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自动分析具有闭合条纹干涉图的新方法

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摘要：提出了一种干涉图自动提取和定级的并行伪等高追迹方法。这种方法不仅能自动分析由任意形状的非闭合条纹组成的干涉图，而且能自动分析由任意形状闭合条纹组成的单心干涉图。