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An algorithm for estimating both fringe orientation and fringe density

Xia Yang [a,*], Qifeng Yu [b], Sihua Fu [a]

[a] College of Astronautics, National University of Defense Technology, Changsha, Hunan 410073, PR China
[b] College of Optical Engineering, National University of Defense Technology, Changsha, Hunan 410073, PR China

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Abstract

In this paper, an algorithm is proposed which can estimate good fringe orientation and estimate fringe density at the same time. This algorithm accumulates differences along four orientations and then obtains the local orientation and estimates local fringe density according to the differences. The obtained orientation results are more accurate and more robust than the plane-fit method. And it will be shown both theoretically and experimentally that the accumulated differences can estimate fringe density roughly.

Keywords: ESPI; Fringe orientation; Fringe density; Fringe analysis

1. Introduction

Fringe orientation [1,2] is always used to help understanding or processing fringes. There are many applications of fringe orientation such as contoured window filter [3–5] for filtering high noise off the ESPI fringes, contoured correlation method [6,7] used to generate noise-free fringe patterns for ESPI or InSAR. In these applications, plane-fit method is always used to calculate the fringe orientations.

Fringe density can also be a good help for analyzing fringes or directing fringe processing. With the estimation of fringe density, complicated phase extracting methods such as the windowed Fourier transform (Gabor filter) method, the phase tracking algorithm and the quadrature filters can obtain better results [8,9]. Olov Marklund proposed a wrapped phase fringe-density estimation method that would facilitate tile-based unwrapping processes and can be applied to phase-map filtering and segmentation. Quan et al. proposed a fringe-density estimation method by continuous wavelet transform (CWT). CWT method calculates the correlation coefficient between the real fringe patterns and the wavelet with scaling and shifting. In this paper, it will be shown that our orientation estimating algorithm based on difference accumulation can also estimate fringe density effectively in a simpler and more direct way.

This paper proposes an accumulated differences method. This method not only is more adaptive than the plane-fit method when it is used to estimate fringe orientation but also can be used to estimate fringe density roughly.

The basic idea of the fringe orientation estimating method is provided in the second part of this paper. The method of estimating fringe density is proposed in the third part. Some experimental results are shown in the forth part. And the fifth part provides a conclusion for this paper.

2. Difference based method

2.1. Basic idea and main steps

Usually for fringes, the directional differences always have minimum value along the tangent direction of the fringe and have maximum value along the normal direction, so one can obtain the fringe orientation by just finding the minimum directional difference. To do this, one can

* Corresponding author. Tel./fax: +86 07314518992.
E-mail address: mr_honson@163.com (X. Yang).

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define the difference as the standard deviation along a direction and choose the smallest one from the values of 8 or 16 predefined directions [10].

In this paper the difference along a certain orientation is defined in a different way and we use differences along four orientations such as 0°, 45°, 90° and 135°. For a local point (x, y), as shown in Fig. 1, the four differences can be calculated as Eq. (1)

$$\begin{aligned} d_0(x,y) &= |f(x-1,y) - f(x+1,y)| \times \sqrt{2} \\ d_{45}(x,y) &= |f(x-1,y+1) - f(x+1,y-1)| \\ d_{90}(x,y) &= |f(x,y-1) - f(x,y+1)| \times \sqrt{2} \\ d_{135}(x,y) &= |f(x-1,y-1) - f(x+1,y+1)| \end{aligned} \tag{1}$$

$I(x, y)$ is the intensity or the gray value of the point (x, y). Because the distances between the four corners and the center point are $\sqrt{2}$ times of the distances between the four neighbor points and the center point (as shown in Fig. 1), so the distances along 0° and 90° should be multiplied with $\sqrt{2}$ for consistency.

Fringes especially the ESPI fringes are often spoiled by noise as shown in Fig. 2. To lower the effects of noise, we use accumulating strategy to do the average in the calculating window. If all the differences between two neighboring points in a window along a certain orientation are add up together, the sum along the local fringe orientation will be the smallest one. So by calculating the sums along all the orientations and finding the smallest one, one can obtain the fringe orientation. But for convenience and efficiency, we only compute four sums along 0°, 45°, 90° and 135°, respectively, and we propose to get the orientation with the smallest sum by plane-fit method. The four sums of differences along the four orientations in a square window $S(m \times m)$ are calculated as follows. And m is the window size

$$D_{\text{angle}}(x,y) = \sum_{(i,j)\in S} d_{\text{angle}}(x,y) \quad (\text{angle} = 0, 45, 90, 135) \tag{2}$$

If one arrange the four differences in Eq. (1) along an axis as shown in Fig. 3 and fit the four values with a polynomial, one can get the orientation (angle) corresponding to the minimum difference. Because orientation is periodical, the four values should be extended to another periodicity to do the fitting.

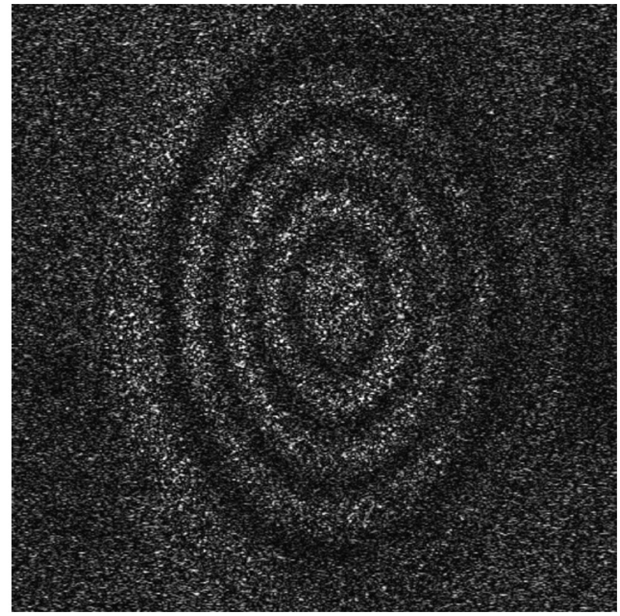

Fig. 2. A ESPI fringe with high speckle noise.

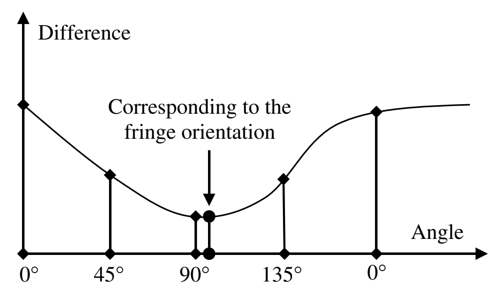

Fig. 3. Fit the four values with a polynomial.

It is feasible to do so but there is a more effective way. As shown in Fig. 4, when the four difference values are arranged at the four corners of a square, the orientations corresponding to the four values are doubled and the angle range is extended to −180° to 180°. In this way, the four differences of D_0, D_{45}, D_{90} and D_{135} are placed at four points of $(1,0)$, $(0,1)$, $(-1,0)$ and $(0,-1)$, respectively. So after fitting a plane with the four differences values, the normal vector of the plane will points to a direction with the smallest value which is corresponding to the fringe ori-

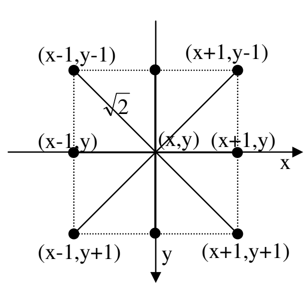

Fig. 1. Neighbors and corners of a point (x, y).

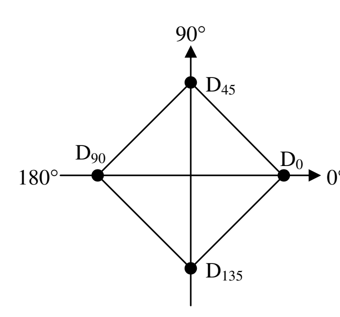

Fig. 4. Four differences are arranged at the four corners.