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Study on inspection method of glass defect based on phase image processing

Yong Jin, Zhaoba Wang*, Yu Chen, Xiaoli Kong, Limei Wang, Weizhe Qiao

National Key Lab for Electronic Measurement Technology, North University of China, Taiyuan 030051, China

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ABSTRACT

To solve the problem in projecting grating method, the paper presents an inspection method based on phase image processing for glass defects. In the proposed method, the wrapped phase difference is achieved according to the images of defect-free and defect-containing. The unwrapping phase algorithm, based on jump corrected is used to eliminate jump error. The segmentation of defect region is implemented by integrating grayscale mathematical morphology with high-low threshold segmentation, and the boundary coordinate of connected region is used to calculate the size and location of defect. The results demonstrate that the proposed method provides reliable identification of defects.
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1. Introduction

The defects from production process will damage the appearance and reduce the grade of glass. Thus, defect inspection is an important task in glass manufacturing [1]. The method based on transmission-mode projecting grating for glass defects is valid, which can calculate the diopter and test the location, size and type of defect [2]. However, it is likely to divide a single defect into several unconnected ones and yield an incorrect size and amount of defects. This will make false classification of the quality grade.

In this paper, the method of defect inspection is proposed to solve this problem by phase image processing. The wrapped phase image is calculated by Fourier transform, and the wrapped phase difference is achieved according to the images of defect-free and defect-containing. The unwrapping phase algorithm is used to eliminate jump error. The segmentation algorithm is implemented by integrating grayscale mathematical morphology with high-low threshold segmentation. The boundary coordinate of connected region is used to calculate the size and location of defect.

2. The wrapped phase difference of typical defects

The grayscale distribution of fringe image on glass surface is given as:

$$I(x, y) = a(x, y) + b(x, y)\cos\ (2\pi f_0 x + \psi(x, y)) \quad (1)$$

where $I(x,y)$ is the fringe intensity, $a(x,y)$ is the background intensity, $b(x,y)$ is the fringe amplitude and $\psi(x,y)$ the fringe phase, $f_0 = 1/p$ is the spatial frequency of the grating, and p the grid pitch of the grating, x and y refer to the spatial coordinates along the horizontal and vertical directions.

In the proposed method, two fringe images, i.e. one defect-free and the other with defects are considered, and the change of phase near the defect will occur compared with the defect-free. Hence, the defect can be inspected by using the information about the phase change.

Taking the several typical defects for example, the fringe images (200×200 pixels) with resolution of (0.1 mm $\times$ 0.1 mm)/pixel, such as defect-free, stone, knot and ream, are shown in Fig. 1.

Fourier transform is applied to solve the phase of fringe image [3,4]. The phase is calculated by arctan function and wrapped in the range between $-\pi$ and π, which is interrupted and jumped. The wrapped phase in Fig. 1 is shown in Fig. 2.

The wrapped phase difference of defects is calculated by

$$\Delta\psi(x, y) = \psi(x, y) - \psi_0(x, y),$$

where $\psi_0(x,y)$ and $\psi(x,y)$ are the wrapped phase of defect-free and defects. The wrapped phase difference $\Delta\psi(x,y)$ is still jumped compared with $\psi_0(x,y)$, and the magnitude is 2π. The typical defects image of wrapped phase difference is shown in Fig. 3.

From Fig. 3, it is clear that the position of the jump is different to each other. For the wrapped phase of knot and ream defects, the deviation of jump position is due to the influence of system noise, the difference between defects and defect-free generates 2π jump. However, the stone defect, in addition to the 2π jump caused by the

* Corresponding author. Tel.: +86 13503515326.
E-mail address: wangzhaoba123@163.com (Z. Wang).

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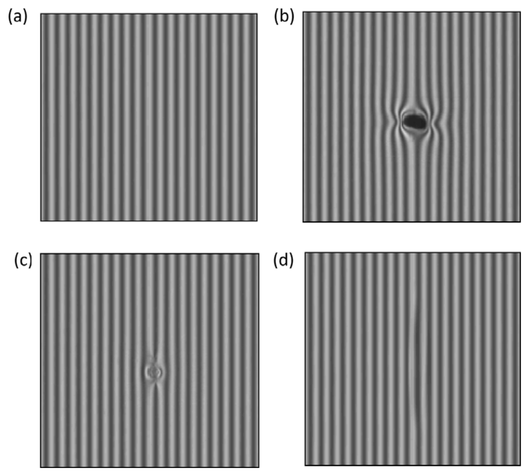

Fig. 1. The fringe images of typical defects: (a) defect-free; (b) stone; (c) knot; (d) ream.

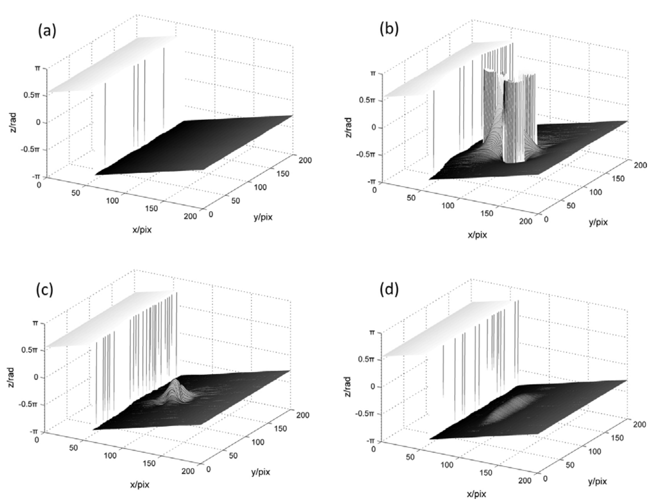

Fig. 2. The wrapped phase of typical defects: (a) defect-free; (b) stone; (c) knot; (d) ream.

system noise, the defect-core also induces the jump and generates the residue, the reason is that the interrupting fringe at defect-core makes dramatic change and calculates the wrong value in the wrapped phase.

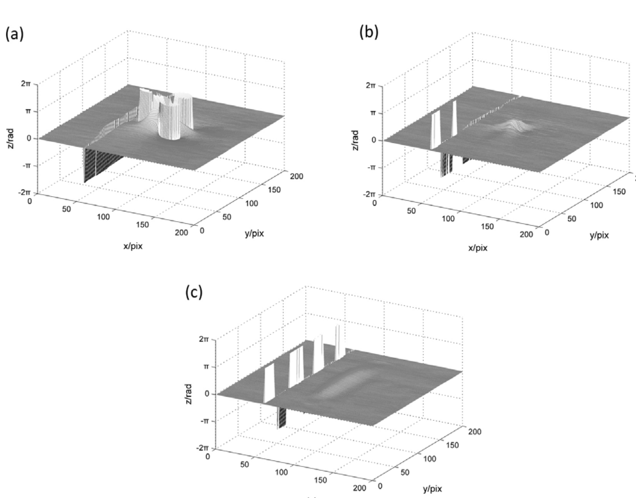

Fig. 3. The wrapped phase difference of typical defects: (a) stone; (b) knot; (c) ream.

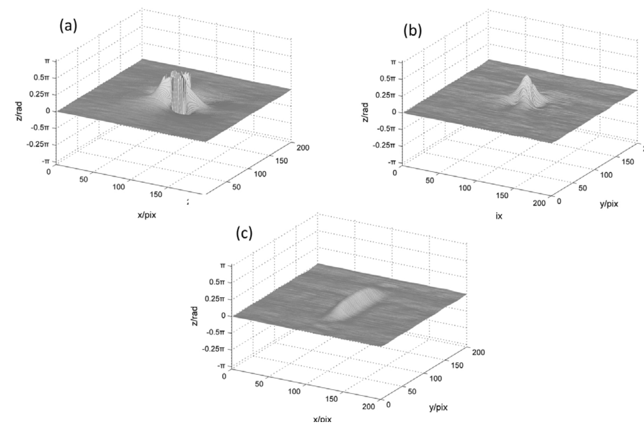

Fig. 4. The unwrapped phase difference of typical defects: (a) stone; (b) knot; (c) ream.

3. The algorithm of unwrapping phase

The wrapped phase difference of typical defects must be unwrapped to obtain the real phase difference. The major phase unwrapping algorithms include the point-by-point unwrapping method [5], the branch cutting method [6], the quality map guidance method [7,8] and the least square method [9]. The efficiency of the point-by-point unwrapping method is the highest. But the residue in the wrapped phase difference will lead to the results related to the path, making the error propagation along the path. The branch cutting method and the quality map guidance method can get the real phase with high quality, but the unwrapping efficiency is lower. The least square method is one of the best approximation algorithms, so the phase change by the defects will extend to the defect-free area.

A phase unwrapping algorithm, based on jump corrected is presented. The concrete implementation process as follows:

By selecting two threshold as $\pm\pi$, and for each pixel with spatial coordinates (x,y) in the fringe image, the unwrapped phase difference $\Delta\phi(x,y)$ can be calculated by the following equation:

$$\Delta\phi(x,y)=\begin{cases}\Delta\psi(x,y)-2\pi & \text{if} \quad \Delta\psi(x,y)>\pi\\ \Delta\psi(x,y)+2\pi & \text{if} \quad \Delta\psi(x,y)<-\pi\\ \Delta\psi(x,y) & \text{otherwise}\end{cases} \quad (2)$$

Compared with above algorithms, the unwrapping algorithm proposed in this paper can be implemented according to the value of each pixel only, with higher efficiency and similar accuracy results. The typical defects image of unwrapped phase difference is shown in Fig. 4.

4. The segmentation of phase difference image

As can be seen in Fig. 4, the change of the phase difference near the defect is pronounced compared to defect-free regions. Hence, by using the segmentation algorithm about the phase difference value, the defect could be identified.

In this paper, the segmentation algorithm of defect region is proposed based on integrating grayscale mathematical morphology with high-low threshold segmentation. A disk structuring element $b(x,y)$ with a diameter of 7 pixels is selected. The enhanced image of the unwrapped phase difference, $f'(x,y)$, can be computed as:

$$f'(x,y)=[\Delta\phi(x,y)\oplus b(x,y)]-[\Delta\phi(x,y)\Theta b(x,y)] \quad (3)$$

where '$\oplus$'denotes the dilation operation of grayscale mathematical morphology, and 'Θ' the erosion operation.

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