Monogenic Filtering Based Automatic Defect Detection from a Single Fringe Pattern

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Abstract. We propose a fringe analysis algorithm for the automatic detection of defects from a single fringe pattern (FP). Typically, the surface defects exhibit high fringe density areas in the FP. Consequently, high fringe density regions can be utilized as a signature for detecting and locating the surface defects. An algorithm based on monogenic filtering of the FP is proposed for an efficient computation of the fringe density. The defect related high density fringe areas are segmented from the defect-free region based on a threshold derived from the fringe density histogram. The algorithm is found to be noise robust and it does not require any pre-processing of the FP. A single FP based analysis approach is suitable in identifying defects using interferometric systems in an industrial environment. Simulation and experimental results are provided to demonstrate the feasibility of the proposed algorithm.

Keywords: Fringe analysis · Interferometry · Monogenic filtering

1 Introduction

Optical interferometric measurement techniques such as digital holographic interferometry, electronic speckle pattern interferometry, and shearography have been employed in the applications of defect detection, deformation analysis and non-destructive testing [1–3]. In these techniques, the information on the measurand is recorded in the form of a sinusoidal variation in intensity, usually termed as a *fringe pattern*. In general, phase shifting interferometry has to be employed for performing quantitative measurement [4]. Since phase shifting is sensitive to vibrations, it is desirable to perform deformation analysis using a single recording of a fringe pattern. In this work, we propose a frequency selective filtering based on monogenic representation of the fringe pattern for surface defect detection.

2 Monogenic Filtering Based Fringe Analysis

The FP can be represented as,

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$$I(\boldsymbol{r}) = a(\boldsymbol{r}) + b(\boldsymbol{r})\cos\phi(\boldsymbol{r})$$

where, $\mathbf{r} = [x, y]^T$ indicates the pixel spatial coordinates of the FP; a($\mathbf{r}$) and b($\mathbf{r}$) represent the background intensity and the fringe amplitude, respectively; $\phi(\mathbf{r})$ represents the phase embedded in the fringe pattern. In deformation analysis using electronic speckle pattern interferometry and holographic interferometry, this phase is proportional to surface displacement. On the other hand, in shearography, the phase is proportional to surface displacement derivative.

Adaptive monogenic filtering has been considered in [5] for the purpose of fringe normalization and denoising. In this work, we propose to use the adaptive monogenic filtering operation for the estimation of fringe density at each pixel. At a given pixel $\mathbf{r}'$, the FP within a small window can be expressed as a single frequency sinusoid as,

$$I(\boldsymbol{r}) = \mathrm{A}\cos\left[\boldsymbol{\omega}_0^{\mathbf{T}}(\mathbf{r} - \mathbf{r}') + \phi\right],$$

where, $\boldsymbol{\omega}_0 = \left[\omega_x, \omega_y\right]^T$ represent the local frequency vector. If an appropriate filter is designed, the local amplitude A and phase ϕ can be estimated accurately. To do so, we need to obtain a two-dimensional analytic signal, i.e. monogenic signal, corresponding to the FP. For the computation of monogenic signal, we consider an isotropic log-Gabor filter, which is given as

$$H(\boldsymbol{\omega}) = \exp\left(-\frac{\left(\log\left(\frac{|\omega|}{\omega_0}\right)\right)^2}{2(\log\sigma)^2}\right).$$

The bandwidth of the filter passband depends on the shape parameter σ. The FP filtered by $H(\boldsymbol{\omega})$ constitutes the real part of the monogenic signal. The two imaginary parts of the monogenic signal are computed using a complex valued filter

$$H_O(\boldsymbol{\omega}) = \frac{j\omega_x - \omega_y}{|\omega|}H(\boldsymbol{\omega}), \quad j = \sqrt{-1}.$$

The real and imaginary components of the output of this filter corresponds to the two odd parts of the monogenic signal. Let $I_e(\boldsymbol{r})$, $I_{01}(\boldsymbol{r})$ and $I_{02}(\boldsymbol{r})$ represent the real and imaginary components of the monogenic signal. The local amplitude estimate is obtained as,

$$I_o(r) = \sqrt{I_{01}(r)^2 + I_{01}(r)^2}$$

$$A(r) = \sqrt{I_e(r)^2 + I_0(r)^2}$$

The local amplitude is computed using a number of filter frequencies (ω_0), say K. The frequencies are selected such that low and high fringe frequencies corresponding to slow phase variations and noise, respectively, are filtered out. Subsequently, at each pixel, the maximum filter output amplitude among all the filter outputs is computed. This maximum amplitude map clearly indicate the defective region with high amplitude against the low amplitude defect-free region. The amplitude map is normalized and a threshold is applied to obtain a binary map segmenting the defective and defect-free region. The threshold is computed based on the histogram of the maximum amplitude map.

3 Simulation and Experimental Results

A simulation example is provided in Fig. 1a with a typical shearogram recorded in shearography setup. Four defect locations with different fringe densities are present. The FP is corrupted by additive noise. Spatially varying background intensity and fringe amplitudes are considered in the simulation. Figure 1b shows the maximum amplitude map. The binary image in Fig. 1c clearly indicates the identified defective regions. Figure 1d is provided for the purpose of illustration.

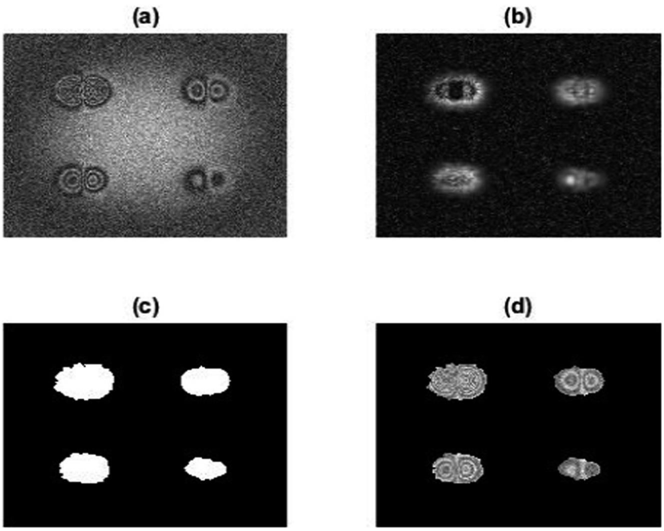

Fig. 1. Simulation results: **a** simulated shearogram with four defects, **b** monogenic filter amplitude, **c** binary image indicating defect locations and **d** high density fringes present at the defect locations.

Figure 2a shows the FP recorded in a holographic interferometry setup corresponding to out-of-plane deformation of an aluminum plate. A circle indicating the point of loading is shown in the figure. The proposed algorithm is implemented to

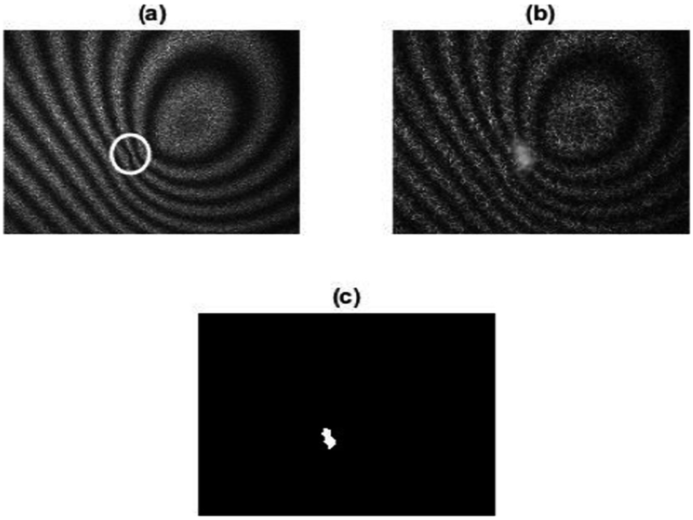

Fig. 2. Experimental results: **a** fringe pattern recorded in a holographic interferometry setup corresponding to out-of-plane deformation of an aluminum plate, **b** monogenic filter amplitude and **c** binary image indicating the point of loading.

locate the point of load. Figure 2b, c show the maximum amplitude map and identified defect map, respectively.

4 Conclusion

A noise robust fringe analysis algorithm is proposed for the automatic identification of surface defects. A monogenic filtering based algorithm effectively computes the local fringe amplitude map at different filter frequencies based on which high fringe density areas are identified. The simplicity of implementation and simulation and experimental results substantiates the practical applicability of the proposed method.

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