Studies of the influence of average intensity changes in phase shifted interferograms on the phase shift histogram distributions

Krzysztof Patorski, Adam Styk

Warsaw University of Technology
Institute of Micromechanics and Photonics

k.patorski@mchtr.pw.edu.pl

Computer and experimental results of the analyses of the influence of average intensity changes of component interferograms (caused by temporal light source power changes or the CCD camera automatic gain control setting) on phase-shift histograms and their lattice-site representations are presented. The studies are conducted for the TPS aided time average method for vibration testing.

1 Introduction

The width and shape of a phase shift histogram can be used for estimating the phase shift spatial variations when implementing the temporal phase shifting (TPS) method for automatic interferogram analysis [1-3]. Till now skewness and spread in the histogram have been attributed to phase errors which may be due to tilting or uneven motion of the phase shifter, high numerical aperture reference surfaces, additive intensity (electronic) noise, multiplicative phase (speckle) noise, higher harmonics in the fringes and the quantization of intensity values in the case of low SNR [4]. Our recent work [5] evidences crucial influence of average intensity changes in component TPS frames on calculated two-beam interferogram contrast maps. They are used for visualization and analysis of Bessel fringes obtained by time-average interferometry applied for vibration testing.

In the paper computer and experimental results of the analysis of the influence of average intensity changes of component interferograms (caused by temporal light source power changes or the CCD camera automatic gain control setting) on phase-shift histograms and their lattice-site representations are presented. The studies are conducted for the TPS aided time average method for vibration testing.

2 Analysis

Experimental discrepancies from ideal TPS parameters (e.g., phase shifter miscalibration and nonlinearity, noise, “dead” pixels, etc.) cause that phase displacements α(x,y) differ in CCD matrix pixels. By calculating the population of pixels with the same phase shift we might search for the information on the contribution of individual experimental errors. Phase shift angle distributions have been calculated using:

1) for four frame algorithms – the so-called Carre equation [1,2]

$$\alpha(x,y) = 2\,\mathrm{arctg}\left\{\sqrt{\frac{3(I_2-I_3)-(I_1-I_4)}{(I_2-I_3)+(I_1-I_4)}}\right\} \qquad (1)$$

2) for five frame algorithms [1,2]

$$\alpha(x,y) = \arccos\left\{\frac{1}{2}\left[\frac{I_5-I_1}{I_4-I_2}\right]\right\} \qquad (2)$$

At the same time the lattice-site representation of phase shift angles [4] was calculated to see the influence of average intensity changes of TPS frames. The “rectangle” coordinate system denotes the range of numerator and denominator in above equations for 256 gray levels. Straight lines passing through the origin represent lattice sites with equal shift angles.
Before calculating histograms and lattice-site representations component TPS frames should be noise preprocessed. The reasons are as follows:

a) high frequency intensity noise changes the bias and modulation of the interferogram intensity distribution;

b) contrast and modulation simulation calculations show that high frequency intensity noise changes the values of the maxima and minima of Bessel fringes.

For preprocessing spin filtering [6] has been chosen because of its two main advantages: no changes in position in the fringe maxima and minima, and no blurring effect involved. Spin filter searches for the tangential direction of the interference pattern at a particular image point, and filters additive and multiplicative noise in that direction. We have used two filter types: with discrete and continuous direction of the filtering window.

Numerical simulations and calculations of histograms and lattice-site representations from experimentally recorded interferograms (for resonant modes at more than thirty resonance frequencies) result in the following conclusions:

1. Spin filtering greatly facilitates extraction of characteristic features in phase-shift maps;
2. Conventional and lattice-site representations provide rather limited information on average intensity changes of TPS frames;
3. Sharp asymmetries and/or quasi-central dips encountered in some cases of conventional phase-shift histograms are of interest. They correspond to vertical displacements of characteristic quasi-elliptical patterns in lattice-site representations;
4. Clear dip in 5-frame histograms appears when I_1 and I_5 represent I_{min} and I_{max} average intensity values, and vice versa;
5. Sharp asymmetries in 5-frame histograms are encountered when I_1 or I_5 correspond to I_{min} or I_{max} values;
6. For $I_1 > I_5$ lattice-site representation pattern shifts upwards, for $I_1 < I_5$ it shifts downwards.
7. Dips and asymmetries in 5-frame histograms are always accompanied by a dip in one of four-frame histograms;

Good experimental corroboration of numerical investigations has been obtained when testing vibrations of silicon micromembranes with specular reflection surfaces. As an example, the results for the resonance frequency of 724 kHz are shown in the figure below.

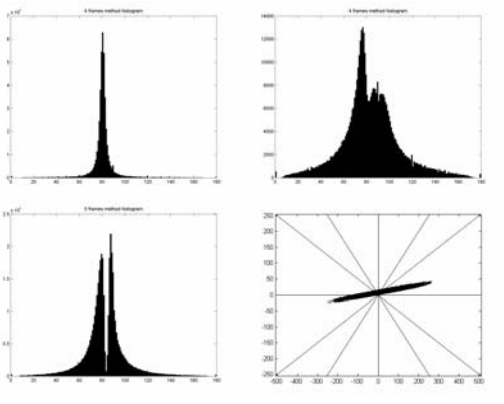

Fig.1 Four frame histograms for $I_1 \div I_4$ and $I_2 \div I_5$ (top row); five frame histogram and its lattice-site representation (bottom row) for a resonance mode at 724 kHz. TPS interferograms have the average intensities expressed by the numbers: 69.5, 70.06, 76.5, 77.48 and 77.78 ($I_1 = I_{min}$, $I_5 = I_{max}$). The results were obtained with TPS frames prefiltered with a spin filter with continuous direction of the filtering window.

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