Application of Digital Image Correlation Techniques in Spatial Phase Shifting Interferometry

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In this contribution a method for simultaneous 3D displacement data acquisition from spatial phase shifted interferograms for the application under instable conditions e.g. as investigations on biological specimen is presented. With the knowledge of the lateral displacements lateral decorrelation effects that occur in speckle-interferometric techniques can be compensated.

1 Introduction

Spatial phase shifting (SPS) interferometric techniques allow a quantitative determination of optical path length changes and displacements in axial direction with low demands on the stability of the experimental setup. Digital image correlation techniques are applied for the determination of the lateral displacement components. The combination of both techniques opens up new possibilities for simultaneous determination of 3D displacement data. The application of digital cross-correlation techniques on SPS interferograms requires the reconstruction of the object wave intensity. Two different algorithms, one in spatial and one in Fourier domain are optimized and compared.
Furthermore, the obtained lateral displacement data are utilized to compensate wave front decorrelation effects that occur e.g. due to rigid body movements of the investigated object surface in Electronic Speckle-Pattern Interferometry.
Finally, the presented methods are applied to investigations on artificial tissue.

2 Experimental methods

The determination of axial object surface displacements is performed by SPS interferometry. For this purpose, spatially phase shifted interferograms are generated by superposition of slightly tilted object and reference wave fronts. By taking into account the intensity values of neighboring CCD pixels the object wave phase mod 2π is determined. For the detection of lateral changes of the object wave front as well as lateral displacements, the object wave intensity in the image plane is reconstructed. Therefore, the squared interferogram modulation is calculated for each object state in spatial domain by a 3 step SPS algorithm (MOD) [1]. In comparison, a Fourier transform method (FTM) is used for carrier fringe removal [2]. Lateral wave front changes and in-plane displacements are determined from the reconstructed object wave intensity data by digital cross-correlation of sub-images. The obtained information is utilized to decrease the noise of phase difference data in SPS Electronic Speckle-Pattern Interferometry that is caused by lateral speckle displacement. For this purpose, the measured speckle field displacement is compensated by lateral shifting in one of the recorded interferograms in sub-areas [3]. Afterwards, the phase difference data is recalculated by an SPS algorithm from the decorrelation compensated interferograms.

3 Results

3.1 Optimization of system parameters

Investigations with an SPS speckle interferometer on a white painted metal plate that is laterally shifted by a calibrated piezo translator for a distance of (40 ± 2.5) µm are carried out to character-

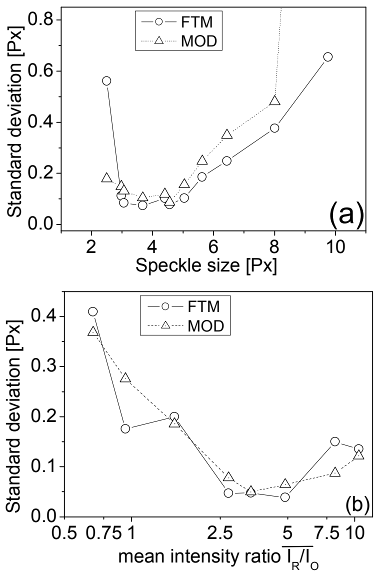

Fig. 1 *Optimization of system parameters for object wave intensity reconstruction with FTM and MOD; the standard deviation of a homogeneous displacement which is a quality parameter for the reconstruction of the object wave intensity is plotted as a function of the (a) speckle size; (b) mean intensity ratio between object and reference wave* $\overline{I_R / I_O}$.

ize and optimize the methods MOD and FTM. As the true displacement is uniform over the image field, the error is given by the standard deviation of the calculated displacements over all sub-images (see Fig. 1).

Fig. 1 (a) shows the dependence of the standard deviation on the speckle size. For FTM and MOD the lowest noise values are obtained between 3 and 5 Pixels. Smaller or bigger speckle sizes lead to increased noise. In Fig. 1 (b) the optimization of the intensity ratio $\overline{I_R / I_O}$ between object and reference wave is depicted. Here, for both – FTM and MOD – intensity ratios in the range between 2.5 and 6 optimal noise values are obtained.

The results show that there is no significant difference in the accuracy of the two techniques. The accuracy of lateral displacement detection is estimated to approximately 0.05 Pixels.

3.2 Compensation of lateral decorrelation effects

Investigation on the compensation of lateral decorrelation effects are carried out with a metal plate which is shifted horizontally piezo-controlled up to 10 µm. In this way an increasing decorrelation is induced which leads to a decreasing quality in the phase difference distributions. The application of a backshift on the source interferograms in each sub-image according to the detected displacement compensates this lateral decorrelation. After the recalculation of the phase difference distribution decorrelation is minimized. Fig. 3 shows the standard deviation of the phase difference distribution, which provides information about the fringe quality as a function of the lateral displacement induced by the piezo-translator. With an increasing lateral displacement the noise of the phase difference distribution also increases. The maximum is reached at about 8 µm or 3 Pixels, which corresponds to the average speckle size. The fringe quality of the compensated phase difference distribution shows no dependence on the lateral displacement for both object wave intensity reconstruction techniques.

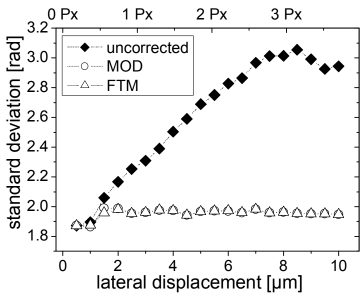

Fig. 3 *Compensation of lateral decorrelation: the noise of the uncorrected phase difference distribution increases with lateral decorrelation; after compensation of decorrelation according to the lateral speckle field displacement obtained after reconstruction with MOD or FTM no dependence of the fringe quality on the lateral displacement is observed within the investigated displacement range.*

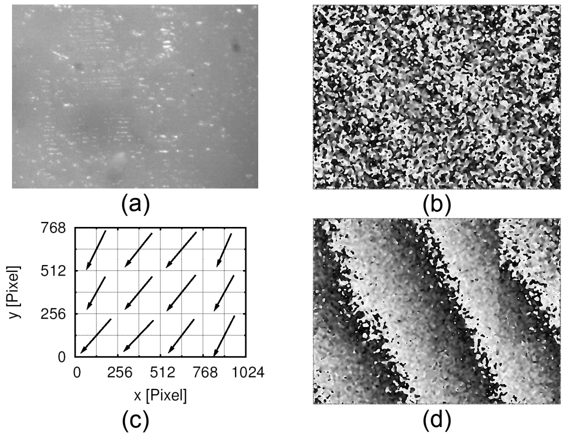

Fig. 2 *Compensation of homogeneous lateral decorrelation due to rigid body movements; (a) white light image of the investigated area of a silicone tissue model; (b) uncorrected phase difference distribution ($\sigma_{\Delta\phi}$=2.78 rad); (c) corresponding lateral displacement field; (d) phase difference distribution after compensation of decorrelation effects with MOD ($\sigma_{\Delta\phi}$=2.28 rad)*

3.3 Investigation on artificial tissue

In Fig. 2 investigations on a silicone tissue model are presented. Fig. 2 (a) shows the white light image of the investigated area (size 5.3 x 4.0 mm^2). The calculated uncompensated phase difference distribution with a high noise level is depicted in Fig. 2 (b). The corresponding lateral speckle displacement field in Fig. 2 (c) shows a homogeneous speckle field displacement that occurred due to rigid body movements of the specimen. The detected mean displacement length in this example is (2.7 ± 0.35) Pixel, which corresponds to (14.0 ± 1.80) µm. By compensation of lateral speckle decorrelation the quality of the phase difference distribution is significantly improved (see Fig. 2(d)).

4 Conclusion

The presented investigations show that lateral displacement components can be determined from of spatial phase shifted interferograms by application of cross-correlation techniques on object wave intensities that are reconstructed without significant differences either in the spatial or in the Fourier domain. In Electronic Speckle-Pattern Interferometry these data can be utilized to compensate speckle decorrelation effects which is demonstrated on investigations on artificial tissue.

References

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