Detection of 3D-Displacements by Application of Digital Correlation Techniques and Spatial Phase Shifting Electronic Speckle-Pattern Interferometry (SPS ESPI)

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A method for simultaneous acquisition of 3D-displacement data out of spatial phase shifted interferograms is presented. Therefore, the axial displacement component is determined by spatial phase shifting electronic speckle pattern interferometry (SPS ESPI) while the lateral displacement components are obtained by application of digital cross-correlation techniques on the modulation distributions of the speckle interferograms. The applicability of this approach on technical and biological surfaces is demonstrated.

Introduction

Spatial phase shifting electronic speckle-pattern interferometry (SPS ESPI) allows a quantitative determination of axial displacements with low demands on the stability of the experimental setup [1, 2] and with only one recording of a speckle interferogram per object state. For this reason, SPS ESPI methods are particularly suitable for investigations on instable surfaces like biological specimen.

The presented method enhances the SPS ESPI for additional lateral displacement data by adding digital cross-correlation techniques. In this way it is possible to detect 3D-displacement components simultaneously with a single interferogram per object state. Furthermore, the obtained lateral displacement data can be utilized to improve the signal-to-noise-ratio through compensation of the lateral speckle decorrelation of the detected axial sensitive phase difference distribution to facilitate the phase unwrapping process.

1 Detection of 3D-displacements by combination of SPS ESPI and cross-correlation methods

The determination of axial displacements of the object surfaces is performed by SPS ESPI. Therefor a spatially phase shifted speckle interferogram is generated by superposition of the object wave front with a tilted reference wave front. By taking into account the intensity values of neighboring CCD pixels the object wave phase mod 2π is determined [1]. Furthermore, the modulation distribution of the speckle interferogram is calculated for each recorded object state [3]. After-wards, the data obtained in this way is utilized to determine lateral displacements by application of digital cross-correlation methods on sub-images [4].
If the quality of the phase difference distribution obtained by SPS ESPI is restricted by speckle decorrelation effects, compensation is carried out by applying a back shift to the source data (the spatial phase shifted speckle interferograms) according to the detected lateral displacement field.

2 Results

2.1 Investigations on technical surfaces

Fig. 1 shows results of investigations on a heated white painted metal plate with a chamfer on the back side (see dashed red line in Fig. 1a) by the application of an endoscopic SPS ESPI system [2]. Fig. 1b depicts the resulting phase difference distribution mod 2π. In Fig. 1c the corresponding lateral displacement field obtained by cross-correlation of the related modulation distributions is shown. The maximal arrow length corresponds to 20 µm.
In Figures 1b and 1c the chamfer can be localized in the phase difference distribution as well as in the lateral displacement field.

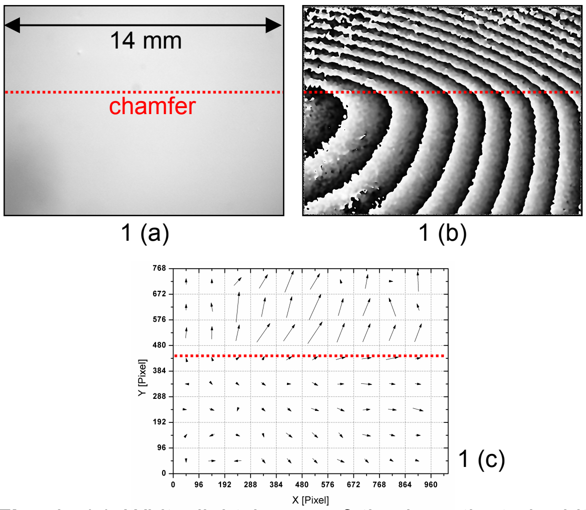
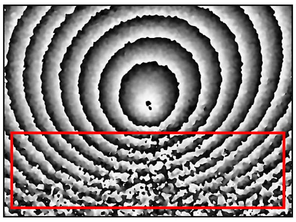
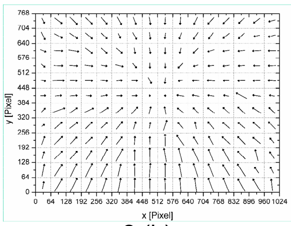


Fig. 1: *(a) White light image of the investigated white painted metal plate with a chamfer on the back side (see dashed red line); (b) smoothed phase difference distribution mod 2π after heating the specimen; (c) corresponding lateral displacement field*

In Fig. 2 the compensation of lateral speckle decorrelation is demonstrated on measurement results obtained from investigations on a centrally loaded plate. Fig. 2a shows the phase difference data mod 2π calculated by SPS ESPI which is affected by speckle decorrelation effects (see red marked area). The lateral deformation field detected by evaluation of the same source speckle interferograms is depicted in Fig. 2b. The application of a back shift on this source data according to the lateral displacement compensates the speckle decorrelation and improves the signal-to-noise-ratio in the obtained phase difference distribution (Fig. 2c).


2 (a)



2 (b)

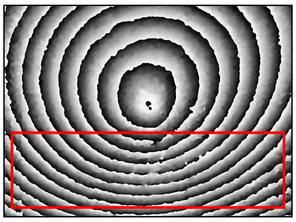

2 (c)

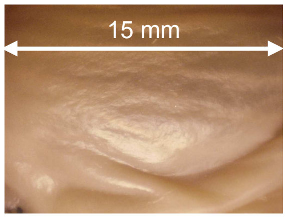
Fig. 2: *(a) smoothed phase difference distribution mod 2π; (b) the lateral displacement field; (c) smoothed phase difference data mod 2π obtained from the speckle interferogram with compensated lateral speckle decorrelation (see red marked area)*

2.2 Investigations on biological heart valve prosthesis

Fig. 3 shows results of investigations on a leaflet of a biological heart valve prosthesis by application of a endoscopic SPS ESPI system [2] which have been obtained during the relaxation process after stimulation with cautious blasts of compressed air to analyze the deformation properties (Fig. 3a: endoscopic color image of the investigated area; Fig. 3b: calculated phase difference distribution mod 2π; Fig. 3c: obtained lateral displacement field).

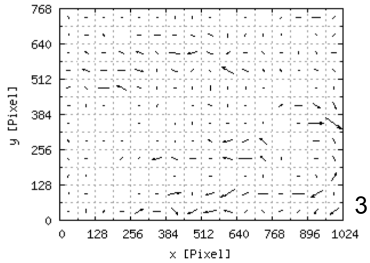
3 Discussion and Conclusion

The results described in section 2 show that lateral displacement components can be determined by application of cross-correlation techniques on the modulation distributions obtained from spatial phase shifted speckle interferograms.
Furthermore, these data can be utilized to compensate speckle decorrelation effects. Finally, the applicability of the presented method on technical and biological surfaces has been demonstrated.



3 (a)


3 (b)



3 (c)

Fig. 3: *(a) Endoscopic color image of the investigated leaflet of a heart valve prosthesis; (b) smoothed phase difference mod 2π after stimulation with short blasts of air pressure; (c) corresponding lateral displacement field obtained by cross-correlation*

4 Acknowledgement

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5 References

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