The aim of our research conducted under two scientific grants (NCN OPUS and MNiSW Diamond Grant) is the development of novel adaptive techniques for processing and analysis of complex fringe patterns acquired in the full-field optical testing methods and STM and AFM microscopy. Developed and enhanced two-dimensional methods, i.e., continuous wavelet transform (2D CWT) [1-2], fast adaptive empirical mode decomposition aided by the Hilbert spiral transform (FABEMD-HST) [3-7], implicit smoothing splines (ISS) [8] and pre-filtering aided Gram-Schmidt (GS) orthonormalization [9] show such features as universality, adaptability, resistance to noise and changes of the image modulation and background levels. Their local character predestines them for nonstationary signal analyses. They are used to retrieve information coded in their phase and amplitude distributions. The main application tasks include processing low quality fringe patterns, separation of multiple fringe families encountered in a single image, analysis of fringe patterns with intensity distribution described by the Bessel function J0, and normalization of fringe patterns.

Full-field optical measurement techniques enable acquisition and processing of experimental data simultaneously for all points of the tested object. Some of them provide the output in the form of a fringe pattern, i.e., interferogram, correlogram, moiregram or structured light pattern. Quantitative analysis of fringe patterns is performed using computer-aided automatic fringe pattern analysis (AFPA) methods.

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Experimental data presented were acquired using the following optical techniques: speckle pattern interferometry, Figs. 1 and 2, grating (moire) interferometry, Figs. 3 and 4, moire and structured illumination technique, Fig. 1 (four techniques for displacement, strain and 3D shape analysis of micro to macro scale objects), structured illumination microscopy. Fig. 5 (noninvasive volumetric imaging of the biological samples) and time-averaged interferometry, Figs. 6 and 7 (vibration testing).

Innovative results described in our recent papers [1-9] and conference proceedings guarantee information retrieval with optimized accuracy and computation time. The impact of our research was recognized by several awards, i.e., two awards of the Rector of the Warsaw University of Technology, two FNP START scholarships, two scholarships funded by the Ministry of Science and Higher Education for best PhD candidates etc.

Experimental DSPI pattern (a), rewrapped 2D CWT result (b) and rewrapped ISS (Implicit Smoothing Splines) algorithm processed pattern (c).

Fig. 2. Experimental DSPI pattern (a), rewrapped 2D CWT result (b) and rewrapped ISS (Implicit Smoothing Splines) algorithm processed pattern (c).

Fig. 3. (a) Experimental crossed interferogram obtained in the grating (moire) interferometry setup, (b) vertical fringes extracted from (a) using adaptive algorithm, (c) vertical fringes adaptively enhanced and normalized, (d) wrapped phase fringes obtained using Hilbert transform, (e-g) analogous processing results for the horizontal fringe set.

Fig. 4. (a) Unwrapped phase maps corresponding to the u(x,y) displacement field obtained using the developed adaptive approach and (b) the 5-frame temporal phase shift method, (c) plot illustrating cross-sections along 50th row of the u(x,y) displacement field obtained using adaptive (red line) and TPS (blue line) methods; (d) unwrapped phase maps corresponding to the v(x,y) displacement field obtained using adaptive scheme and (e) TPS, (f) plot illustrating the cross-section along 200th row of the v(x,y) displacement field obtained using adaptive (red line) and TPS (blue line).

Fig. 5. Images of phantoms containing SiHa cervical cancer cells labeled with anti-EGFR gold conjugates. The field of view is 54 x 54 µm². The approximate depth of the imaged optical section is 15-20 µm below the phantom surface. Part (a) shows an inverted wide-field reflectance microscope image, and part (b) shows a structured illumination microscopy (SIM) raw image. Reconstructed optically sectioned images using (c) 3-frame SIM technique, (d) HiLo microscopy, and (e) our adaptive algorithm.