Project description for the general public

Project title: Numerically advanced phase and amplitude demodulation for optical interference microscopy and tomography
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Contemporary state-of-the-art optical measurement techniques basing on the laser radiation and interference phenomenon enable full-field quantitative examination of biomedical and technical objects in microscale. Information about local features of the studied structure is encoded in the complex optical field of the light transmitted or reflected from the specimen. Object complex optical field comprising amplitude and phase components is registered by, e.g., CCD camera in the form of characteristic light intensity distribution. Scattering and absorption of light by the measured object are imaged by the amplitude component whereas light refraction (local deviations of optical path difference) results are stored in the phase term of complex optical field. Photoelectric optical field registration produces image with enhanced object amplitude term (light intensity is proportional to the amplitude component everaged in the acquisition time) and object phase term completely lost. Interferometric or holographic optical measurement procedures employ interference of object field with the reference beam creating interferogram (hologram) – real 2D distribution (image) of light intensity encapsulating information about amplitude and differential phase terms of the object and reference optical fields. Most commonly it is in the form of fringe pattern, with phase information encoded in the shape of interference fringes ready to be extracted. Hence unique features of transmission phase objects (e.g. biological – red blood cells, sperm cells, prostate cancer cells etc.; or technical – polystyrene microbeads, microlens arrays etc.) connected with the refractive index distribution invisible in the classical misroscopic image are unraveled and clearly readibly (high contrast) in the interferogram phase field. Additionally features of the reflective technical microelements like silica micromembranes can be stored in the interference pattern phase (3D shape) and amplitude components (vibration amplitude and phase).

Work in the project will be focused on three main objectives:

(1) designing advanced algorithmic solutions for dynamic demodulation (extraction) of the object amplitude and phase terms utilizing single interferogram (hologram) and sophisticated tailored numerical transformations, e.g., Hilbert-Huang transform concept;

(2) phase and amplitude imaging for efficient and robust analysis of live and fixed biomedical and technical in novel grating-based microscopic technique employing second harmonic generation of recorded interferogram intensity distribution. Advantages of the envisioned optical method encompass doubled sensitivity, large dynamic range of the studied phase functions, simple setup, straightforward common-path configuration and innovative phase/amplitude demodulation techniques;

(3) evaluation the possibility of 3D refractive index distribution reconstruction of live dynamic biological samples following specific track adaptable as tomographic sequence. This novel and innovative phase tomography technique is envisioned to achieve significant reduction of currently encountered tomographic limitations (complicated setups, cumbersome illumination sequences and sample rotation, aberration corrections, etc.) adapting characteristic sample movement.

Employed methodology implies utilizing numerical simulations to develop digital models of the interferometric microscopes allowing to compile specialized and versatile algorithmic solutions for analysis of interferometric data in full field of view with efficient error minimization procedures. Final verification of the implemented processing techniques will be conducted in experimental conditions using real biological and technical subjects (i.e., red blood cells and sperm cells). Novel grating-based microscope will be built in one of the Institute of Micromechanics and Photonics Warsaw University of Technology labs while tomographic analyses of live biological micro-objects is planned in cooperation with professor Vicente Mico group from Departamento de Optica University of Valencia – well-established optical measurements experts.

Achievement of the envisioned research project goals will constitute significant contribution advancing optical phase and amplitude imaging – multidisciplinary techniques on the verge of physics, optics, biology and numerical data analysis methods. Project will result in development of specialized and versatile numerical techniques with expanded capabilities for interferometric and holographic measurement data (image) processing robust to environmental influence, registration errors and complicated structure of studied phase-amplitude biological micro-objects. Additionally novel grating-based sensitivity-enhanced multi-beam phase microscope employing second harmonic generation of interferometric intensity distribution will be developed, assembled and tested. Finally the concept of phase tomography profiting from the live dynamic sample characteristic movement – novel potentially attractive technique for examining inner structure 3D refractive index distribution of microorganisms - will be evaluated.