Improved 3D imaging of phase shifting digital holographic microscope by compensation for wavefront distortion

V. Cazac[1,2]

[1]Institute of Applied Physics of Moldova, Academiei 5, Chisinau, Moldova, MD-2028
[2]Tampere University, Tampere, Korkeakoulunkatu 1, Finland, 33720

Abstract. This paper is focused on improving the performance of quantitative phase imaging via phase-shifting digital holographic microscope. The novelty of the optical arrangement is that in the reference beam of DHM system a liquid crystal variable retarder (LCVR) is introduced. Thus, it became possible to actively control the polarization state of light for realizing the necessary phase-shifts. In addition, a spatial light modulator (SLM) is integrated in the optical setup to produce computer-controlled compensation of the spatial wavefront distortion. Topography investigations of phase masks recorded on carbazol-based azopolymers provided the experimental testing of the achieved accuracy in phase reconstruction.

1. Introduction to phase imaging problem

In the last decade, different phase imaging techniques as Differential Interference Contrast, Fourier phase microscopy, Hilbert phase microscopy, and digital holographic microscopy (DHM) were developed to obtain full field, absolute and quantitative phase imaging, especially for life sciences applications. These techniques are very similar, but from all of them the DHM can deliver high resolved images as well as quantitative data of the phase with nanometres accuracy [1-3]. DHM is a quantitative imaging tool applied to optical microscopy, which involves the numerical manipulation of the complex object wavefront. It enables the recording of both phase and amplitude of the specimen and it is the key instrument for 3D investigation of transparent samples [4-6]. Nevertheless, a major disadvantage has been identified in accurate measurement of specimen phase, namely wavefront aberrations introduced by the optical components of the setup (microscope objective, lenses, etc.), which may corrupt the focus, resolution and sensitivity of DHM [7-10].

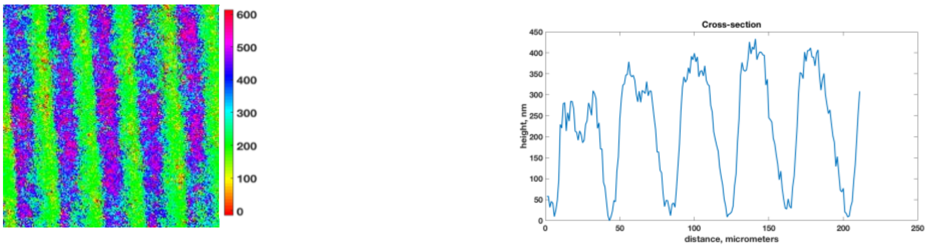
We present a phase-shifting(P-S) DHM arrangement where the digital modulation of light in the object beam is operated by the spatial light modulator(SLM) to optimally shape the wavefront in order to compensate the wavefront deviations. Whereas, the P-S in the reference arm of the setup are computer-controlled by the liquid crystal variable retarder (LCVR). The utilisation of LCVR allows to overcome the probable P-S errors present in the typical P-S scheme resulted from mechanical P-S made by a piezoelectric transducer that may suffer from nonlinearity, hysteresis, and sensibility to temperature.

2. Experimental configuration

The schematic of the proposed P-S interferometer offers the advantage of simultaneously capturing 3D information about the sample under study. For precise phase control, the LCVR and SLM were calibrated, preliminary. It was determined that the four phase shifts equal to $\varphi_1 = 0$, $\varphi_2 = \pi/2$, $\varphi_3 = \pi$, $\varphi_4 = 3\pi/2$ correspond to the voltages V_1 = 2.02V, V_2 = 2.39V, V_3 = 2.76V, V_4 = 3.14V, respectively. To compensate the DHM wavefront deviations caused by intensity fluctuations and quantization errors of the system, the object beam is modulated by the SLM. For this purpose, Fresnel lens(displayed on SLM) with varying period of concentric rings were verified. The object signal is shaped using the determined optimal parameters of Fresnel lens, that is projected on the SLM display. As a result, the hologram quality enhanced due to a finer contrast and larger concentric fringes of the interference pattern.

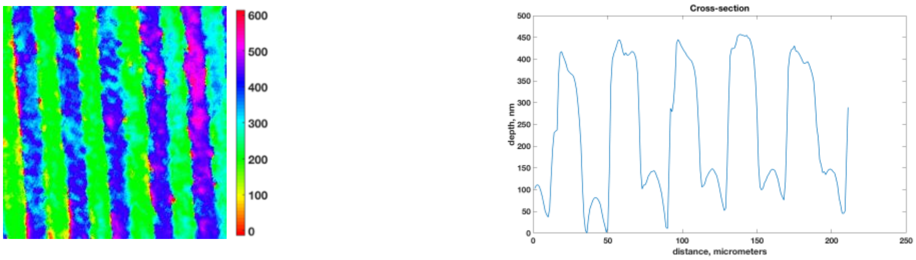
3. Results and discussions

The feasibility of the developed system was tested on a phase mask recorded on a thin film of polyepoxypropil carbazole: disperse orange film azoploymer. Fig. 1. and Fig. 2. illustrate the phase image, 3D topography and surface cross-section of the phase mask in the experiment where the phase imaging is made in preliminary P-S DHM configuration and in the case of corrected object wave performed via SLM, respectively.



a) b)

Figure 1. Initial results- a. Phase image; b. Cross-section of the phase mask recorded on carbasol-based azopolimer.



a) b)

Figure 2. Performance results of the experiment including the compensation stage implemended by the SLM- a. Phase image; b. Cross-section of the phase mask recorded on carbasol-based azopolimer.

The measurements effectuated by the P-S DHM indicate the depth of the mask relief that equals to 400 nm and the periodic shape of the surface. The obtained phase image corresponds to the theoretical data about the phase mask. By analyzing both experiments Fig. 1 compared to Fig. 2, we observe a better accuracy of recovered phase in the second scenario, where the phase image is sharper without using additional noise filtering. The improved imaging system resolves the side peaks that have appeared in the areas of depth minima (Fig. 2). These peaks are related to the shape of the dual-range diffraction grating recorded on the polymer material.

In summary, this work proves the feasibility of the modified P-S DHM technique as a tool for quantitative phase measurements. In particular, we have demonstrated that by utilizing liquid crystal devices in the interferometric setup we can control the precision of the phase reconstruction. Due to the independent control of the object wave and the motionless P-S of the reference wave, significantly improved phase images are obtained. Moreover, the proposed method implies compensation of the low-experimental conditions that are caused by system vibrations typically present in the laboratory environments.

4. Acknowledgement

The author of this paper is thankful to the Laboratory for Materials of Photonics and Photovoltaics from the Institute of Applied Physics, especially to Elena Achimova and Vladimir Abashkin who provided expertise that greatly assisted the research and Alexander Prisacar for sharing the phase masks recorded on the carbazol-based azopolymer.

5. References

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