Digital Holographic Microscopy applied to 3D Computer Microvision by using Deep Neural Networks

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The application of advanced microscopy imaging techniques to 3D specimens or motions faces the problem of the limited depth of field of optical lenses [1]. Thanks to numerical focus computations, digital holography (DH) releases these limitations and extends significantly the allowed axial range of imaging. However, the digital cost of focus distance determination and of object reconstruction makes real-time 3D imaging hardly possible, especially when both in-plane and out-of-plane metrics must be extracted simultaneously.

We address this issue by applying deep neural networks to video-rate microvision measurement of 3D trajectories by means of DH. On the one hand, the ability of new generation of deep neural networks such as vision transformers to predict the focus distance with a high accuracy was demonstrated [2]. On the other hand, the micro-structured pattern used as in-plane position encoder has allowed a 10^8 range-to-resolution ratio through robust phase-based decoding applied to conventional imaging [3]. Here we present deep neural networks dedicated to DH microvision and able to perform simultaneous in-plane and out-plane measurements, at video-rate and without object reconstruction. 3D trajectories were reconstructed using the experimental setup presented in Fig. 1. It consists in a Digital Holographic Microscope (DHM), a hexapod capable of precise motions along the six degrees of freedom and a micro-encoded pattern. We also show a typical hologram obtained and its reconstruction (Fig. 1).

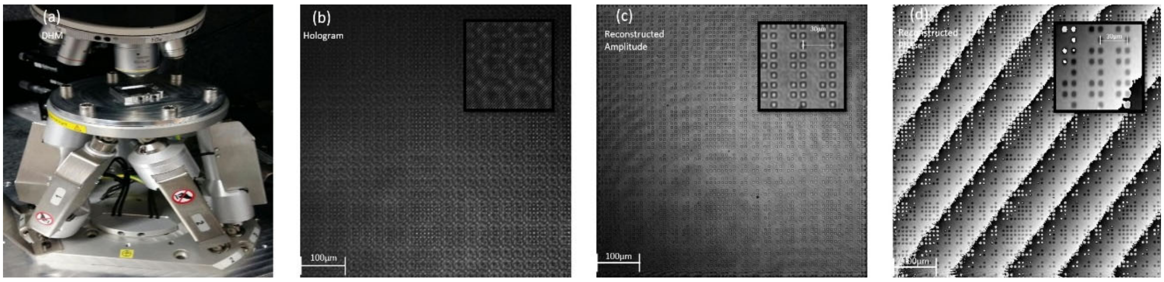

Fig. 1: (a) DHM observing a micro-structured pattern moved by the hexapod. (b) Experimental hologram of the pattern. Image reconstruction (c) in amplitude and (d) in phase. In focus distance at 130µm.

The interferometric character of DH converts out-of-plane position of the sample in phase data that, combined with in-plane information retrieved from the micro-structured pattern, allows accurate measurement of 3D trajectories. Deep neural networks speed up data processing to achieve video-rate position detection.

Deep neural networks require to be trained in order to realize expected tasks and to reach the best performances. In our work, the training step is carried out from dataset constituted by simulated holograms (about 40000 holograms per dataset). Different types of Deep networks have been used as Convolutional Neural Networks and Vision Transformers. Spherical aberrations, noise, have been implemented in simulated hologram datasets, with the aim of being able to mimic real experimental conditions. Such a prospect would significantly improve the current capabilities of combining computer microvision and digital holography for pose measurement and sensing applied to automated 3D microscopy.

References

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