

Hybrid deep-neural network in digital holographic microscopy

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Holography is an advanced coherent imaging technique that allows to reconstruct wavefield in both amplitude and phase, and can be applied to micro-objects using Digital Holographic Microscopy (DHM). Thanks to a digital image processing [1], aberrations can be compensated and digital refocusing can be achieved without mechanical displacement. Fast and simple numerical calculus can be implemented using the Angular Spectrum Method (ASM), and recently deep neural networks (DNNs) increased drastically performances of DHM techniques [2].

The estimation of the in-focus distance can be done by using adapted metrics, but it becomes heavy to compute due to the various multi-plane propagation distances to realize. One challenge is to process hologram reconstruction at high speed to perform video-rate automatised microscopy. Using hybrid DNNs based on physics-driven learning arrangement [2], make possible to transfer part of the digital processing into the optical domain, and to reduce the dataset to be trained.

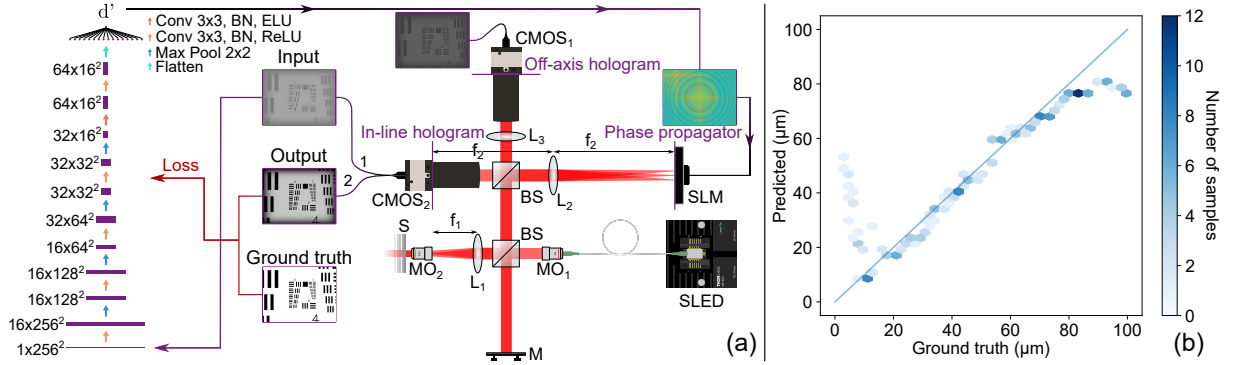


Fig. 1 (a) Experimental set-up. SLED, Superluminescent Diode; MO, Microscope objective; L, Lens; BS, 50:50 Beamsplitters cube; M, Mirror; S, Sample; Camera CMOS; SLM, Phase spatial light modulator. (b) Predicted in-focus distances by the deep encoder with respect to the ground truth value.

We developed an experimental hybrid DHM setup that performs autofocusing without mechanical displacements. When a sample (USAF resolution test chart) is moved along the z axis, its spatial spectrum is imaged onto a SLM plane in order to apply a phase mask. It acts as a phase propagator and depends only on the propagation distance, when all the other parameters are fixed. An optical 2D Fourier transform is then realized to display a sample image onto a camera (CMOS₂). Another camera (CMOS₁) is used to record the off-axis hologram in order to provide ground truth images. The hybrid deep neural network constructed is shown in **Fig. 1(a)**. It is composed of a numerical deep encoder which takes as input an in-line hologram (path 1) to infer the in-focus distance, and to generate the corresponding phase propagator, displayed onto the SLM. The output image, recorded through path 2, is then compared to a ground truth image, to optimize the DNN during a learning step.

Numerical simulations have been conducted to train the deep encoder, based on a set of 1000 simulated in-line hologram generated with various propagating distances ranging from 0 to 100 μm . The training step is then based on a data-driven approach, by minimizing a mean square error between the predicted and ground-truth in-focus distance as loss function. The outputs of the testing (**Fig. 1(b)**) show that the DNN is still limited when out-of-focus distances are too high, due to the simple DNN architecture used, and more advanced DNN will be implemented in the future to overcome this limitation [4].

References

- [1] T. Zeng, Y. Zhu, and E. Y. Lam, "Deep learning for digital holography: a review", *Opt. Express*, **29**, 40572 (2021).
- [2] J. Wu, K. Liu, X. Sui, and L. Cao, "High-speed computer-generated holography using an autoencoder-based deep neural network", *Opt. Lett.*, **46**, 2908 (2021).
- [3] L. Huang, H. Chen, T. Liu, and A. Ozcan, "Self-supervised learning of hologram reconstruction using physics consistency", *Nat. Mach. Intell.*, **5**, 895 (2023).
- [4] S. Cuenat, J. E. B. Carcaño, B. Ahmad, P. Sandoz, R. Couturier, G. J. Laurent, M. Jacquot, "Digital holographic microscopy applied to 3D computer micro-vision by using deep neural networks" *J. Eur. Opt. Soc.: Rapid Publ.* **20**, 31 (2024).