Experimental Evaluation of Single-shot Higher-order Transport-of-intensity Quantitative Phase Imaging Based on Deep Learning

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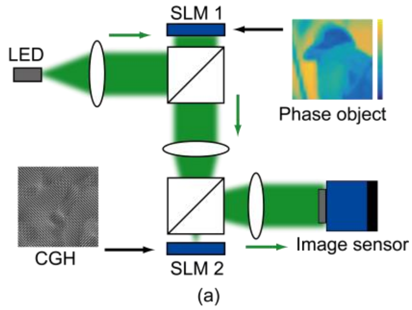
1. Introduction

Quantitative phase imaging (QPI) based on the transport of intensity equation (TIE) is one of non-interferometric phase retrieval techniques [1]. The quality of a measured phase distribution is improved by using a series of intensity distributions with different defocus distances for approximation of an intensity derivative along the optical axis, which is termed the higher-order TIE [2]. However, axial scanning of an image sensor is required to capture multiple intensity distributions. To overcome the problem, the single-shot higher-order transport-of-intensity (SHOT) QPI has been proposed [3]. The SHOT-QPI is realized by using a computer-generated hologram (CGH) technique. If a phase-type CGH is employed in the SHOT-QPI, detected intensity distributions are unnaturally defocused since point spread functions (PSFs) reconstructed from the CGH are not ideal [4]. Therefore, the quality of a measured phase distribution by the SHOT-QPI with a phase type CGH is low. To suppress the problem, deep learning has been applied [4]. However, its experimental evaluation has not been addressed. In this paper, we demonstrate the results of the feasibility of the phase-type SHOT-QPI experimentally.

2. Experimental evaluation

The optical setup shown in Fig. 1 (a) is used. To mitigate the effect of coherent noises, a green LED is used as a light source. A phase-only spatial light modulator (SLM) 1 is used for displaying objects as training, validation, and test sets. Objects are selected from CIFAR-10 [5]. The number of training, validation, and test sets are 9500, 450, and 50, respectively. A phase-type CGH is generated from the Gerchberg and Saxton algorithm. The CGH is displayed by an SLM which is placed at the Fourier plane of objects (SLM 2). Detected intensity distributions shown in Fig. 1 (b) are convolutions between an object and PSFs from the CGH. As shown in Fig. 1 (b), multiple intensity distributions with unnatural defocus are simultaneously obtained. These intensity distributions are input to a deep convolutional neural network (DCNN). Densely connected convolutional network (DenseNet) is used in this experiment. Experimental results are shown in Fig. 2. Accuracies of measured phases are quantitatively evaluated by the root mean squared error (RMSE). The image quality with the higher-order TIE is lower than that from DenseNets because defocused intensity distributions are not ideal. On the other hand, because the proposed method learned the relation between input and output to DenseNets, the better phase distribution can be measured.



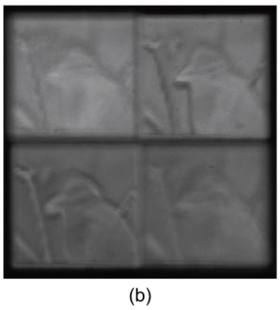


Fig. 1 (a) Optical setup and (b) detected intensity distribution.

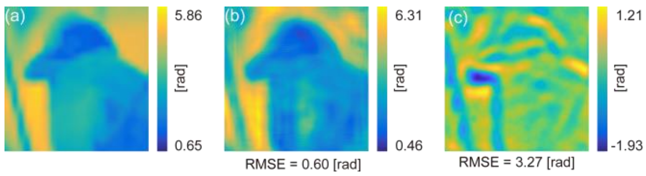


Fig. 2 Phase distributions: (a) True phase, (b) output phase from DenseNet, and (c) retrieval phase by higher-order TIE.

3. Conclusions

To demonstrate the feasibility of the deep-learning-based SHOT-QPI with a phase-type CGH, the experimental results are quantitatively evaluated. From these results, the proposed method can realize simple, scanning-less, in-line, single-shot, and high tolerance QPI through deep learning.

References

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