Double phase hologram based high-capacity holographic memory

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The storage capacity of holographic memory is determined by the hologram recording area, the number of holograms multiplexing and the encoding efficiency of one data page. Encoding efficiency can be improved by utilizing multi-dimensional modulation such as complex amplitude. In this report, a double phase hologram (DPH) based complex amplitude-modulated holographic memory is proposed. In the encoding process, only one phase spatial light modulator (SLM) is needed to realize the complex amplitude modulation. In the decoding process, using deep learning to demodulate the complex amplitude from the intensity image captured directly by a detector. A convolutional neural network (CNN) is used to detect the features of the intensity distribution to establish the relationship between the captured intensity and the data pages. After training, the corresponding amplitude and phase data can be inferred directly from the intensity of the reconstructed beam through the trained CNN.

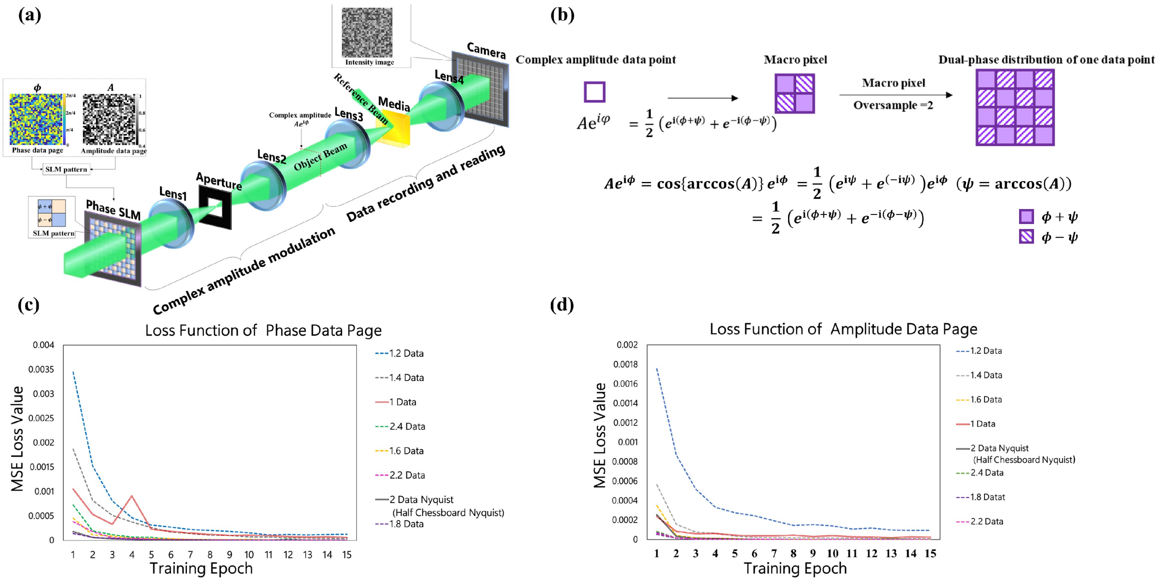

Fig.1 (a) DPH-based holographic memory; (b) Double phase data page generating process; (c) Loss function value of phase data page (d) Loss function of amplitude data page. The aperture size should be no smaller than **Data Nyquist=λ*f/d$_{data}$**, where f is the focal length of Lens1 and d_{data} is the minimum period of the one encoded data. Meanwhile, to guarantee the complex amplitude modulation, the max aperture size should be no larger than **Half Chess Nyquist=1/2*λ*f/d$_{chess}$**, where **d_{chess}** is the period of the chessboard pixel. Here, Half Chess Nyquist equals to 2 times Data Nyquist.

As shown in Fig.1, the system includes two parts: complex amplitude modulation and holographic memory. The double-phase page uploaded on the SLM is calculated from complex amplitude data pages as shown in Fig. 1(b). The decomposed dual-phase components are interspersed pixel by pixel, and adjacent pixels are coherently superimposed due to the filtering of the aperture, then the complex amplitude light field can be obtained at the back focal plane of Lens2. In the decoding process of the holographic memory, using a camera to detect the reconstructed beam intensity directly which will be the input of the CNN. Here, the aperture serves three functions: first, to achieve the complex amplitude modulation; second, to control the hologram recording area in holographic memory; third, to provide cross-talk between the adjacent data points. Using 9000 corresponding intensity-amplitude, intensity-phase image pairs to train Unet neural networks separately and 1000 pairs to test the generalizing ability. The convergence curves of the training process with different aperture sizes are shown in Fig.1(c)(d). From the simulation experiment, the loss curve of CNN training can converge from the aperture size of 2-times the data Nyquist (the optimal size for complex amplitude representation) to 1-times the data Nyquist (the extreme case of signal reconstruction). The proposed method can retrieve the complex amplitude from the intensity image with a small recording area. In physical experiments, due to the influence of device imperfections, system noise, and calibration errors and so on, the actual complex amplitude modulation and data reading effects will deteriorate. Further experiments are needed to verify the effectiveness of the proposed method in practical applications.

Reference: [1] Arrizón V, Sánchez-De-la-Llave D. Applied optics, 2002, 41(17): 3436-3447. [2] Hao J, Lin X, Lin Y, et al. Optics Letters, 2021, 46(17): 4168-4171.

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