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Off-Axis Digital Hologram Retrieval Based on Single-Pixel Optical Imaging

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Abstract: We present a method for retrieving off-axis digital hologram based on single-pixel imaging. High-quality hologram is first retrieved, and the object is further recovered.

OCIS codes: 090.1995 (Digital holography), 100.2000 (Digital image processing)

1. Introduction

Digital holography is a technique to recover complex-valued object by taking advantage of interference between object wave and reference wave. Conventional holography utilizes photographic plate as the recording medium. Subsequently, digital holography was developed by using a two-dimensional camera, which makes the holography more flexible [1–4].

Single-pixel imaging (SPI) is also a promising technique, which has shown great advantages in imaging at non-visible wavelengths and under low-light conditions [5–7].

In this paper, we present a method to recover the object from off-axis digital hologram based on SPI. By applying the SPI into digital holography, we can extend digital holography to more practical applications.

2. Theoretical Analysis

A schematic setup is shown in Fig. 1.

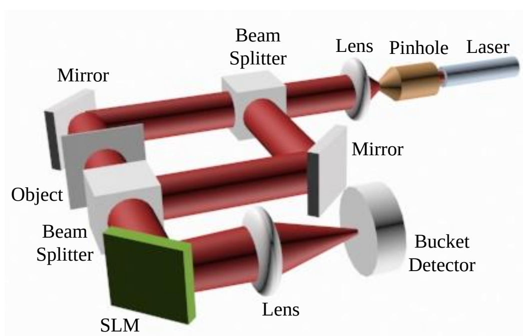

Fig. 1. A schematic setup: SLM, spatial light modulator.

As shown in Fig. 1, a laser beam is expanded by a pinhole and collimated by a lens. A beam splitter splits the beam into two beams, i.e., object beam and reference beam. The object wave and reference wave interfere. The interference pattern (complex-valued) is then modulated by a spatial light modulator (SLM), and the modulated light is collected by a bucket detector. The intensity part H (i.e., hologram) before SLM can be described by [1–4]

$$H = \left|R(x,y)\right|^2 + \left|O(x,y)\right|^2 + R(x,y)O(x,y)^* e^{jkx\sin\theta} + R(x,y)^* O(x,y) e^{-jkx\sin\theta}, \tag{1}$$

where R represents reference beam with an angle θ between the two beams, O represents object wave on the SLM plane, $j=\sqrt{-1}$, k represents wave number, and $*$ denotes complex conjugate. The interference pattern is modulated by random patterns, and its intensity is retrieved by using correlation algorithm [5–7].

$$H' = \frac{1}{M}\sum_{i=1}^{M}\left(B_i - \langle B_i\rangle\right)\left(P_i - \langle P_i\rangle\right), \tag{2}$$

where H' represents the retrieved hologram (intensity), $\langle\cdot\rangle$ denotes an ensemble average over M measurements, P_i denotes a random pattern, and B_i denotes the single-pixel value. Since quality of the retrieved hologram by using

Eq. (2) is low, Gerchberg-Saxton-like algorithm [5] is further used to improve its quality. Using this hologram with improved quality, the test object can be further recovered by using free-space wave propagation principle.

3. Results and Discussion

The work is computationally conducted to illustrate the method, and a laser with wavelength $\lambda = 632.8\ nm$ can be used to illuminate the object in practice. The object consists of 64×64 pixels with pixel size of $10\ \mu m$. The propagation distance of object wave is $4.0\ cm$. To show the reconstructed objects, we implement the reconstruction procedure as illustrated in Fig. 2. In the SPI, 20000 random patterns are used.

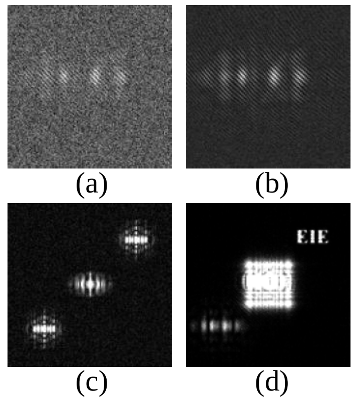

Fig. 2. (a) Hologram retrieved by using Eq. (2), (b) quality-improved hologram further obtained by using Gerchberg-Saxton-like algorithm, (c) Fourier spectrum of (b), and (d) a recovered object.

As can be seen in Fig. 2(a), correlation algorithm, i.e., Eq. (2), can be used to successfully retrieve a hologram. The Gerchberg-Saxton-like algorithm can further improve its quality as shown in Fig. 2(b). The Fourier spectrum of hologram shows that it is an off-axis hologram, as shown in Fig. 2(c). Hence, zero-order term can be separated as shown in Fig. 2(d). It is worth noting that a small pixel size of SLM (e.g., $< 10\mu m$) is important for realizing such an off-axis hologram method in real experiments which will be further conducted in the future.

4. Conclusions

We have presented off-axis digital hologram retrieval method based on SPI. The results have illustrated effectiveness of the method. The method has a great potential to extend applications of digital holography.

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