Three-dimensional Surface Measurement by Amplified Off-axis Digital Holography

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ABSTRACT

A new optical configuration for amplified off-axis digital holographic microscopy is presented and applied to surface measurement. By symmetrical configurations in the optical path, aberration compensation for phase curvature can be avoided in the reconstructed process. Three dimensional surface texture of a grating plate is reconstructed via a single hologram and its parameters are verified.

Keywords: Digital holography, phase measurement, three-dimensional microscopy

1. INTRODUCTION

Digital holography was initiated by U.Schnars et al.[1] in the 1990s. Up to now, digital holographic microscopy (DHM) has been applied in many areas, such as surface measurement[2], cell biology[3], vibrometry[4] and particle tracking[5]. In the early period, phase-shifting interferometry was proposed for in-line digital holography[6,7]. In order to achieve reconstruction via a single hologram, amplified off-axis digital holography was presented by E.cuche et al.[8,9].

By bringing in microscope objectives, higher resolution is obtained, while phase curvature is introduced at the same time. To solve this problem, P.Ferraro et al.[10] proposed a lateral shear approach to compensate the aberration, and T.Colomb et al.[11] presented an automatic procedure for it. However, the compensation for phase curvature can be avoided physically if we bring in the same aberration in both arms of the interferometry. In this paper, amplified off-axis digital holograph with symmetrical configurations in the optical path for aberration compensation is adopted for three-dimensional surface measurement.

2. THE CONFIGURATIONS OF THE MICROSCOPY

The basic model of the microscopy is a Mach-Zehnder interferometer, and the reference wave also passes through the MO, as shown in Fig. 1. For simplification, the optical path in the schematic diagram is in-line, while in fact we can adjust the mirror of the reference arm to provide off-axis configurations.

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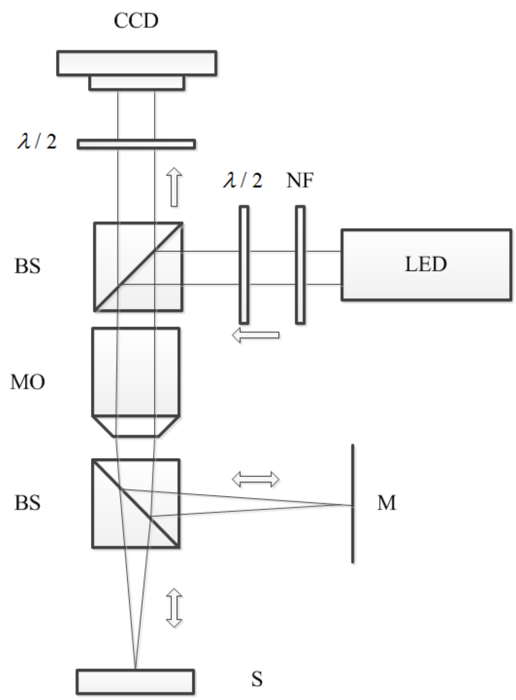


Fig.1. The schematic diagram of the proposed configurations: BS, beam splitter; NF, neutral filter; λ /2, half-wave plate; MO, microscope objective; M, mirror; S, sample; LED, light emitting diode.

As we know, the intensity of the hologram can be described as:

$$I = OO^* + RR^* + OR^* + RO^* \tag{1}$$

After filtering in the frequency spectrum, we can obtain the information:

$$I_2 = OR^* = A_O A_R \cdot \mathrm{e}^{i(\varphi_O^{'} - \varphi_R^{'})} \tag{2}$$

where $\varphi_O^{'}$ is the phase distribution of the object wave modulated by MO and $\varphi_R^{'}$ is that of the reference wave. They can be described as:

$$\varphi_O^{'}(x, y) = \varphi_o(x, y) + \frac{-i\pi}{\lambda D_O}(x^2 + y^2) \tag{3}$$

$$\varphi_R^{'}(x, y) = \frac{2i\pi}{\lambda}(k_x x + k_y y) + \frac{-i\pi}{\lambda D_R}(x^2 + y^2) \tag{4}$$

By symmetrical configurations, the same phase curvature of both optical paths is introduced:

$$D_O \approx D_R \tag{5}$$

Thus, we can rewrite Eq. (2) as:

$$I_2 = OR^* = A_O A_R \cdot \exp\left\{ i[\varphi_o - \frac{2i\pi}{\lambda}(k_x x + k_y y)] \right\} \quad (6)$$

Thus, the compensation for phase curvature is omitted. After a linear filtering process in the phase map or an adjustment procedure for the carrier frequency, we can finally acquire the original phase distribution of the object wave.

3. EXPERIMENT RESULTS

According to the principle of the microscopy, an experiment setup is built. The digital hologram of the grating plate was imaged by a MO (10×, NA=0.25) and recorded on a CCD camera (1024×1024 pixels, pixel size Δx=Δy=3.2μm), as shown in Fig. 2(a). A LED was used to provide a coherence source (λ =632.8nm).

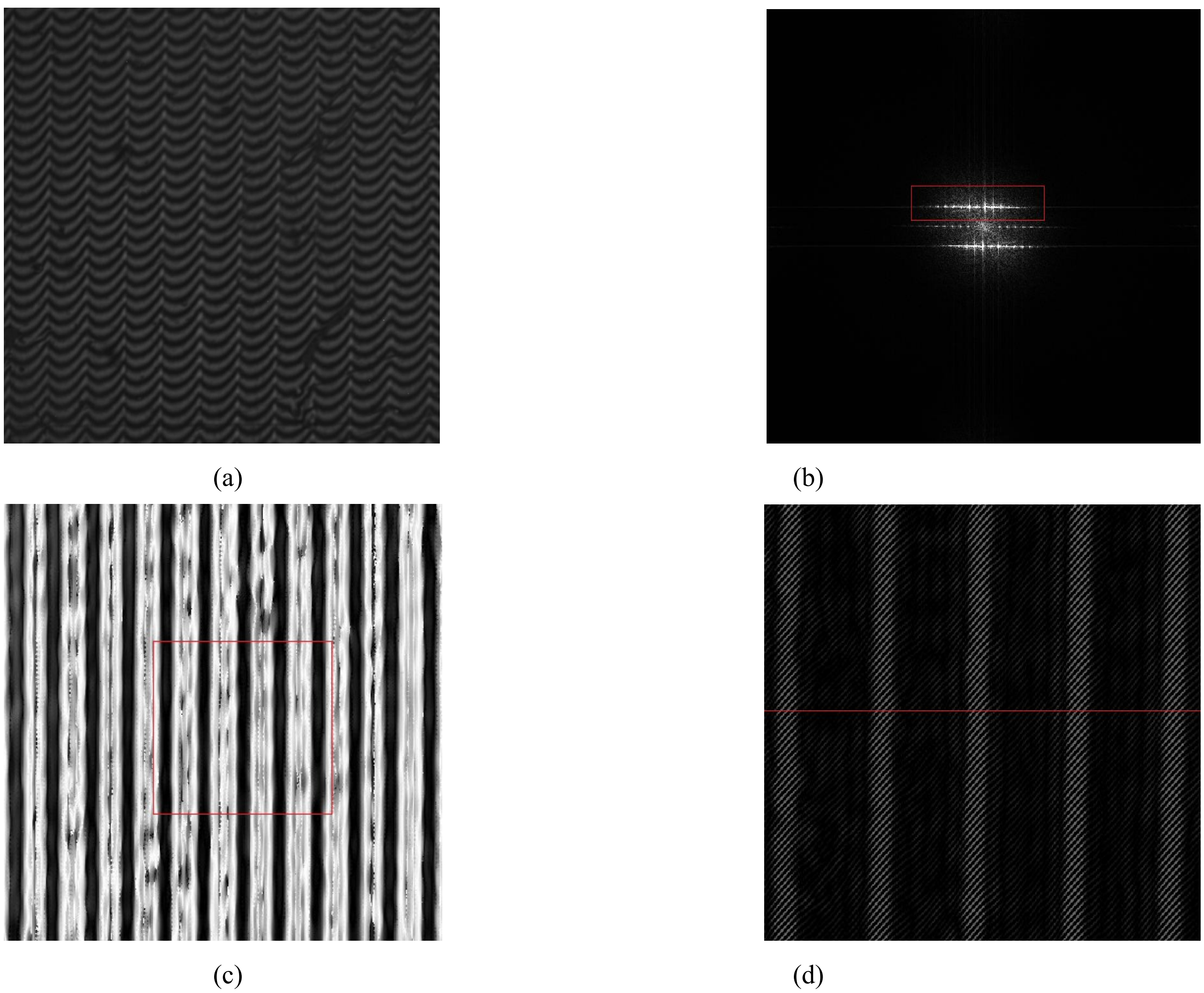
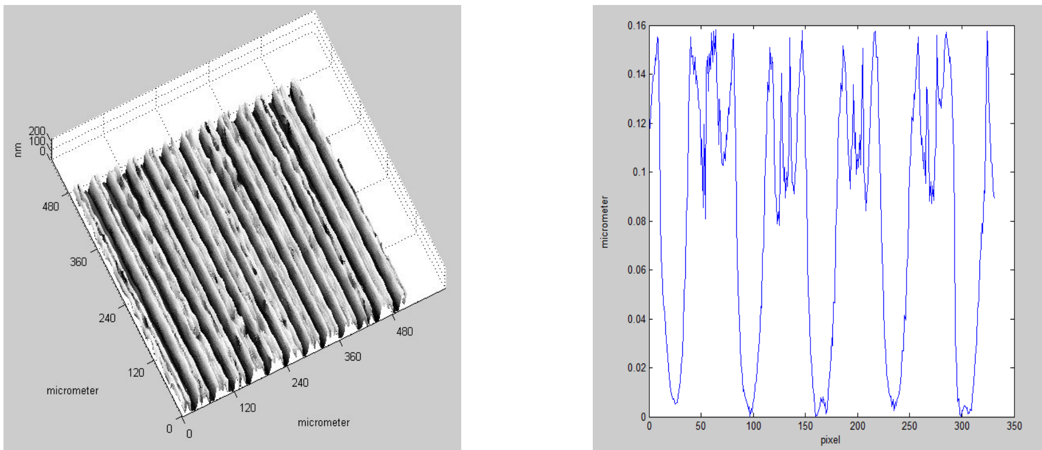


Fig.2. (a) The hologram of the grating plate. (b) The frequency spectrum of the hologram and its' filtering window. (c) The reconstructed image of the object. (d) The phase map in the window of (c).

Fig. 2(b) shows the frequency spectrum of the hologram and its' filtering window. Fig. 2(c) shows the reconstructed image of the object. The digital hologram was reconstructed at d=16.6*mm*. Fig. 2(d) shows the phase map (before the adjustment for the carrier frequency) in the window of Fig. 2 (c), it's easy to view that there is nearly no phase curvature.

Fig. 3(a) shows the reconstructed 3D texture of the grating plate. The adjusted parameter for the carrier frequency on the X axis is 0.0254 and that on the Y axis is 0.0078. The grating period is about 40.3μm, and its' given standard value is 40.0μm. Fig. 3(b) shows the phase map in the line of Fig. 2(d), the grating height is about 0.16μm.



(a) (b)

Fig.3. (a) The reconstructed 3D surface texture of the grating plate. (b) The phase map in the line of Fig.2 (d).

4. CONCLUSION

In this paper, to solve the problem of phase curvature and aberration compensation, a new optical configuration for amplified off-axis digital holographic microscopy is presented and applied to surface measurement. In this new microscopy configuration, symmetrical optical path is adopted so that the compensation for phase curvature is omitted. The 3D surface texture of a grating plate is reconstructed via a single hologram. The reconstructed grating period is about 40.3μm, while its height is 0.16μm, which are in good accordance with the standard values.

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