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Digital Fourier Transform Holography Using a Beam Displacer †

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Abstract: Fourier transform holography overcomes the phase recovery challenge through recording complex field information of the object in an interference pattern recorded at the far field, i.e., Fourier plane. Moreover, this geometry helps to reconstruct the complex field of the object from a single Fourier transform, which is an attractive feature for the numerical reconstruction of the digitally recorded hologram. In this paper, we present a nearly common path experimental design for recording a digital Fourier holographic hologram using a beam displacer, and recover the complex valued objects using the Fourier analysis. The performance of the system is experimentally examined for different objects.

Keywords: digital Fourier transform holography; phase imaging; common path configuration

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1. Introduction

Phase information of the objects in imaging systems are usually extracted to estimate the optical features of transparent objects, such as cells, glasses, optical elements and any transparency objects. The transparent structure and topology of the object can be estimated using the refractive index difference between the object measured and its neighboring media. Thus, quantitative phase information of the object plays a vital role to explain the realistic features of the object. However, phase is not a directly observable quantity in the optical domain due to the high frequency of the wave.

Where retrieving the phase information of an object is concerned, digital holography (DH) is a useful emerging techniques due to its capability to record and reconstruct complex fields [1,2]. DH appears as a promising computational and quantitative 3D imaging technique, being rooted in interferometry of the coherent light and numerical reconstruction of the optically recorded hologram [3]. Quantitative information of the object is recorded as an interference fringe pattern using a digital camera. Different experimental techniques were previously proposed for the DH and major designs are the on-axis, off-axis and phase shifting. The on-axis, or Gabor's, geometry is compact and stable; however, it faces the challenge of the twin image issue and overlap of the spectra [4]. Off-axis holography overcomes these limitations at the cost of angular separation between the interfering beams [5,6]. Different experimental designs were previously developed to provide the angular separation between the interfering beams at the cost of strict requirement of vibration isolation in the experimental design [7]. Nevertheless, an-off axis holography scheme is highly desired due to its capability to recover the quantitative image from a single measurement in contrast to phase shifting and iteration-free nature. Moreover, the cost of numerical reconstruction of the hologram can be reduced using the Fourier transform geometry in the off-axis holography [8].

In this paper, we demonstrate a new experimental design for recording the Fourier transform holography (FTH). This outcome is achieved through making an experimental design using the beam displaces to spatially separate the orthogonal polarization components of the light source. Subsequently, we used an appropriate method to interfere with these polarization components, with one loaded with the object and other used as a reference, to record an off-axis hologram. The phase information of the object is encoded into the interference pattern recorded at the far field. Our experimental setup uses nearly common paths for the interfering waves; hence, the experimental design is stable. The performance of the system is experimentally examined for different objects; the results are shown below.

2. Experimental Setup

A schematic design of the proposed system is shown in Figure 1. A horizontal polarized coherent light source from a He-Ne laser with an optical wavelength of 632.8 nm (model no.: HNL150LB; makes: Thorlabs) is used and collimated using a spatial filter assembly composed of the microscope objective (MO), pinhole, and a bi-convex lens L1. This collimated light beam is turned to a diagonal polarization using a half-wave plate (HWP) placed at an angle of 22.5° from the horizontal pass axis. The diagonally polarized beam splits into two orthogonal polarized components (horizontal and vertical) after passing through a beam displacer (model no.: BD40; makes: Thorlabs). One of the polarization components, for example horizontal, passes through an object placed at the front focal plane of lens L2, as shown in Figure 1. This beam works as an object beam, which is transversely separated from the vertically polarized component. On the other hand, a parallel propagating vertically polarized beam is filtered using a pinhole placed at the same transverse plane as the object plane at a distance f from the L2. This beam works as the reference beam. Lens L2 performs the Fourier transform of both these beams, and the interference pattern is recorded through placing a polarizer at 45° from the pass axis of the horizontal in front of the CMOS camera (model no.: DCC3240M; makes: Thorlabs). A complete information of the complex-valued object (i.e., amplitude and phase information) is encoded into the recorded Fourier transform of the hologram. In order to reconstruct the recorded hologram, we used a single fast Fourier transform. The complex information of the objects is shown below.

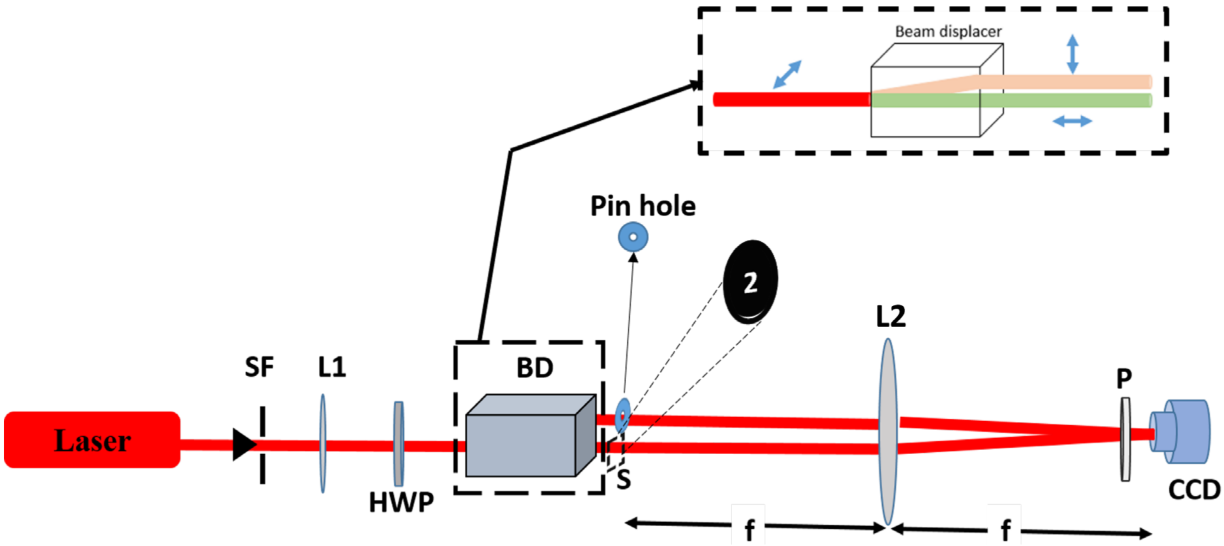
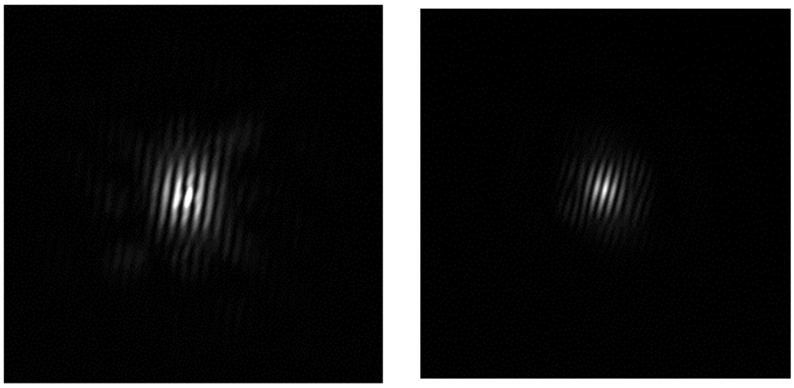


Figure 1. A compact experimental setup design for recording digital Fourier transform hologram with help of a beam displacer. HWP is a half wave-plate, SF is a spatial filter, L1 and L2 are lenses, BD is beam displacer, S is sample, P is a polarizer and CMOS is complementary metal oxide semiconductor camera.

3. Result and Discussion

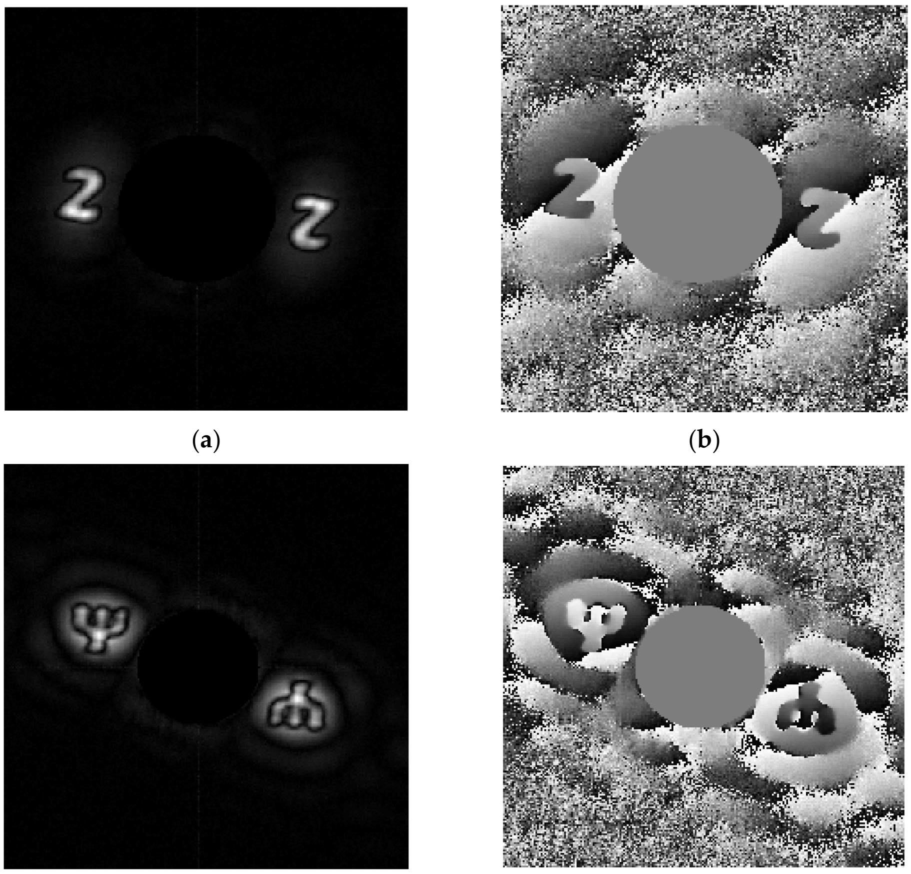
To demonstrate the appropriateness of our technique, we used two different transparency objects (2 and ψ). Figure 2 shows recorded holograms corresponding to these objects.



(**a**) (**b**)

Figure 2. Fourier transform hologram of object (**a**) 2; (**b**) ψ.

Reconstruction of the complex valued objects from these two holograms are shown in Figure 3.



(**c**) (**d**)

Figure 3. (**a**,**b**) show amplitude and phase information of object 2, and (**c**,**d**) show amplitude and phase information of object infrormation ψ.

A Fourier transform of the hologram generates three dominant frequency regions, as shown in Figure 3. The central part, i.e., the unmodulated components, is strong and suppressed in order to highlight the reconstructed object and its conjugate in the off-axis position. The off-axis location of the reconstructed object in the frequency domain is decided using the transverse spatial separation between the interfering beams, as shown in Figure 3a,b for object 2. Similarly, the reconstruction of object ψ is shown in Figure 3c,d.

The experimental result of the objects (2 and ψ) validates the performance of the proposed design of the holographic setup. The proposed design of this experimental setup provides a nearly common path configuration system using a beam displacer, which makes the system more stable in comparison to experimental designs based on the Michelson and Mach–Zehnder configurations.

4. Conclusions

In this paper, we present a nearly common path experimental configuration system using a beam displacer for recording a digital Fourier transform hologram, while the complex-valued objects information are presented using the fast Fourier analysis. Moreover, this geometry helps to reconstruct the complex field of the object from a single Fourier transform. The performance of the system is experimentally examined for different objects.

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