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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 by 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 the for numerical reconstruction of the digitally recorded hologram. In this paper, we present a nearly common path experimental design for recording of a digital Fourier holographic hologram using a beam displcer, 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

1. Introduction

Phase information of the objects in imaging system is usually extracted to estimate the optical features of transparent objects like cells, glasses, optical elements and any transparency objects. Transparent structure and topology of the object can be estimated using the refractive index difference between an 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 directly observable quantity in the optical domain due to high frequency of the wave.

In order to revive the phase information of the object, digital holography (DH) is one of the emerging technique due to its capability to record and reconstruct complex fields [1,2]. DH has been appeared as a promising computational and quantitative 3D imaging technique, rooted on interferometry of the coherent light and numerical reconstruction of the optically recorded hologram[3]. Quantitative information of the object is recorded with a camera as an interference fringe pattern using digital camera. Different experimental techniques have been 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 but it faces challenge of the twin image issue and overlap of the spectra [4]. An off-axis holography overcomes these limitations at the cost of angular separation between the interfering beams [5,6]. Different experimental designs have been 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 the phase shifting and also free from the iteration. Moreover, cost of numerical reconstruction of the hologram can be reduced by using the Fourier transform geometry in the off-axis holography [8].

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Published: date

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In this paper, we demonstrate a new experimental design for a recording of the Fourier transform holography(FTH). This is achieved by making an experimental design using the beam displaces to spatially separate the orthogonal polarization components of the light source and subsequently use an appropriate method to interfere these polarization components, one loaded with object and other 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 a nearly common paths for the interfering waves, hence experimental design is stable. The performance of the system is experimentally examined for different objects and results are shown below.

2. Experimental setup

A schematic design of the proposed system based 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 by 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 by 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 & vertical) after passing through a beam displacer (model no.: BD40; makes: Thorlabs). One of the polarization components, say horizontal, passes through an object placed at the front focal plane of lens L2 as shown in Fig.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 by 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 by 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.

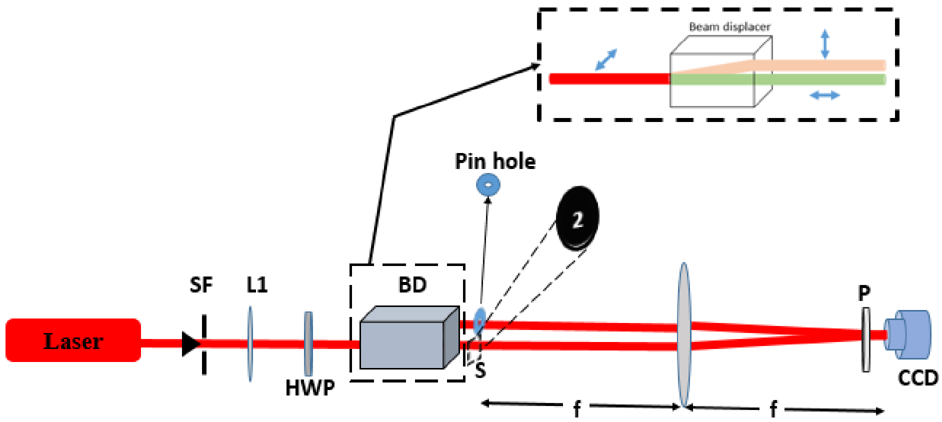

Fig.1: A compact experimental setup design for recording the digital Fourier transform hologram with the help of a beam displacer. HWP is a half wave-plate, SF is a spatial filter, L1 &L2 are lenses, BD is the beam displacer, S is the sample, P is a polarizer and CMOS is the complementary metal oxide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

3. Result and discussion

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

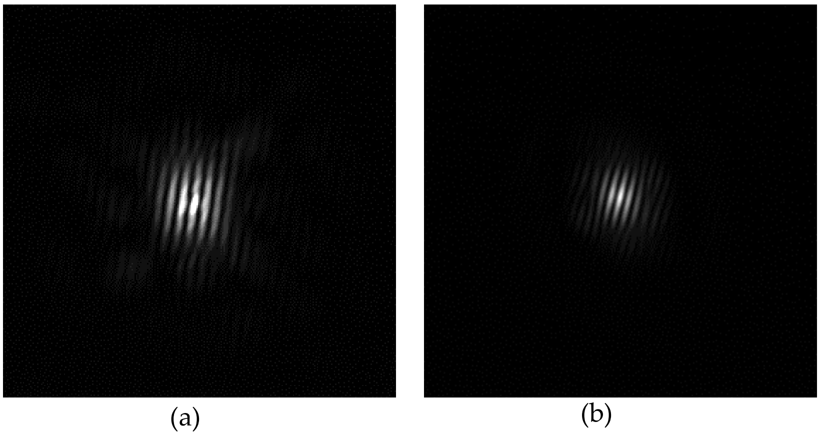

Fig.2: Fourier transform hologram of object (a) **2;** (b) ψ

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

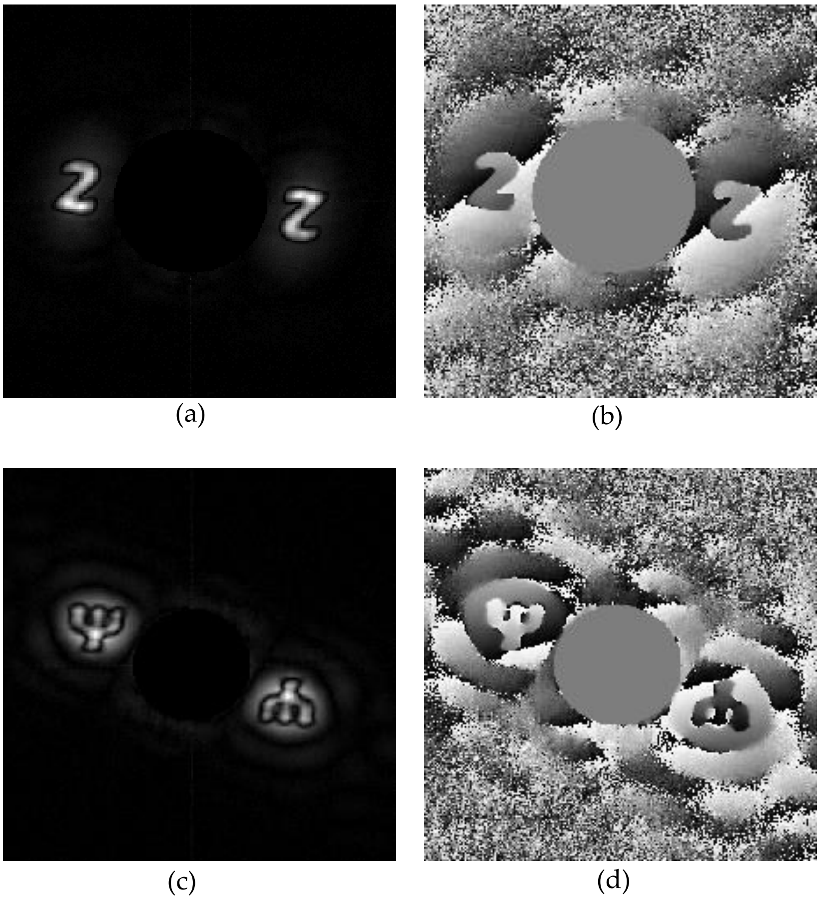

Fig.3: (a) & (b) shows the amplitude and phase information of the object **2** and (c) & (d) shows the amplitude and phase information of the object infrormation **ψ**

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

Experimental result of the objects (**2** and **ψ)** validates 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 system more stable in comparison to experimental designs based on the Michelson and, Mach-Zehnder configurations.

4. Conclusion

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

Author Contributions: Conceived the idea, prepared manuscript, methodology, M.R.; manuscript preparation, methodology, experimental design, S.K.C.; provided advice, review, supervision and editing the work, R.K.S. was involved in supervision, formulation of research goals, funding acquisition , reviewing and editing.

Data Availability Statement: The data that used in this paper are not currently publicly accessible, although they are available from the authors upon justifiable request.

Acknowledgments: Mohit Rathor would like to acknowledge the Department of Biotechnology (DBT) grant no. BT/PR/35587/MED/32/707/2019 and Board of Research in Nuclear Science (BRNS) grant no. 58/14/04/2021-BRNS/37092 for financial support.

Conflicts of Interest: The authors declare no conflict of interest.

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