Optics and Lasers in Engineering 82 (2016) 159–172

Contents lists available at ScienceDirect

Optics and Lasers in Engineering

journal homepage: www.elsevier.com/locate/optlaseng

A new wavelet-based reconstruction algorithm for twin image removal in digital in-line holography

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ARTICLE INFO

Article history:
Received 4 November 2015
Received in revised form
10 February 2016
Accepted 11 February 2016

Keywords:
Twin image removal
Digital holography
Focus plane
Convolutive blind source separation
Wavelet transform

ABSTRACT

Two original methods are proposed here for digital in-line hologram processing. Firstly, we propose an entropy-based method to retrieve the focus plane which is very useful for digital hologram reconstruction. Secondly, we introduce a new approach to remove the so-called twin images reconstructed by holograms. This is achieved owing to the Blind Source Separation (BSS) technique. The proposed method is made up of two steps: an Adaptive Quincunx Lifting Scheme (AQLS) and a statistical unmixing algorithm. The AQLS tool is based on wavelet packet transform, whose role is to maximize the sparseness of the input holograms. The unmixing algorithm uses the Independent Component Analysis (ICA) tool. Experimental results confirm the ability of convolutive blind source separation to discard the unwanted twin image from in-line digital holograms.

1. Introduction

Unlike classical holography [1], digital holography [2] makes possible the numerical processing of digital holograms, such as the focusing at variable depths of 3D objects, tracking, localizing and estimating the sizes of particles in 3D volume [3].

The in-line configuration of digital holography uses a simple instrumental scheme, where the object and reference beams are the diffracted and non-diffracted parts of the same beam. This configuration has proved its effectiveness in the study of particles, aerosols, fluid-flow analysis [4], coherent diffractive imaging with X-ray holography [5], atomic imaging with complex γ-ray holography [6] and size recovering of nanoparticles with cavitation air bubbles [7].

However, both zero-order and twin images are serious obstacles to the retrieval of the reconstructed image with high quality. These parasitic zero-order and twin images are due respectively to the acquisition process, where different intensities of both waves and the object wavefront information are recorded, and to the complex conjugate of the object wave. This redundant information generates unwanted fringes that make difficult an accurate reconstruction of the image, and can even heavily disturb the recovering of its microphysical properties.

In the last decade, many techniques were developed to solve the twin image removal problem. Usually, this problem was processed by both spatial carried-frequency approaches and numerical in-line geometry means [8]. In [9], a suitable algorithm was developed for simultaneous measurement of refractive index and thickness which enabled the removal of the unwanted twin image. This tool involves the dual-wavelength diffraction phase microscopy based on the spatial filter as the form of a common-path imaging interferometer. In [10,11], various advanced spatial carrier phase-shifting (SCPS) manipulations were described for the removing of the twin image on the reconstructed hologram. In other respects, many algorithms were proposed to track the unwanted fringes based on the principal-vector-directed fringe-tracking technique [12]. Using the Gaussian derivatives to estimate the fringes gradients, this technique involves some thresholding hysteresis for singular points segmentation. By means of some deconvolution techniques [14], the authors of [13] propose an iterative algorithm to discard the unwanted fringes from the reconstructed images. Based on wavelet transform theory, the authors of [15] proved the perfect suppression of twin image by angular spectrum diffraction at the ridge of Gabor wavelet transform (GWT). In our preview work, we presented a robust twin-image removal method based on blind source separation (BSS), combined with an efficient quincunx lifting scheme [16].

Convolutive blind source separation (BSS), also known as blind source deconvolution, consists in separating a set of source signals from a set of convolutely mixed signals without any information

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http://dx.doi.org/10.1016/j.optlaseng.2016.02.009
0143-8166/

about the source signals and the mixing process. The inputs of BSS unmixing process are the mixed images received over Q sensors (Q observed images or Q observations), and the outputs are P estimated images (i.e. estimated source images). Several methods have been proposed to solve convolutive BSS, among which is our contribution based on sparse and multiscale representation of image mixtures [17,18].

In this paper, we present our enhanced BSS-based approach for twin image removal. As explained in [14], the mathematical model of digital Fresnel holography shows that the image in the reconstructed plane can be written as a convolution formalism of different physical functions involved in digital holography. In this context, these physical effects, that are the image of the object, the Fresnel kernel and the twin image, convolutely mixed, form the observed images in the reconstructed plane. The input of our deconvolution algorithm is the hologram fringe pattern, the real part and the imaginary part of the reconstructed hologram to obtain the original image of the object.

The paper is organized as follows. In Section 2, a brief overview of hologram recording and reconstruction of in-line holograms is given. In Section 3, we present a new method for focus plane retrieving based on an entropy criterion. In Section 4, we emphasize the concept of sparse image representations as a preprocessing for the blind source separation task. In Section 5, we describe the proposed reconstruction algorithm and its underlying sparseness measure. In Section 6.2, we illustrate and validate the proposed method using various real and simulated reconstructed holograms. Finally, Section 7 contains the summary and concluding remarks.

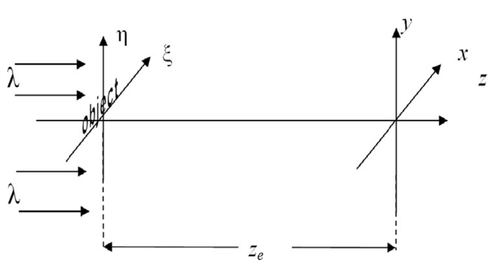

Fig. 1. Recording system of digital in-line holograms (ξ,η): object plane. (x,y): sensor plane.

2. Digital in-line holography

2.1. Digital hologram recording

In the detector and reconstruction planes, in-line holography uses the convolution formalism for mathematic model of recorded and reconstructed images. We note by $1-T(\xi,\eta)$ the binary amplitude distribution of an opaque object illuminated by a monochromatic plane wave and located at a distance z_e from a camera as shown in Fig. 1. As explained in [19], the particles are

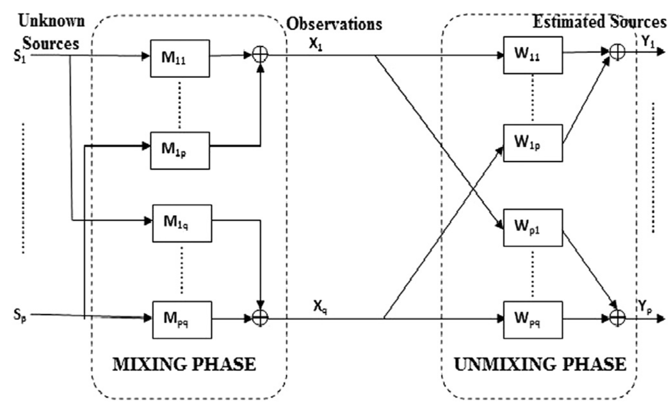

Fig. 3. Mixing and unmixing system.

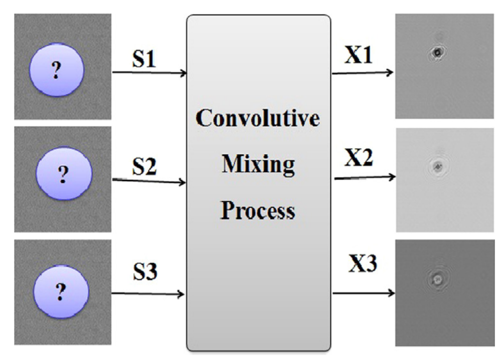

Fig. 4. Illustration of the in-line holography process as convolutive BSS problem: X_1: intensity function of hologram, X_2: real part of the reconstructed image and X_3: imaginary part of the reconstructed image.

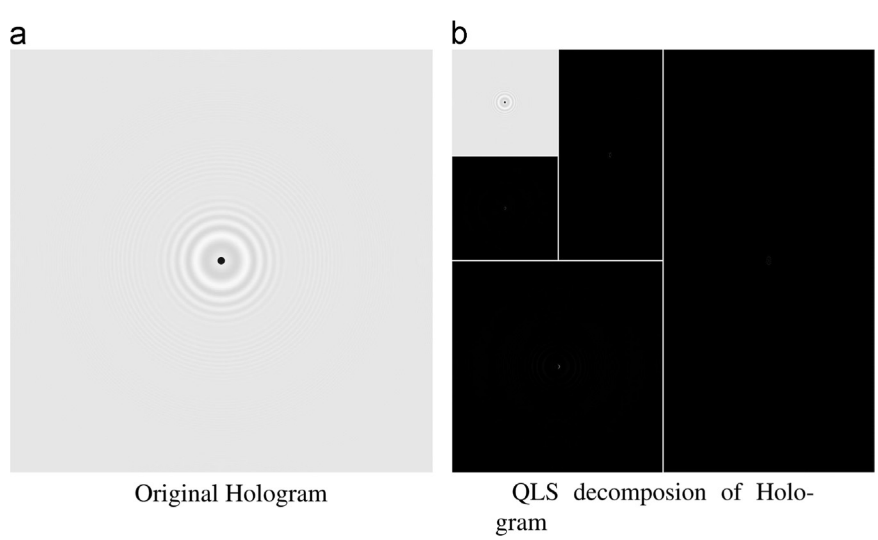

Fig. 2. QLS decomposition of digital hologram at $J=4$.