Optics Communications 355 (2015) 596–601

Contents lists available at ScienceDirect

Optics Communications

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

Improvement of the image quality of random phase-free holography using an iterative method

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ARTICLE INFO

Article history:
Received 9 June 2015
Received in revised form
13 July 2015
Accepted 14 July 2015
Available online 25 July 2015

Keywords:
Computer-generated hologram
Electroholography
Hologram
Holography
Holographic projection
Kinoform
Phase-only hologram

ABSTRACT

Our proposed method of random phase-free holography using virtual convergence light can obtain large reconstructed images exceeding the size of the hologram, without the assistance of random phase. The reconstructed images have low-speckle noise in the amplitude and phase-only holograms (kinoforms); however, in low-resolution holograms, we obtain a degraded image quality compared to the original image. We propose an iterative random phase-free method with virtual convergence light to address this problem.

1. Introduction

Digital holographic display is a promising technique, because a wavefront of light scattered from an object can be appropriately reconstructed from the display; therefore, this property will enable the realization of an ideal three-dimensional display and projector. Holographic projections [1–5] have unique properties, including multi-projection [6] (by which a multi-image is projected on multiple screens), projection on screens of arbitrary surface, and lensless zoom-able holographic projection [7–9]. The lensless zoom-able holographic projection will lead to the development of an ultra-small projector. Reconstructed images exceeding the hologram size, in general, require the random phase; however, this causes considerable problems of speckle noise.

There are well-known methods for improving the random phase applied-holograms: the Gerchberg–Saxton (GS) algorithm [10,11], the multi-random phase method [12], the one-step-phase-retrieval method (OSPR) [13], and pixel separation methods [14–16]. The multi-random phase and pixel separation methods require display devices with high-speed refresh rates. Conversely, random phase-free methods have also been proposed, for example, the error diffusion [13,17–20] and down-sampling methods [21]. These methods can reconstruct clear images; however, the quality of the reconstructed image is degraded if its size exceeds that of the hologram, because light from the object does not spread widely [5]. Therefore, these methods cannot be used for lensless zoom-able holographic projections.

Recently, new random phase-free methods using virtual special convergence light for amplitude and phase-only holograms (kinoforms) have been proposed [22–24]. Without the assistance of the random phase, this method can reconstruct images that exceed the hologram's size with low-speckle noise; however, in low-resolution holograms, e.g. 2048 × 2048 resolution holograms, we obtain a degraded image quality by ringing artifacts, as will be shown in the next section.

In this paper, we propose an iterative random phase-free method with virtual convergence light to address this problem. Sections 2 and 3 describe the proposed method and the results of simulation performed using it. Section 4 concludes this work.

2. Proposed method

The random phase-free method using virtual convergence light is outlined in [22–24]. The calculation setup is shown in Fig. 1. This

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http://dx.doi.org/10.1016/j.optcom.2015.07.030

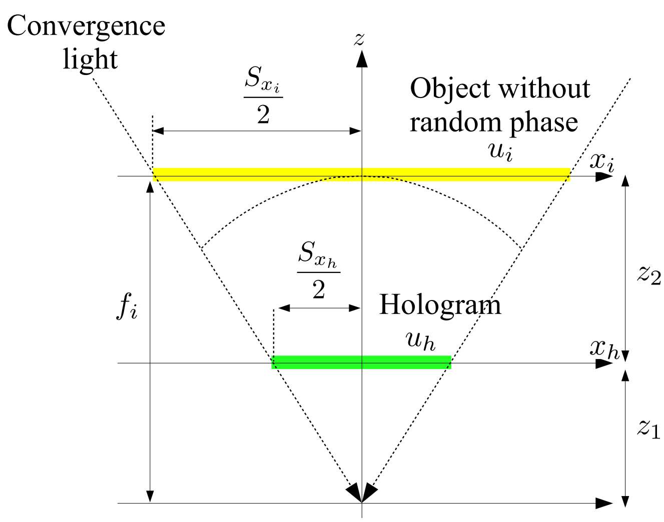

Fig. 1. Calculation setup for the random phase-free method using virtual convergence light.

method is applicable to amplitude computer-generated holograms (CGHs) and kinoforms. Instead of using the random phase, the complex amplitude on the image plane $u_i(x_i, y_i)$ is multiplied using virtual convergence light given by

$$w(x_i, y_i) = \exp(-i\pi(x_i^2 + y_i^2)/\lambda f_i), \tag{1}$$

where $f_i = z_1 + z_2$ is the focal length, z_1 is the distance between the focus point of the convergence light and the hologram, and is set to the distance at which the hologram just fits to the cone of the convergence light, and z_2 is the distance between the object and the hologram.

Here we describe how to determine f_i. Using a simple geometric relation, we can derive $S_h/2$: $S_i/2 = z_1$: f_i where the areas of the image and the amplitude CGH (or kinoform) are given by $S_i \times S_i$ and $S_h \times S_h$, respectively. Therefore, we obtain

$$f_i = z_2/(1 - S_h/S_i). \tag{2}$$

To avoid overlap between the reconstructed image and the 0th order light, the original object must be shifted from the optical axis by a distance of o. Owing to the addition of this shift amount, the focal length of the convergence light is expressed as

$$f_i = z_2/(1 - S_h/(S_i + 2o)). \tag{3}$$

We calculate the complex amplitude in the hologram plane by

$$u_h(x_h, y_h) = \mathrm{Prop}_{z_2}\{u_i(x_i, y_i)w(x_i, y_i)\}, \tag{4}$$

where $\mathrm{Prop}_{z_2}\{\cdot\}$ denotes the diffraction calculated at the propagation distance, z_2. The following equation is used to calculate the amplitude CGH, $I(x_h, y_h)$ from $u_h(x_h, y_h)$

$$I(x_h, y_h) = \Re\{u_h(x_h, y_h)\}, \tag{5}$$

where $\Re\{\cdot\}$ denotes the real part of $u_h(x_h, y_h)$. In calculating the kinoform, $\theta(x_h, y_h)$, from $u_h(x_h, y_h)$, the following equation is used:

$$\theta(x_h, y_h) = \arg\{u_h(x_h, y_h)\}, \tag{6}$$

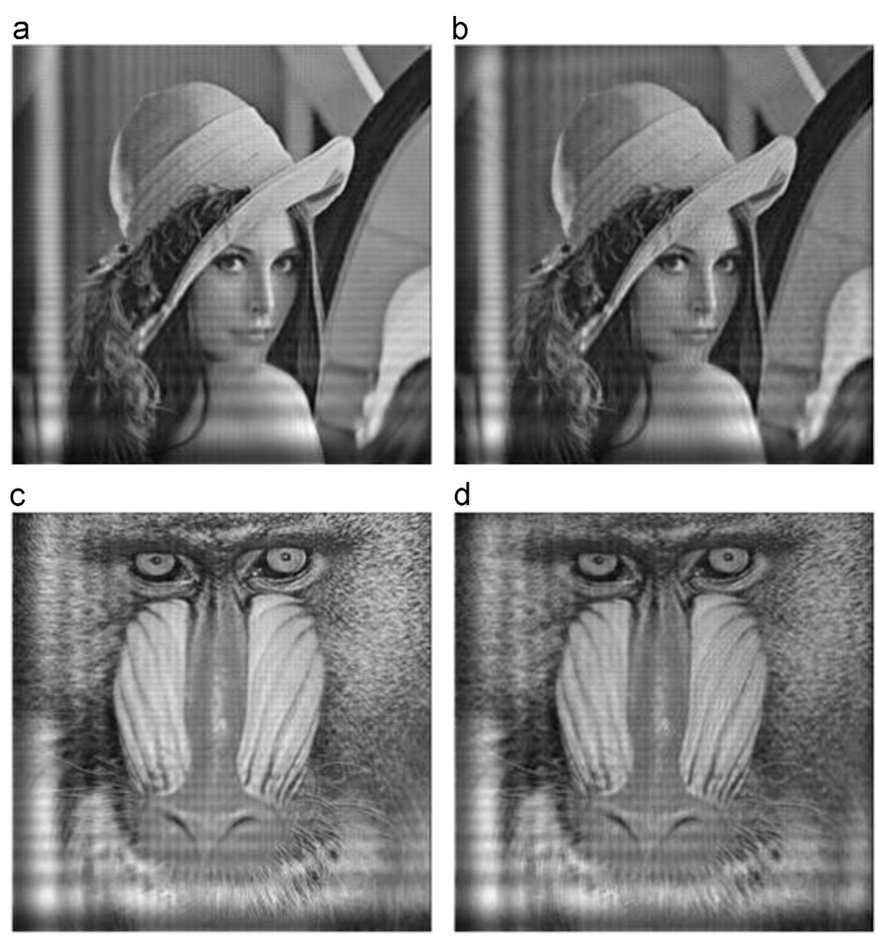

Fig. 2. Reconstructed images from amplitude CGH and kinoform. (a) and (c) reconstructed images from amplitude CGHs: (b) and (d) reconstructed images from kinoform: these reconstructed images are contaminated by ringing artifacts.