Optics Communications 340 (2015) 131–135

Contents lists available at ScienceDirect

Optics Communications

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

Holographic projection of images with step-less zoom and noise suppression by pixel separation

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ARTICLE INFO

Article history:
Received 6 November 2014
Received in revised form
28 November 2014
Accepted 29 November 2014
Available online 3 December 2014

Keywords:
Computer-generated hologram
Holographic projection
Speckle reduction
Scaled diffraction

ABSTRACT

A new method of projection of color images without color-sequential technique is proposed. It is a combination of the spatial division of the phase-only light modulator with a pixel separation noise suppression technique and an efficient propagation method called a scaled Fresnel diffraction. The unique property of a step-less and lossless zooming of the projected image is shown. The experimental demonstration of the method is presented, showing high quality, low noise images of a variable size at reasonable frame rates.

1. Introduction

The projection of images without any lenses has numerous advantages like the lack of aberrations, compactness, simplicity and, above all, the outstanding energetic efficiency. The main limitation of the progress in commercialization of this idea is the image quality. Many attempts have been proposed to reduce the speckle noise which is the result of using coherent illumination and diffuse-type computer generated holograms (CGHs) displayed on pixelated spatial light modulators (SLMs). To our best knowledge the pixel separation method provides the best image quality up to date, nevertheless it has been only tested in color-sequential mode [1].

In this paper we test the novel approach to holographic projection with the pixel separation method [1] combined with a spatial division of the SLM surface into three areas dedicated to red, green and blue illuminating beams [2].

2. Proposed method

The scheme of the simple experimental setup is shown in Fig. 1. We used three single-mode optical fibers (a) fed with three solid-state lasers (b) with wavelengths of 671 nm, 532 nm and 445 nm. The bare polished endings of the three fibers were placed close to one another (with a spacing of 5 mm) and they constituted three quasi-point sources for our experiment. In this way the three divergent light beams from the fibers illuminated the surface of the SLM (c) through a polarizer (d) and a beam splitter cube (e), as shown in Fig. 1.

The distance between the sources and the SLM was set to 125 mm, which ensured a good trade-off between the homogeneous illumination of the SLM and the spill-over losses. The phase-modulated light reflected from the SLM reached the recording camera through the beam-splitter. The intensity fields were captured directly on the surface of the CMOS matrix of the camera. The distance between the cube and the Canon EOS 650D camera (f) was approximately 300 mm. The computer (g) controlled the light intensity of the lasers, exposure parameters and a shutter of the camera and additionally it calculated and displayed the phase patterns on the SLM.

The light directly reflected from the SLM constitutes the zero order of diffraction and it reaches the projection screen as a vast patch of light spread on the large area. In the first order of diffraction we formed the projected images by proper addressing of the three sections of the SLM with iterated Fresnel holograms. Obviously the divergent shapes of the illumination beams were compensated by adding spherical phase functions to the iterated holograms. We used the Holoeye Pluto SLM with a pixel pitch of 8 um and a resolution of 1920 by 1080 pixels. The spatial division

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http://dx.doi.org/10.1016/j.optcom.2014.11.100
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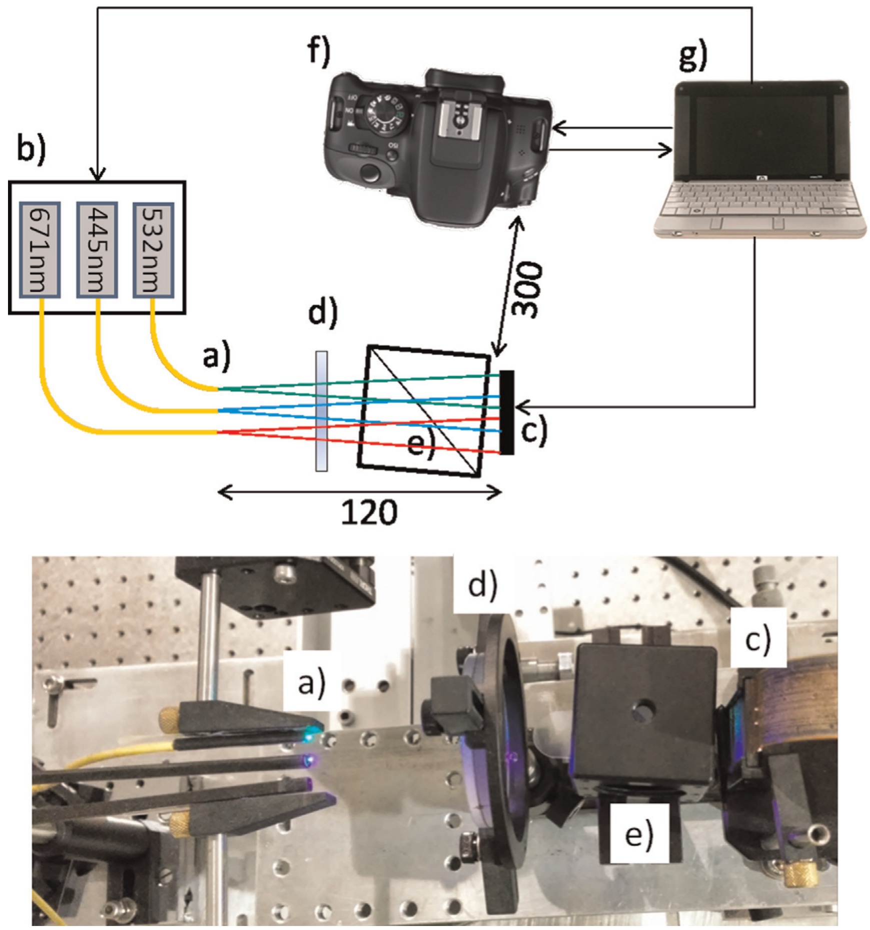

Fig. 1. The scheme of the experimental setup (top). The close-up of the fibers and the illuminated SLM (bottom).

of the SLM allowed the instantaneous creation of a full-color image on the projection screen because three primary-colored real images overlapped in the same moment of time. Such an elimination of the color sequence in the display allows three times higher frame rate (or more for a higher number of primary colors). This enables the method to be used in practical situations where fast switching SLMs are available.

The downside of the pixel separation method is that it assumes the calculation of numerous holograms of the same input animation frame, but for a different sub-group of pixels (i.e. interleaving) [1]. For this reason the required computing power is very high, hence in this work the GPU (graphics processing unit) multi-parallel computing was used, combined with an effective scaled Fresnel diffraction [3–5].

Fig. 2 shows the close-up of the projection screen with a color image reconstructed in a given moment of time. One can easily see the fragmentation of the image caused by the pixel separation method. The noise is very low due to transversal separation of the created light spots, which eliminates the unwanted and uncontrolled interference patterns usually interpreted as a noise.

We also performed numerical simulations of the size of the light spots formed by the three used wavelengths and in exactly

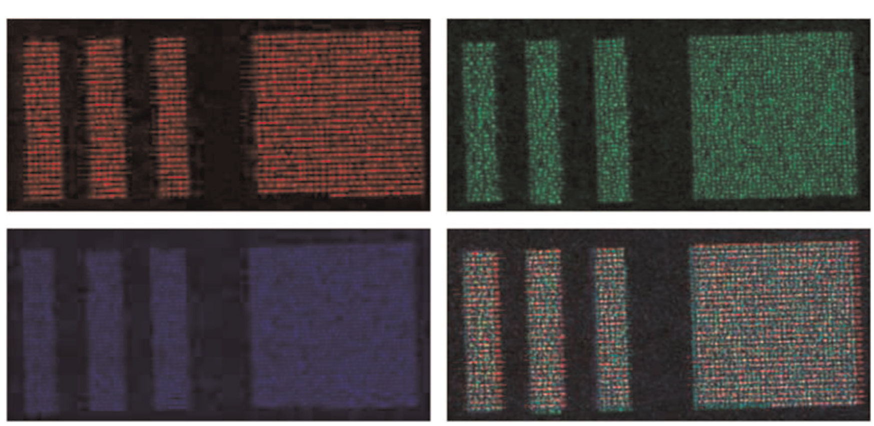

Fig. 2. Magnified part of color images displayed on the projection screen in a given moment of time for red, green, blue and combined RGB illumination. The point-like fragmentation is caused by the pixel separation noise suppression technique. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)