DIGITAL FOURIER HOLOGRAPHY: RECORDING AND OPTICAL RECONSTRUCTION

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Abstract

We present a Fourier Hologram recorded by a charge coupled device (CCD) camera, and its optical reconstruction, which is displayed using a spatial light modulator (SLM) XGA4 Miniature, monochrome, Liquid Crystal Display (LCD), with a spatial resolution of 1024 x 768 pixels. The proposed technique belongs to the relatively recent field of the digital holography. The core of the digital holography is supported by the classic holography framework with the bonus of the optoelectronic sensing and display devices, allowing the real time holographic process.

Keywords: Digital holography, Fourier digital holography, Spatial Light Modulator.

1. Introduction

It is well known that the main purpose of the holography is the recording and reconstruction of optical wavefront. A hologram contains a codified record in amplitude and phase of the optical wave [1,2]. In contrast to the conventional holography proposed by Gabor in late1940's and to electronically detected holography by Goodman and Laurence 1967, Yaroslavskii and Merzlyakov have established the fundamental theory of digital holography in early 1980's. Moreover, practical implementation of digital holography was not achieved until recent years when the register devices have advanced significantly, in terms of space-bandwidth product and gray level resolution. Schnars and Jüptner were among the firsts in report digital holography with a CCD camera in 1990's[3]. Nowadays this technique have been extend step by step in the fields which the classical holography is employed, such as particles image velocimetry (PIV)[4], fast events recording [5], pattern recognition and security [6], holographic interferometry [7], holographic microscopy, optical wavefields and three-dimensional object reconstruction [8,9].

In this work a digital Fourier hologram is recorded by a CCD camera and its optical reconstruction is performed using a liquid crystal display spatial light modulator (LCDSLM). Briefly the theoretical considerations about Fourier holography are given, next some basic aspects on digital Fourier holography and finally experimental results are presented.

2. Principle of Fourier Holography

Fourier holography is applied to transparent objects where the recording is in a plane with an intensity distribution proportional to the scaled Fourier transform of the transmittance [1,2,10]. Let the input scene $u(x,y)$, placed in the front focal plane of a lens, consisting of the object $o(x,y)$ and the point source of reference positioned in (x_0, y_0), with amplitude A and expressed like a Dirac distribution in equation (1).

$$u(x,y) = o(x,y) + Ad(x - x_0, y - y_0) \tag{1}$$

The spectral content of the input scene is found in the back focal plane of the lens, with spatial frequency coordinates (x', y'), it can be written as

$$U(x', y') = O(x', y') + A' exp\{j2p(x' x_0 + y' y_0)\} \tag{2}$$

In above equation, O is the scaled Fourier transform of the object wave o and A' is a constant.

The Fourier hologram I is proportional to the intensity of the Fourier transform of the input scene and preserve the amplitude and phase information of the object $o(x, y)$.

$$I = |O|^2 + |A'|^2 + A' O\, exp\{-j2p(x' x_0 + y_0 y')\} + A' O^* exp\{j2p(x' x_0 + y' y_0)\} \tag{3}$$

$|O|^2$ and $|A'|^2$ are the intensities of the object and reference waves respectively, the third and fourth are the interference terms[1].

In order to reconstruct the Fourier hologram, is necessary illuminating I with a coherent plane wavefront and amplitude R, and then, diffracted light is projected in the back focal plane of a lens. The amplitude distribution r of the reconstructed hologram yields

$$r = Cd(h, x) + Bo(h + x_0, x + y_0) + B' o^*(-h - x_0, -x - y_0) \tag{4}$$

Where C, B and B' are constants; in the last equation the first term is the zero order of diffraction, second and third terms are the object and its conjugate waves respectively. Naturally the intensity is given by $I_r = rr^*$.

3. Digital Fourier Hologram

The image recording by CCD camera or any other solid-state device is not the continuum function I (like appear in equation 3); but its sampled version, I_D of the Fourier hologram, which is given by

$$I_D(m, n) = I(X, Y) rect\left[\frac{X}{L_X}, \frac{Y}{L_Y}\right] \sum_{m=-(N_X/2)}^{N_X/2} \sum_{n=(N_Y/2)}^{N_Y/2} d(X - m\Delta_X, Y - n\Delta_Y) \tag{5}$$

Here, L_X , L_Y , corresponding to the dimensions of the CCD sensor along of X and Y respectively. Δ_X , Δ_Y , N_X , N_Y are the size and number of pixels.

[1] In above equation, “*”, denote complex conjugate.

Once the hologram is recorded, it can be reconstructed displaying it on a LCDSLM and lighting with a coherent plane wavefront and Fourier transformed by a lens. The hologram displayed, in the most cases result in a scaled version of the original hologram, due to the disparity between the number and size of the pixels and pitches of the camera and LCDSLM.

4. Experimental Setup

The experimental setup for digital Fourier holography is shown in figure 1. A Helium-Neon (He-Ne) laser beam (λ =0.633 μm and 5 mW of power), is expanded, filtered (by spatial filter, SF) and collimated (by a lens L1), lighting the input scene, which consist of the reference (point source) and the object "UIS acronym" (see figure 1a). The maximum dimension at the input plane, between reference and object, is 7 mm, thus the Shannon-Whitaker theorem is fulfilled. This means that the minimum spatial period of the interference fringes obtained at the back focal plane of lens L2, with focal length $f = 35$ cm, is closed to 34 μm. The hologram is recorded onto 754 $\times$480 pixels CCD camera (see figure 2a) and digitized at 256 gray levels. The whole optical system used in our experiment, camera and Fourier lens exhibit a cutoff frequency near to 43 lp/mm, horizontal (H) by 20 lp/mm vertical (V). That is, in the sampled hologram the sampling theorem is satisfied at least in the horizontal direction and a low-pass filtered version of the hologram in the vertical direction is obtained.

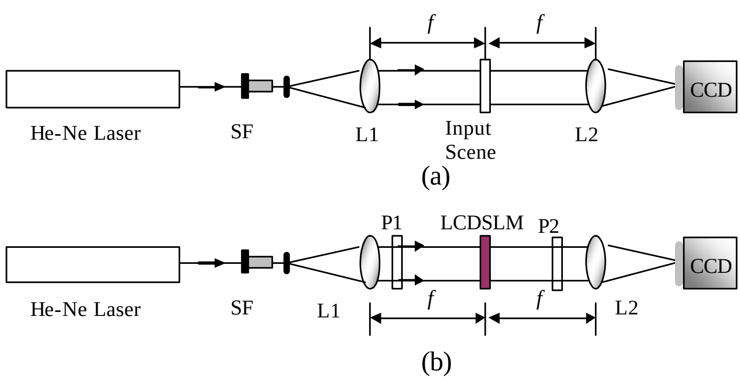

Figure 1. Optical setup for digital Fourier hologram recording (a) and its reconstruction (b)

In optical reconstruction (see figure 1b), the hologram is displayed on a 1024$\times$768 pixels LCDSLM with pixel dimension 14 μm $\times$ 14μm, any information is lost due to the higher number of pixels of LCDSLM in both direction related the recorded hologram. A He-Ne laser beam does the readout the hologram and then is Fourier transformed by a lens (L2). The intensity distribution corresponding to the zero order diffraction from LCDSLM of the reconstructed hologram is shown in figure (2b). In order to improve the diffraction efficiency, the SLM is placed between a couple of polarizes P1 and P2.

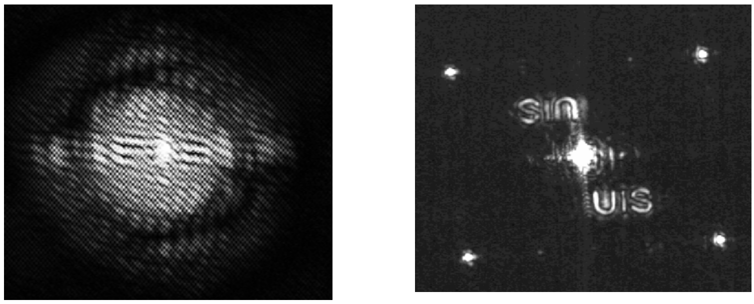

Figure 2. Intensity distribution of the digital Fourier holograms (a) and optical reconstruction (b)

Conclusions

Although generally digital holography is worked recording onto a Megapixel camera, we have shown that is possible recording a digital Fourier hologram using a CCD with a low spatial resolution on condition that the Shannon-Whittaker theorem is respected. Naturally the size of the input scene is strongly restricted.

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