Conference Paper

Zero Order Correction of Shift-multiplexed Computer Generated Fourier Holograms Recorded in Incoherent Projection Scheme

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Abstract

Application of computer holography methods provides the possibility to obtain the high quality holograms of objects that exist as digital models without the necessity of complex and high precision optical schemes. Computer generated Fourier holograms (CGFH) are widely used for record and optical restoration of relatively simple 2D raster objects. Application of incoherent photolithography methods such as incoherent projection allows the record of CGFHs as micro-holograms onto the photosensitive medium with desired reduction of hologram sizes using relatively simple optical setup. The reconstruction optical schemes of CGFHs can be implemented in augmented reality displays and optical sight indicators. In this article the specificity of CGFH shift-multiplexed record process and particularly the method of zero order correction is discussed.

Keywords: computer generated hologram, Fourier hologram, incoherent projection scheme.

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Received: 28 January 2018
Accepted: 15 March 2018
Published: 25 April 2018

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the PhIO Conference Committee.

1. CGFH realization

Computer holography is the approach when holographic patterns of object that exist as digital model can be obtained using numeric calculation of optical fields propagation and interaction. Calculated holographic patterns known as computer-generated holograms (CGH) can be realized as real holograms using high-resolution spatial light modulators (SLM) and photolithography methods [1]. In the cases when object is presented as 2D raster model the point-oriented computer generated Fourier holograms (CGFH) are very perspective by means of computational burden, quality of the restored object, and record or copying simplicity. CGFHs have been successfully used in optical memory systems [2, 3], optical correlators [4], wavefront sensors [5], augmented reality displays [6] and target sight indicators [7].

Figure 1 represents the basic procedures that contain the CGFH realization process. Firstly a digital model of 2D object to be encoded onto the hologram must be formed. This object must be represented as a matrix of real or complex values. The resolution of object should not exceed one half of the resolution of hologram to be synthesized in order to avoid the degradation of object image. In the cases, when object is represented by real values it is useful to provide the masking of object function by randomized phase mask. This allows the widening of object spatial spectrum and increase of the diffraction efficiency of CGFH [8].

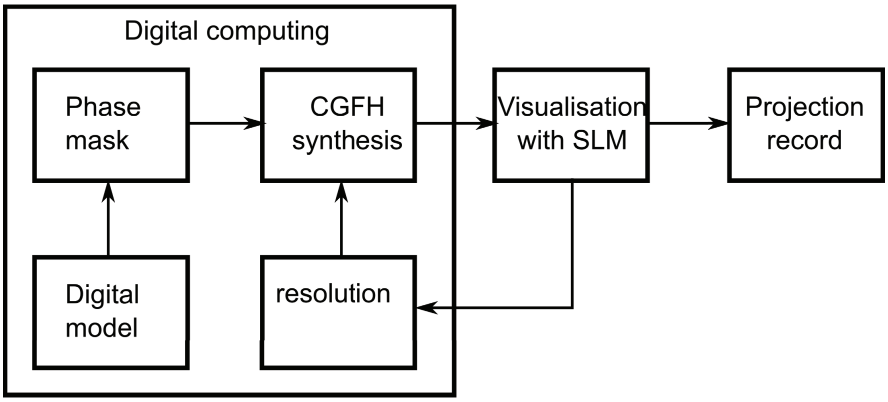

Figure 1: Block scheme of CGFH realization method.

Then CGFH transparency function can be calculated. Equation (1) represents the main mathematical definition of CGFH synthesis:

$$H\left(n_f, m_f\right) = C_0 + Re\left[\tilde{F}\left\{t\left(n_0, m_0\right)\right\}\right] \tag{1}$$

where $H\left(n_f, m_f\right)$ is a matrix of CGFH discrete pattern presented by positive real values, $t\left(n_0, m_0\right)$ is a matrix of object discrete complex amplitude function, $\tilde{F}\{\ \}$ – indicates a discrete Fourier transform operation (DFT), and C_0 is a reference beam amplitude coefficient matrix contained by equal values c_0, which can be defined as:

$$c_0 \geq -min\left(Re\left[\tilde{F}\left\{t\left(n_0, m_0\right)\right\}\right]\right) \tag{2}$$

A hologram transparency function that was synthesized according to (1)-(2) can be represented as a matrix of real non-negative values. Quantization of $H\left(n_f, m_f\right)$ values with 8 bit depth allows representation of CGFH as arbitrary bitmap image and displaying using amplitude spatial light modulator (SLM). The described method utilizes only one Fourier transform operation with matrix of complex values and can be rapidly provided using fast Fourier transform (FFT) algorithms.

A hologram displayed by SLM can be inputed into the incoherent optical scheme of image projection and recorded onto photosensitive carrier. Figure 1 represents the example of optical projection scheme based on transparency type SLM. The other configurations of a scheme that also based on reflection type SLMs and on OLED display could be considered [9]. A semiconductor light diode (LD) is used as a light source in the scheme. A light beam being properly collimated uniformly illuminates the aperture of SLM, which modulates the spatial amplitude of a beam. SLM being driven by personal computer displays the bitmap image of CGFH transparency function. Next to SLM a projection system is used to translate the plane of SLM display into the imaging plane with desired reduction. A carrier with photosensitive medium, which is placed in the image plane of the scheme, captures the intensity of light that falls onto its surface. Optical components of projection scheme should be designed considering aberrations caused by wide spectrum of light diode to provide the spatial resolution determined by reduction requirements and SLM resolution [8]. Shifting the holographic carrier in vertical and horizontal directions in the image plane provides the record of several holograms along the surface of a carrier (shift-multiplexed record).

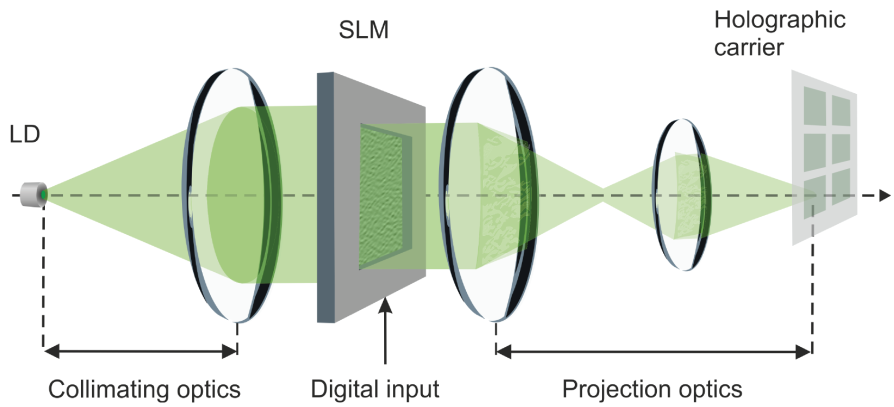

Figure 2: Equivalent scheme of CGFH incoherent projection and shift multiplexing.

2. Shift-multiplexed record and zero order correction

In the cases when CGFH is used for imaging of 2D object in augmented reality display or sight indicator it is useful to provide multiplexed record of several holograms stacked in a regular manner such as imaged on Figure 2. This allows imaging of the object with high angular sizes efficiently using the reading beam aperture. The main problem in this case is distortions of zero order caused by diffraction of light on regular raster of rectangular holographic structures and narrow gap between them. This gap could be

DOI 10.18502/ken.v3i3.2068

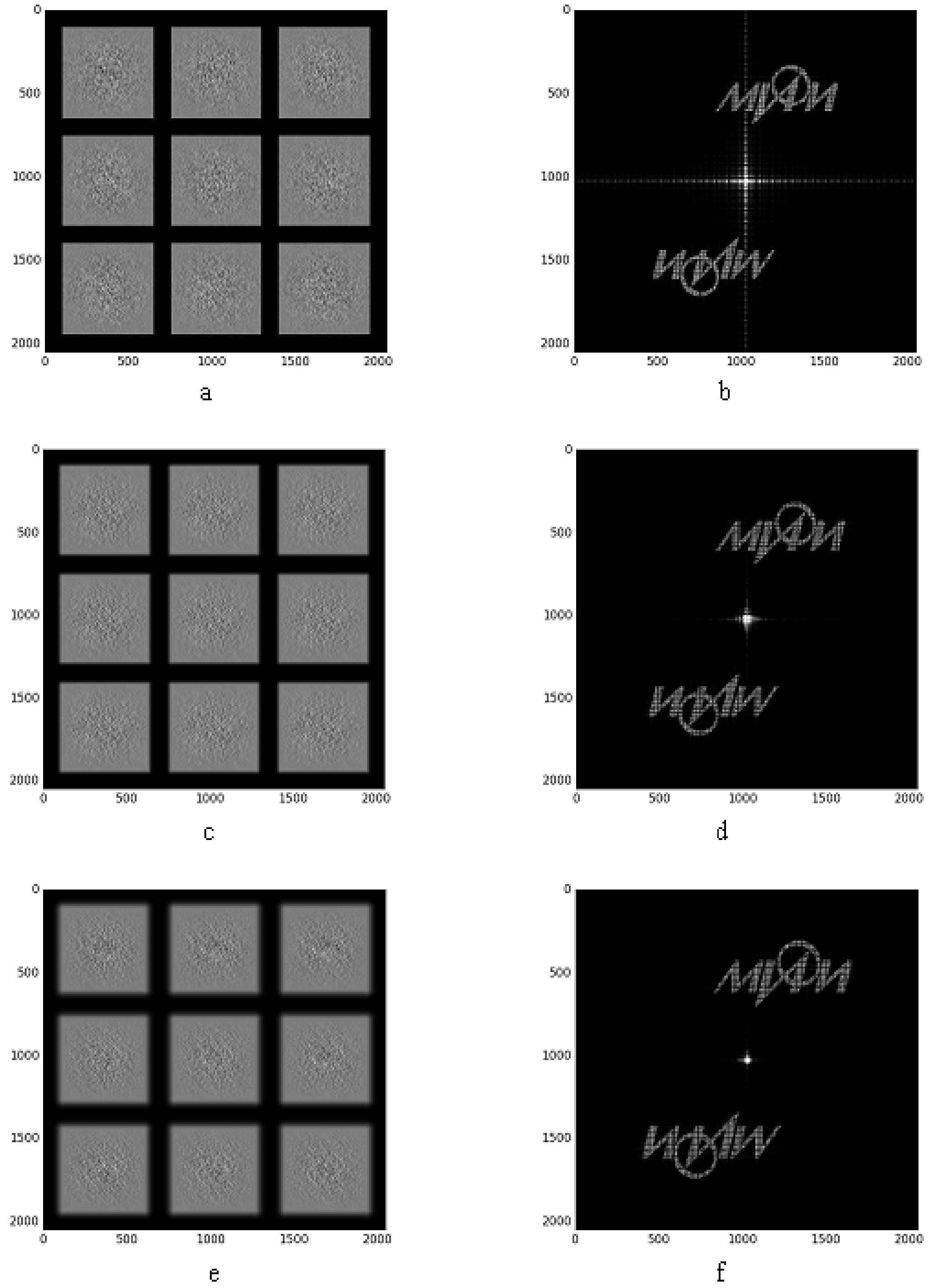

Figure 3: The results of numeric simulation of holograms shift-multiplexing and restoration: a)-b) holograms (544x544 pixels) without gradient frames and restored light field; c)-d) holograms (480x480) with 32 pixels frames, and restored light field; e)-f) holograms (416x416) with 64 pixels frames, and restored light field.

the result of positioning errors of recording head and causes significant widening of zero order in the reconstructed light field along vertical and horizontal directions.

In order to suppress these distortions we propose to add a thin gradient frame to the synthesized holographic structures for the price of slight reduction of CGFH resolution. In the case when object resolution is less then one half of the resolution of hologram that is determined by the resolution of SLM display that is used in projection scheme, this allows the amplification of low spatial frequencies of holograms raster spectrum and suppression of high frequencies in the reconstructed light field. In order to investigate the affect of gradient frame onto the reconstructed image a numeric modeling of CGFH synthesis, multiplexing and restoration have been carried out. We used a binary object model with 200x100 pixels resolution; the resolution of holograms to be synthesized was 544x544 pixels. 9 shift-multiplexed copies of the same CGFH filled holographic plate model contained by 3x3 cells. The total resolution of holographic plate model was set to be 2048x2048 pixels. The width of gap between holograms was 104 pixels (20% of hologram size). Figure 3(a) represents the model of shift-multiplexed hologram with sharp rectangular edges and Figure 3(b) demonstrates the result of numeric restoration of holographic image by this hologram. The presence of wide bright *sinc*-type zero order that affect the image of the encoded object is observed. Figures 3(c)-3(f) demonstrate the results of calculations for the case when frame with Gaussian gradient function was used. It was observed that addition of 32 pixels frame (~6% of hologram size) causes significant reduction of zero-order distortions enough for imaging of the encoded object without distortions, however it is still has significant width of about 50% of object size. For 64 pixels frame (~12% of hologram size) zero order is mainly concentrated around small area in the center of the restored light field with sizes of about 5% of object size.

3. Conclusion

The results of numeric modeling of shift-multiplexed record and reconstruction of computer-generated Fourier holograms in incoherent projection-type recorder demonstrate that the record could be efficient if thin gradient Gaussian frame is added to hologram transparency image. This simple method allows the suppression of wide zero-order caused by gaps between multiplexed holograms without affecting the encoded object image. The gradient frame could be about 10-15% of hologram width to concentrate zero-order energy in small area in the center of the light field restored by hologram. The method is useful for the cases when object resolution is sufficiently less than one half of the resolution of SLM to be used in projection scheme for CGFH displaying.

Acknowledgments

The study was supported by Russian Foundation of Basic Research (RFBR) project No. 17-07-00254.

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