Multispectral high-resolution hologram generation using orthographic projection images

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Abstract. We present a new method of synthesizing a digital hologram of three-dimensional (3D) real-world objects from multiple orthographic projection images (OPI). A high-resolution multiple perspectives of 3D objects (i.e., two dimensional elemental image array) are captured under incoherent white light using synthetic aperture integral imaging (SAII) technique and their OPIs are obtained respectively. The reference beam is then multiplied with the corresponding OPI and integrated to form a Fourier hologram. Eventually, a modified phase retrieval algorithm (GS/HIO) is applied to reconstruct the hologram. The principle is validated experimentally and the results support the feasibility of the proposed method.

1. Introduction

The applications of digital holography have been applied widely as it captures and displays whole three-dimensional (3D) information of the real world objects [1, 3]. Nevertheless, practically, the holography imaging is a tedious process, as it requires coherent light source and demands scrupulous stability of the optical system that can work under darker environment [3]. In order to alleviate, approches that includes hybrid interfaces between Integral imaging (II) and holography has been suggested in the past decade [4-7].

The principle of II is based on Integral Photography (IP) that uses a circular or square lens array to capture and display 3D images. In this process, a series of multiple two-dimensional (2D) images, Elemental Image Array (EIA), are captured under white-light illumination and that can be used to reconstruct the 3D image. II makes the 3D image visualization and 3D depth extraction process easier and also it removes the necessity for camera calibration [3, 5].

In this paper, we propose a new method for the hologram generation using white-light (i.e., incoherent source) based orthographic images. The 3D objects are digitally recorded and then the orthographic projection images (OPI) are obtained from the captured EIA. Each OPI is numerically modulated by the plane wave (i.e., reference beam) propagating in the direction of the corresponding view angle and combined into a single complex value that refers to one pixel in the synthesized digital hologram [7]. By repating this process for all OPIs, we can generate the Digital Fourier Hologram (DFH) of the 3D objects. We note that the process of generating DFH is more compact and that does not requires a coherent illumination system [5].

This paper is organized as follows: In section 2 we describe the prinicple of OPI obtaining process. In section 3 we discuss about the generation and the reconstruction of an integral Fourier hologram. Experimental results are presented in section 4. Finally, in section 5 we conclude our discussion.

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2. Orthographic Projection Image (OPI)

Orthographic projection geometry describes the geometrical relationship between the 3D objects and the captured view image at the image plane (i.e., CCD or CMOS imaging sensor). As it can be seen from Fig.1, in this procedure, the projection lines are considered to be parallel with each other [7].
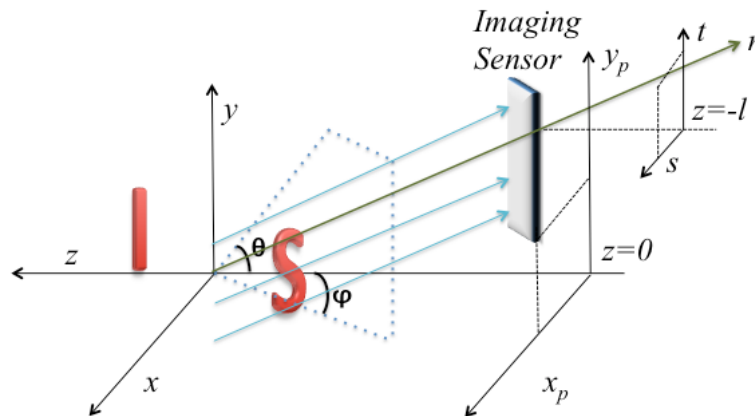

Figure 1. Orthographic Projection Geometry.

If we consider r as one of the projection lines (see Fig. 1 green color line), the angle φ is the angle between the projection line r and the $x - z$ plane. Similarly, the angle θ is the angle that the projection of r onto the $y - z$ plane. Thus, the projection image coordinates (x_p, y_p) is given as follows:

$$x_p = x + z\tan\varphi = x + \frac{zs}{l}\,,$$
$$y_p = y + z\tan\theta = y + \frac{zt}{l}\,, \tag{1}$$

where s, t and l are used to explain projection direction, conveniently. It is said that in [7], orthographic projection leads to the exact Fourier and Fresnal based hologram generation.
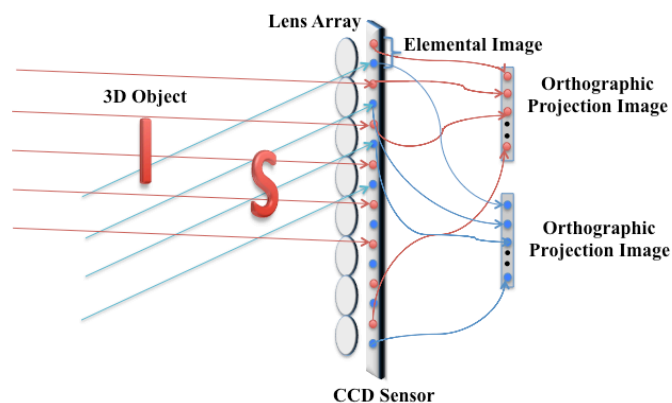

Figure 2. Process of generating orthographic projection images using lenslet array.

Figure 2 shows the process of generating OPI using lenslet array. As it can be noticed, the 3D object is imaged through the lens array and thus the captured elemental images represent a different perspective of the 3D object. It also can be seen from Fig. 2 that the orthographic projection image is a collection of pixels at the same local position from all the captured elemental images. For example, in Fig. 2, a pixel at the position of red dot is collected from all elemental images to form one orthographic projection image. Analogously, the pixels from blue dot are gathered to form another OPI. Since, one pixel is extracted from each EI the number of pixels in the synthesized OPI is same as captured EI. Therefore, the number of pixels in one EI gives the total number of the synthesized OPI [7, 8].

3. Digital Fourier Hologram (DFH)

Figure 3 shows the process of Fourier hologram generation using the orthographic projection images. At first, the OPIs are generated from the captured EIA. Then the each synthesized OPI is multiplied by the phase factor of the slanted plane wave (i.e., reference beam). This product is then combined into a single complex value (i.e., one pixel value in the synthesized DFH). Finally, by repeating these process for all OPIs, an entire Fourier hologram can be generated [7].
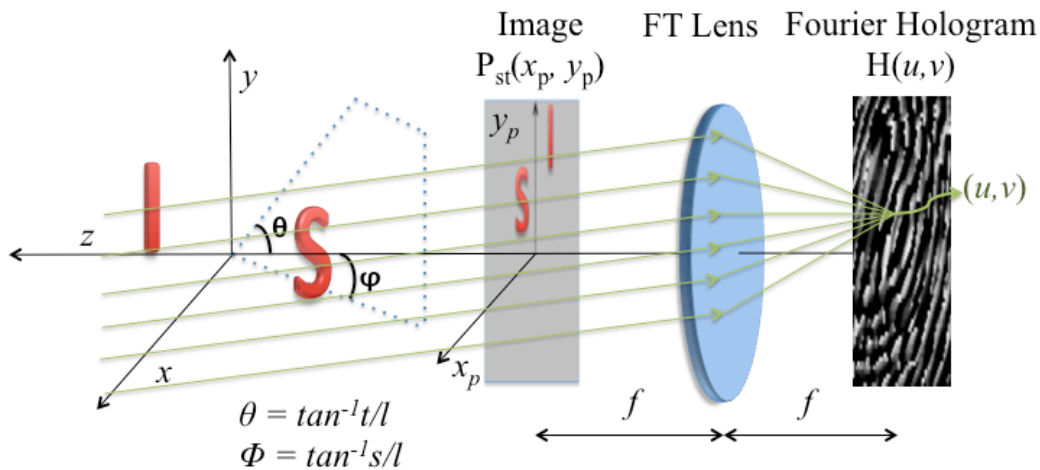

Figure 3. Fourier Hologram generation using the orthographic image.

Mathematically, the generation of Fourier hologram from OPI is derived as follows:

$$H(u,v) = \iint P_{st}(x_p, y_p)\exp\left[-j2\pi k\left(x_p s + y_p t\right)\right]dx_p dy_p, \qquad (2)$$

where $P_{st}(x_p, y_p)$ denotes OPI and it directional information can be derived using s, t. k is a constant value used in [7] and we note that an exact Fourier hologram can be obtained using this process.

4. Simulation Results

Experiments and simulation results are presented in this section. We used two different 3D objects (see Fig. 4) longitudinally separated and illuminated using incoherent white light. We considered an elemental image in the size of 1024(H) x 1024(V). From these EIs, the orthographic projection images are generated as explained in section 2. Later, by using these OPIs the Fourier hologram can be

generated using Eq. 2. In our experiments, we used GS/HIO phase retrieval algorithm [9] to numerically reconstruct the Fourier hologram.
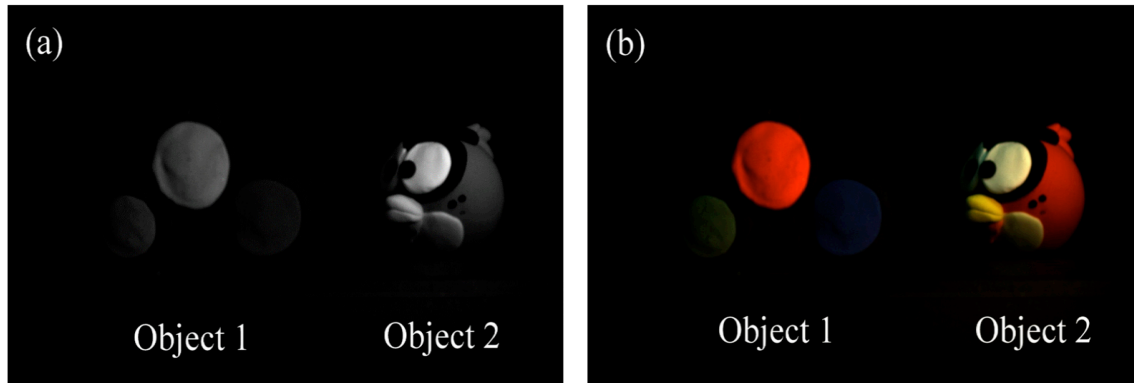

Figure 4. Objects used in our experiment. (a) Raw Bayer image; (b) Interpolated multispectral image.

Figure 5 shows the simulation results of the reconstruced 3D sectional image. It is clearly evident from Fig 5. that in the reconstructed plane, only one of the objects is focused.
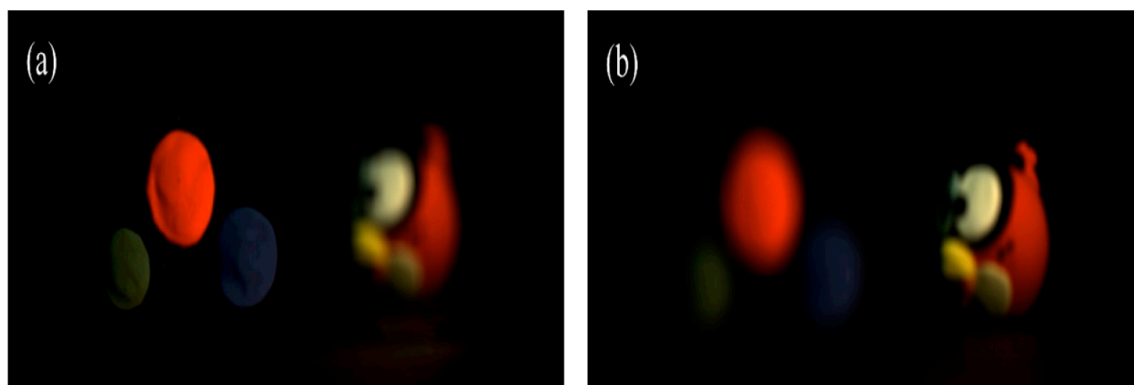

Figure 5. Reconstructed objects. (a) 1st object is in focus; (b)2nd object is focused.

Figure 5(a) shows the reconstruction in the best focus plane of the first 3D object while the second object is out of focus and Fig 5(b) shows the reconstruced focused second 3D object. By these results, it is evident that the volumetric information is indeed encrypted inside the hologram synthesized.

5. Conclusion

In this paper, we have presented a compact method of synthesizing digital Fourier hologram using orthographic projection images (OPI). OPIs are generated from computationally recorded Bayer patterened elemental images that captured under spatially incoherent illumination. Later, a slanted plane wave (i.e., reference beam) is multiplied with OPI and combined to generate Fourier hologram. We note that using computational elemental images improves the reconstructed hologram image quality. We verified this technique by experiments and simulations also the results proves the feasibility.

Acknowledgement

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