White-Light Single-Shot Digital Hologram Recorder

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Abstract: A new technique, coined integral holography, for recording holograms of three-dimensional objects under spatially incoherent white-light illumination, and in a single camera shot, is presented. Experimental results validate the correctness of the new technique.

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1. Introduction

The main disadvantage of conventional holography, in which a laser reference beam and a laser object beam create an interference pattern that is recorded into a film, is the fact that the acquisition process is complicated. In this kind of holography, the two beams must be coherent to each other and the optical system must be extremely stable in order to create the interference pattern. In addition, the light intensity needed for this process is relatively high.

Refs. [1-3] present a partial solution to these problems. According to the methods presented there, it is possible to record a Fourier hologram under spatially incoherent white-light illumination. This is performed by capturing images of the 3-D scene from multiple viewpoints and digitally processing the captured images in the computer, which yields a Fourier hologram. The criticism against this solution derives from the fact that obtaining a hologram with an acceptable resolution requires the camera to be re-positioned many times in order to capture a relatively large number of images. This might be a complicated process.

In the current paper, we employ a microlens array (MLA), a device which is usually used in the integral imaging field [4,5], in order to view the 3-D scene simultaneously from multiple viewpoints. This means that the acquisition of the multiple projections of the 3-D scene for the synthesis of the hologram can be performed in a single camera shot, but still under spatially incoherent white-light illumination. This makes the acquisition process much faster and more convenient. We designate this new holography technique as integral holography (IH).

2. Acquisition of the Multiple Projections of the 3-D Scene

Fig. 1 shows the IH optical system used for recording the hologram. Multiple viewpoint projections of the 3-D scene are created by the MLA and imaged onto a camera by the spherical lens L_2. A plano-convex lens L_1 is attached to the MLA on the side of the 3-D scene. The focal length of this lens is approximately equal to the distance between the 3-D scene and the plano-convex lens. This helps to collimate the beams coming from the 3-D scene and thus increases the number of microlenses participating in the process. Then, the camera records in a single shot the MLA image plane containing elemental images, each of which is another projection of the 3-D scene from a different viewpoint.

3. Using the Obtained Projections of the 3-D Scene for the Synthesis of a Fourier Hologram

As soon as the camera acquires the multiple projections of the 3-D scene in a single shot, mathematical operations are performed. The latter include taking each of the projections, centering it around the same reference point used for all of the projections, and multiplying it by a linear phase function which is dependent on the position of this specific projection in the entire set of projections or, in other words, on the angle at which the 3-D scene is viewed in this projection. After the multiplication of the projection image by the phase function, the obtained 2-D complex matrix is summed up into a single complex value positioned at the corresponding pixel in another 2-D complex matrix. The latter represents a 2-D complex function, which is equivalent to the complex amplitude in the rear focal plane of a spherical lens due to a coherent light diffracting from the same 3-D scene and propagating through this lens. The analogy between the result of the above-described projection-based algorithm and a conventional Fourier hologram is proven in Ref. [2]. The obtained 2-D complex function can be encoded, by one of many well known

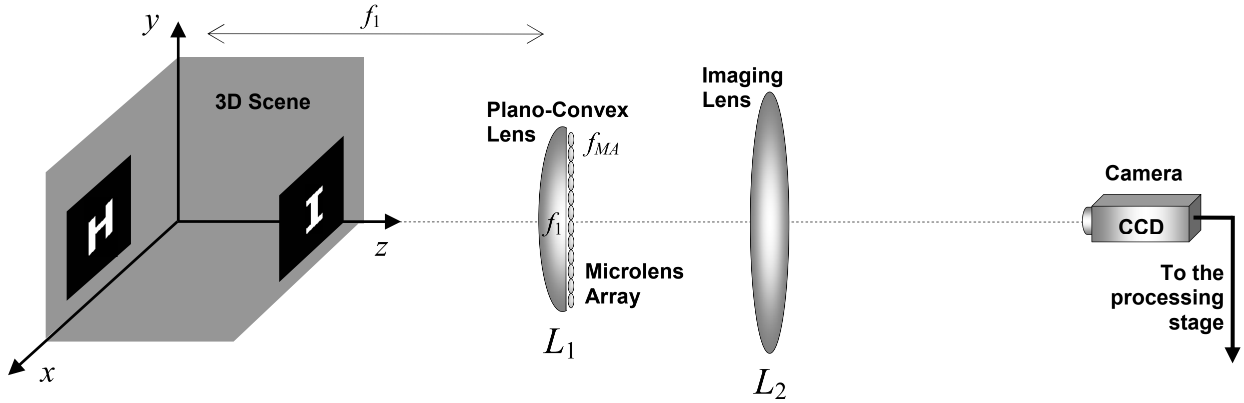


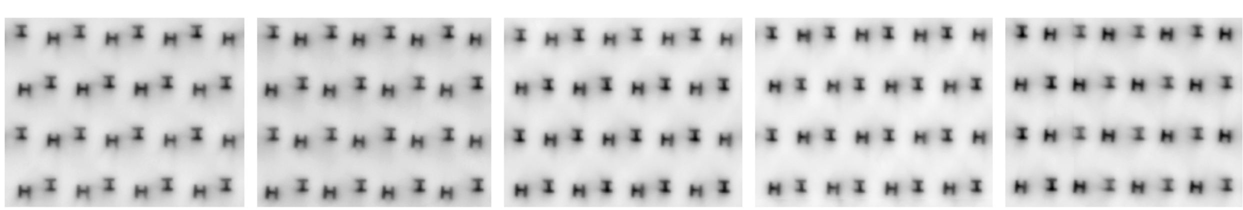
Fig. 1: The IH optical system for recording the hologram.

methods, into a computer generated hologram (CGH) with real and positive transparency values. Illuminating the CGH by a plane wave reconstructs the 3-D scene. Alternatively, the CGH can be used in order to electronically reconstruct the 3-D scene by employing digital holography techniques.

4. Experimental Results

The IH optical setup shown in Fig. 1 has been implemented in our laboratory. Two bright letters ‘I’ and ‘H’ have been illuminated by a spatially incoherent white-light source. The size of the letters is approximately 2cm × 2cm each. The distances between the letters on the optical axis *z*, the vertical axis *y* and the horizontal axis *x* are 10 cm, 1 cm and 3 cm, respectively. A plano-convex lens L_1 with focal length f_1 = 40 cm and a diameter of 10 cm is positioned 40 cm apart from the 3-D scene. This lens is attached to the MLA. We have used a hexagonal-format MLA, 5 cm in diameter and with 115×110 microlenses (practically, only the 64×64 middle ones are used in the experiment). The focal length of each of the microlenses is f_{MA} = 3.3 mm and the pitch of the array is 500 microns. A spherical imaging lens L_2 with a focal length of 10 cm is used to magnify the image plane of the MLA onto the CCD camera (PCO Scientific, 230XS), with 1280×1024 pixels and an 8.6×6.9 mm^2 active area. Since the number of pixels in our camera is relatively low compared to other cameras on the market today, we have concatenated several camera planes.

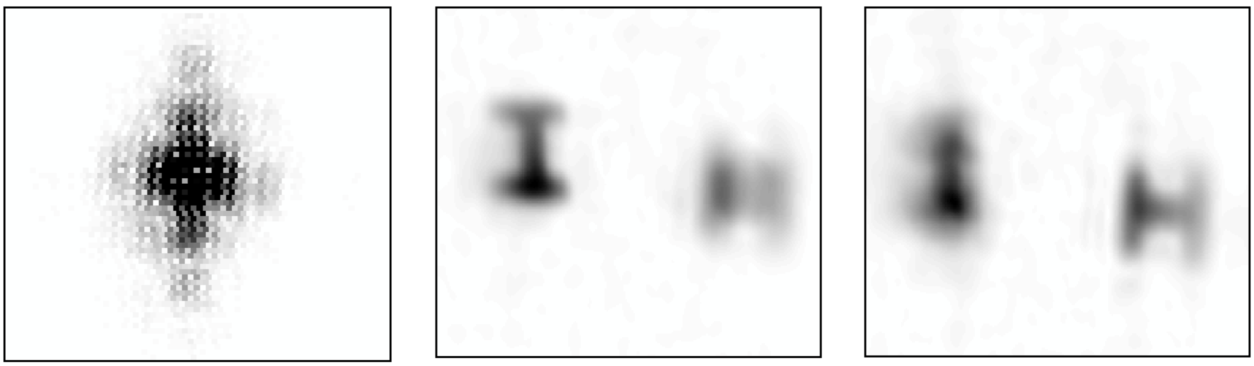
Fig. 2 shows several small portions of the MLA image plane. As seen in this figure, the distance between the letters changes in different parts of the MLA image plane. The next stage is to cut each of the projections from the recorded image plane and center it around the same reference point used for all of the projections. Because of the centering process all parts of the MLA are positioned in an equal distance from the reference point. In our experiment, we have chosen this reference point as the center of the letter ‘I’. Thus, the cut projection images are centered around the center of the letter ‘I’. Fig. 3 shows the cut and centered projections across a single row of elemental images from the MLA image plane. According to the processing stage explained above, each of the centered projections is multiplied by a linear phase function with an argument that represents the relative position of the current projection in the entire MLA image plane. The result is summed up into a single pixel in a 2-D complex matrix representing the Fourier hologram of the 3-D scene.



(a) (b) (c) (d) (e)

Fig. 2: Small portions of the MLA image plane recorded by the CCD camera (contrast-inverted pictures):
(a) Upper-left portion; (b) Upper-right portion; (c) Middle portion; (d) Bottom-left portion; (e) Bottom-right portion.

Fig. 3: One row of projections taken from the MLA image plane, after centering each of the projections around the center of the letter 'I' (contrast-inverted picture).



(a) (b) (c)

Fig. 4: (Contrast-inverted pictures) (a) Magnitude of the Fourier hologram, obtained by the processing stage. (b) Reconstruction of the hologram at the best focus distance of the letter 'I'. (b) Reconstruction of the hologram at the best focus distance of the letter 'H'.

Fig. 4(a) shows the magnitude of the Fourier hologram obtained after performing the above-described process for each of the 64×64 projections taken from the MLA image plane. The hologram can be digitally reconstructed by performing a Fresnel propagation along the optical axis. Two different reconstruction planes are shown in Fig. 4(b) and 4(c). In Fig. 4(b), the letter 'I' is in focus. This plane is obtained by inverse Fourier transforming the hologram. On the other hand, in Fig. 4(c), the letter 'H' is in focus. This plane is obtained by performing a Fresnel propagation from the inverse Fourier transforming plane toward the best focus distance of the letter 'H'. The fact that in each plane one letter is in focus, whereas the other letter is out of focus, validates the volumetric information which is encoded in the hologram obtained by the new method.

5. Conclusions

We have presented and experimentally demonstrated a new optical technique, designated as integral holography, for obtaining holograms of realistic 3-D objects in a single camera shot and under conventional spatially incoherent white-light illumination. This is done by obtaining multiple projections of the 3-D scene using an MLA and processing the projections in the computer. By integrating the MLA into a digital camera, it may be possible in the future to easily record holograms under regular conditions and without most of the limitations of conventional holography. This, of course, can make holography to be much more common in many fields of science.

6. References

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