Computer Generated Holograms Applied to 2D and 3D Objects

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INTRODUCTION

The production of holograms using conventional techniques is a tedious job which is sensitive to many influences (Bulanon, 1999). During the recording process high stability of the experimental set-up is required to achieve a satisfying result. The production of holograms using the computer is a recently developed technique which provides an alternative for this demanding procedure (Trester, 1996; Fetthauer, 1995; Kato & Sakuda, 1992). In computer generated holograms (CGH) the interference pattern between the object wave and reference wave is calculated directly. By using standard equipment available in every office, like printers and copiers we can avoid the use of more difficult photographing techniques (Walker, 1999). We started to apply this technique to construct holograms of 2D objects. Presently, the procedure is being modified to apply this technique to 3D objects, a method which incorporates stereographic technique.

FOURIER TRANSFORM CGH

The production of holograms uses the principle of the off-axis reference beam technique developed by E. Leith and J. Upatneiks (Rastogi, 1994). One method of recording holograms uses the concept of Fourier transformation. Waves interfering at the hologram plane are the Fourier transforms of the object and reference waves (Knight, 1991). In Fig. 1, a planar transparent object placed in an opaque x, y plane (object plane), located a distance z, from the x', y' plane (hologram plane). The reference point source is at x_r, y_r coordinates in the object plane. The electric field amplitude $E(x', y')$ for the resultant light wave at any point in the hologram plane is given by:

$$E(x', y') = C\exp(ikz) \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}[A_o(x,y) + A_r(x,y)]\exp[-i(k'_x x + k'_y y)]dxdy$$

where $A_o(x, y)$ is the amplitude transmittance function for the object and $A_r(x, y)=a_r\delta(x-x_r, y-y_r)$ is the amplitude transmittance for the reference point source. The right hand side of the equation above is proportional to the Fourier transform of the sum of the amplitude transmittance functions of the object and the reference beam. The intensity $I(x', y') = E(x', y')E^*(x', y')$, which will contain four terms, is the quantity recorded by a film placed in the hologram plane. The first term is the Fourier transform of a constant while the second is proportional to the autocorrelation function of A_o. When the hologram is illuminated by an appropriate light source, these two terms will manifest itself as a bright spot at the center of the observation plane. The other two terms of the intensity function contain the information of the object wave. These two terms will produce the two images seen during optical reconstruction.

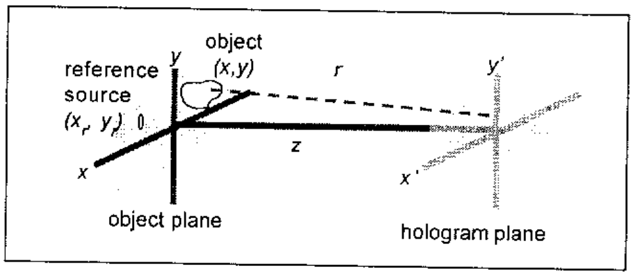

Fig. 1. Relevant Geometry of the Fourier transform hologram theory

METHODOLOGY

Using the PC to produce Fourier holograms

The production of CGH using a PC involves two steps. In the first step, the Fourier transform of the object wave is calculated. The object wave is represented by $N x N$ matrix elements. From this matrix the $N x N$ coefficients of its discrete Fourier transform are evaluated using the Fast Fourier Transform routine of the MATHCAD software. In the second step the computed values are used to produce a transparency (the hologram). The intensity hologram matrix is computed from the values of the discrete Fourier transform. The resulting hologram matrix is modified using a digital spatial filter. Spatial filtering reduces the intensity of the central bright spot, an artefact of CGH. The MATHCAD software converts the values of each element of the hologram matrix into 8-bit grey scale representation. The result is printed using a 600 dpi laser printer. The printout is reduced to a size of about 15 x 15 square-mm with a high resolution photocopier onto an overhead transparency film. The high-resolution capability of the printer is even greater than that of the monitor whose resolution is limited by the pixel size. Reducing the hologram by photocopying the printout instead of reducing with the computer has the advantage of preserving more detail.

The experimental set-up for optical reconstruction is shown in Fig. 2. A He-Ne laser was used and a telescope was employed to produce an expanded and collimated laser beam. Two converging lenses were used, with focal lengths of 100 mm and 250 mm respectively, to make the laser beam large enough to fill the hologram. A screen placed at the equivalent focal plane of the lens system served as the observation plane where the reconstructed image could be viewed. The size of the reconstructed image can be adjusted by changing the distance between the 250 mm lens and the 100mm.

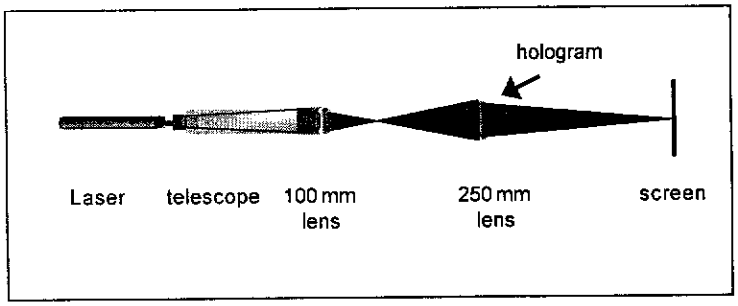

Fig. 2. Experimental set-up for CGH optical reconstruction

Application of Fourier CGH to 3D objects

For the production CGH of 3D objects, a stereographic technique is employed. The method starts with representing 2D projections of the object within an *128* x *128* matrix. The value of the elements ranges from 0 to 255 (grey level scale). One element of the matrix is assigned a value of 255 which represents the reference beam. All other elements of the matrix are assigned a value zero. Each element of the 2D Fourier transform of this matrix is transformed into amplitude values. The resulting matrix represents a hologram for a particular viewing angle. By vertical scanning of different viewing angles, each view would yield a different hologram matrix. If there are M number of viewing angles, there will be M number of hologram matrices. These matrices are combined in the following manner: the hologram matrices are arranged from the highest to the lowest viewing angle. Each hologram matrix is divided into M horizontal strips. The element values for each matrix are changed according to the following procedure: elements of the i^{th} strip of the i^{th} hologram matrix are retained while all the other elements are assigned zero values. The sum of these new matrices will form the final hologram matrix which is expected to reconstruct an image with a 3D character. The 3D character will manifest itself by the vertical parallax, not in the horizontal parallax.

RESULTS, DISCUSSION, AND CONCLUSION

Fig. 3 displays the computer graphics of the original images created from 2D objects and the corresponding holograms produced and the reconstructed images. The hologram matrix contains information of the object, which does not resemble the object as seen by the naked eye. With the use of a laser illuminating the hologram, the image of the object is reconstructed. It can be seen from the optical reconstructions that the image of the smaller object (F) has better quality than that of the bigger object (USC). This is due to the fact that the square of the autocorrelation function of the object contributes to the intensity of the central spot. This contribution arises from the computation of the Fourier transform to form the hologram matrix. Thus, smaller objects would have better image quality.

The process of applying Fourier transform CGH to a 3D object using a stereographic technique is shown in Fig. 4. The computer-simulated reconstruction is shown. The computer simulation is done through MATHCAD software. The computer reconstruction shown in the figure does not show how the object is viewed from different angles. For optical reconstruction, tilting the hologram will simulate viewing from different angles. When done properly, the use of stereographic techniques can extend the application of CGH on 2D objects to 3D objects.

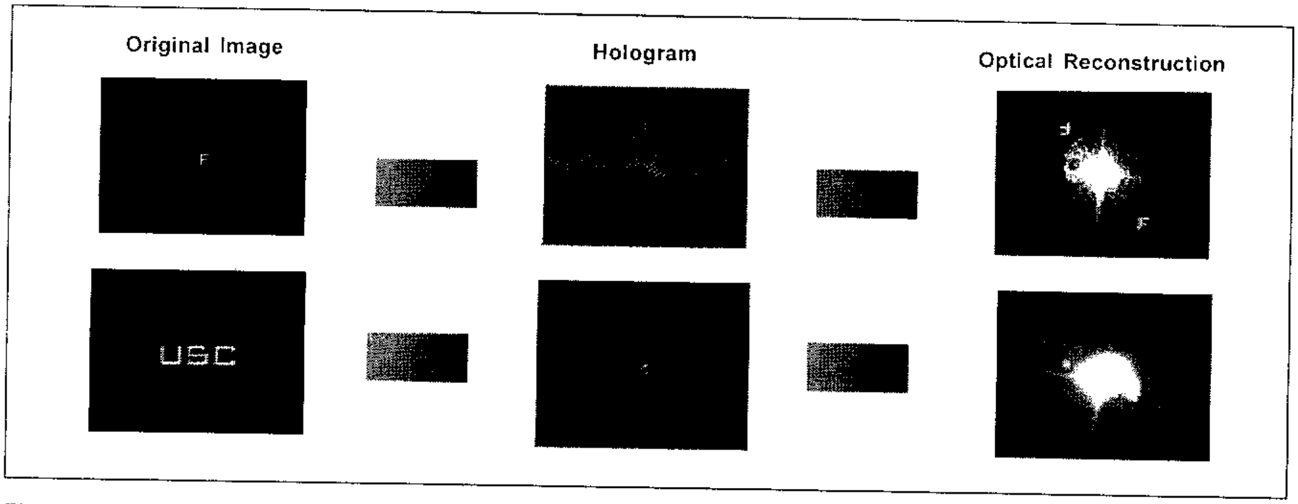

Fig. 3. Computer graphic of 2D objects with corresponding hologram matrices and optical reconstructions as captured by a CCD camera

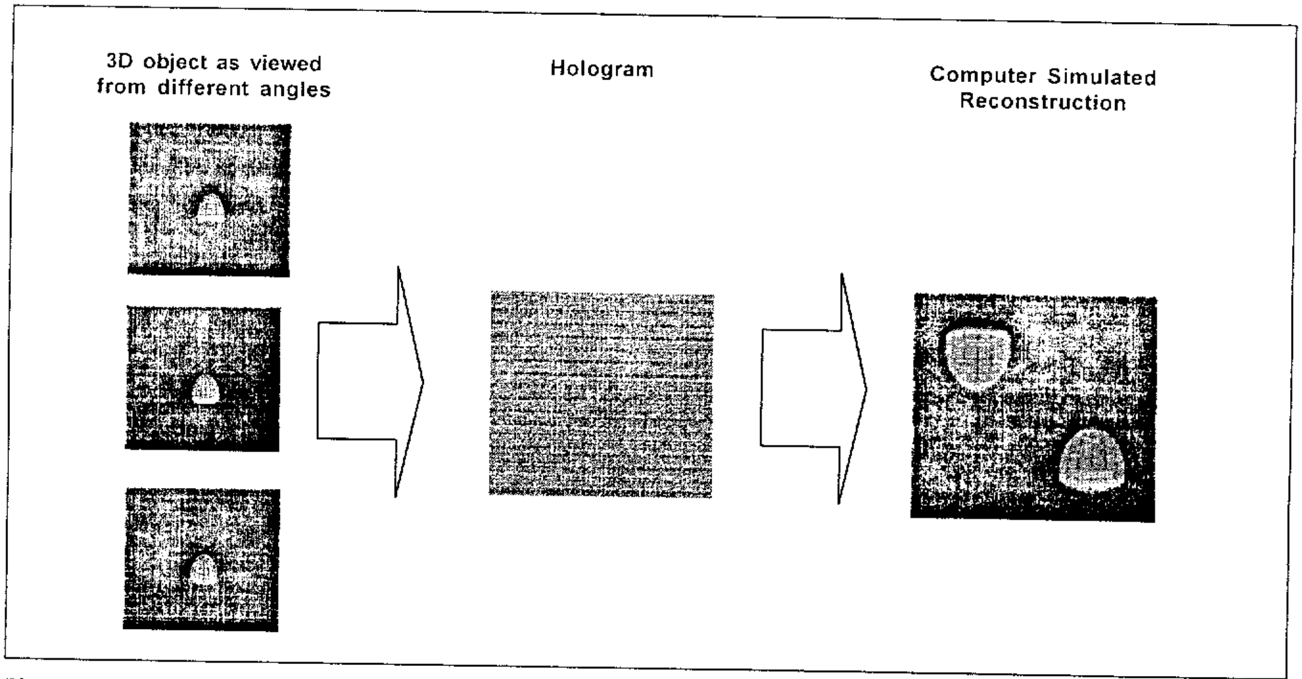

Fig. 4. Computer graphic representations of a 3D object (left) used to produce the CGH (center). Computer simulated reconstruction (right) is shown.

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