Computer Generated Fresnel Hologram using Liquid Crystal Display

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Synopsis

Fresnel hologram pattern was calculated using the interference of spherical waves from model points and plane reference wave. Calculated hologram was displayed on an LCD. When the LCD was illuminated by a He-Ne laser, the real images of the patterns consists of points were clearly observed in spite of the bad resolution of LCD. It is shown that each pattern situated in different positions was reconstructed at corresponding positions.

KEYWORDS: holography, computer-generated hologram, Fresnel hologram, LCD, He-Ne laser

Introduction

Photo-films and dry-plates were often used as display media of computer generated hologram. To make holograms of them, chemical processes such as development and fixing are necessary, which are annoying processes. A liquid crystal display (LCD) does not need such processes, and a calculated hologram pattern can be displayed immediately. So it has a possibility of real time holography. Such an LCD is a convenient element to make a holography experiment. The resolution of it, however, is much worse than that of film. We have already made an experiment of LCD Fourier transformation hologram.[1] In this note we show some examples of reconstructed image by LCD Fresnel hologram.

Calculation of Hologram

The object to be holographically reconstructed consists of point light sources[2] As shown in Fig.1, the spherical wave from the i-th point and the plane reference wave on the hologram plane (z = 0) are described by the following equations.

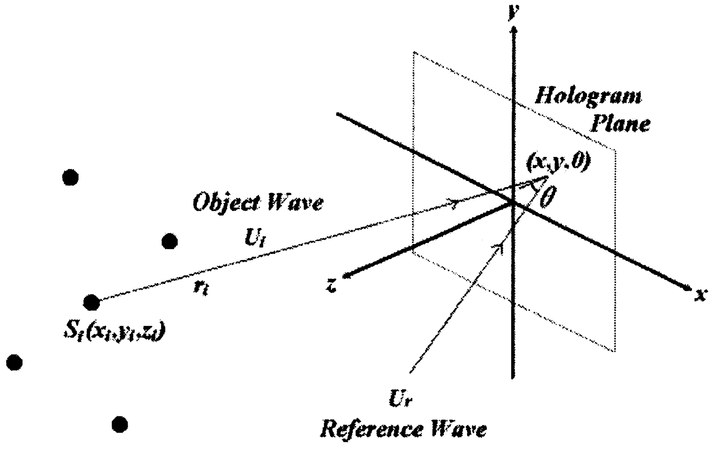

Fig.1. Co-ordinate system of hologram calculation

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$$U_i(x,y) = A_i \exp(ikr_i) / r_i,$$
$$U_r(x,y) = R \exp(ik_x \sin\theta),$$

where θ is the angle between the reference beam and z-axis. Other variables are used in the standard notation. The intensity distribution on the hologram plane is

$$I(x,y) = \left| \sum_i U_i + U_r \right|^2$$
$$= \left| \sum_i U_i \right|^2 + \left| U_r \right|^2 + (\sum_i U_i) U_r^* + (\sum_i U_i)^* U_r.$$

The first term, interference between the point sources was calculated to be negligible. The second term is independent of the light phase, so it is ignored. Then the intensity becomes

$$I(x,y) = 2 \sum_i A_i R \cos(kr_i - kx \sin\theta) / r_i$$

Assuming an in-line holography case ($\theta = 0$) and putting R = 1/2, we after all obtain the hologram pattern formula in the following form.

$$I(x,y) = \sum_i A_i \cos(kr_i) / r_i.$$

The computation is made by a personal computer (NEC PC-9821V200, Pentium 200 MHz CPU) using Visual C++. The hologram size is 26.4 mm × 16.5 mm with 640 × 400 pixels, therefore the pixel interval is 40 μm, which corresponds to the LCD dimension. The calculated result is in real number. It must be converted to integer number from 0 to 255 to be saved as a 256 level BMP file. When the conversion is made, contrast emphasizing is applied. The computation time is about 2 sec per a point.

In computation the sampling point is taken at the center of the CCD pixel. The hologram pattern of a single point light source is a Fresnel zone plate. In the region where its radius is large, many fringes gather densely in a single pixel, and the sampling becomes fault. Then many ghost patterns appear in that region. To avoid such ghosts, we make a maximum limit of the radius d_{max} of computation region. Where $d > d_{max}$ we put the intensity zero. By testing, we got the optimum value of $d_{max} = z \sin 0.4°$.

An example of the hologram pattern calculated in this way is shown in Fig. 2. The original object is three patterns arranged in different positions in z-axis. A circle with the radius of 9 mm is positioned at z = 700 mm, a triangle with a side of 12 mm is placed at z = 500 mm, and a square with a side of 8 mm is placed at z = 300 mm. The numbers of points are 28, 36 and 32 respectively.

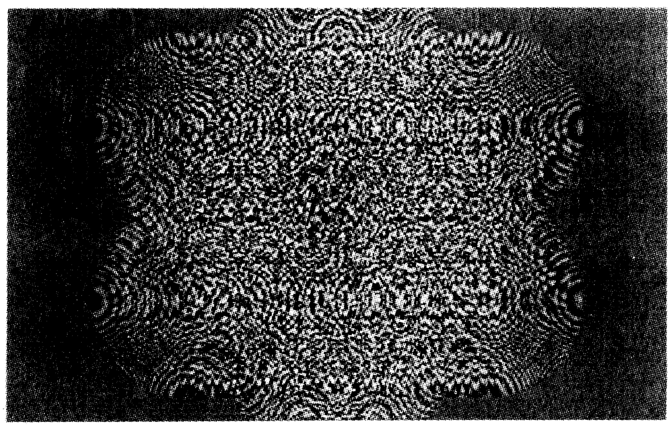


Fig.2. Calculated hologram of circle, triangle, and square in different position

The periphery region has no holography pattern, because such region is under the condition of $d > d_{max}$. This region has no holographical contribution, which is necessary to avoid the ghost images.

Holography System and Reconstructed images

Figure 3 shows the holography system using an 1.3 inch TFT-LCD, which is an element of an LCD projector (SONY : VPL-V500QJ). The LCD with a polarizer work as an amplitude hologram. The hologram pattern is displayed on the LCD using another computer (EPSON, PC-486AU). The beam from a He-Ne laser is expanded by an objective lens (×20) and a close-up lens (f_c = 330 mm). After the beam passes the LCD, many higher order images and a strong 0-th order light appear. To remove them a filter system consists of a couple of lens (f = 100 mm) and a filter at its focal plane is used. The filter is a 2 mm×2 mm square aperture on a black paper, which allows to pass only the first order image. A transparent film (Saran Wrap) is put on the aperture. A black point with 0.2 mm diameter is drawn at its center by a felt-tip pen to cut the 0-th order light. A screen is moved along z-axis. Because of the filter system, the z-coordinates of the screen shifts as $z' = (z + 4f)$, where f = 100 mm is the focal length of the filter lens. The real image on the screen is taken by a CCD camera and recorded by a image capture (SONY, MVC-FDR3). As for the true image, it cannot be observed because the laser light is strong.

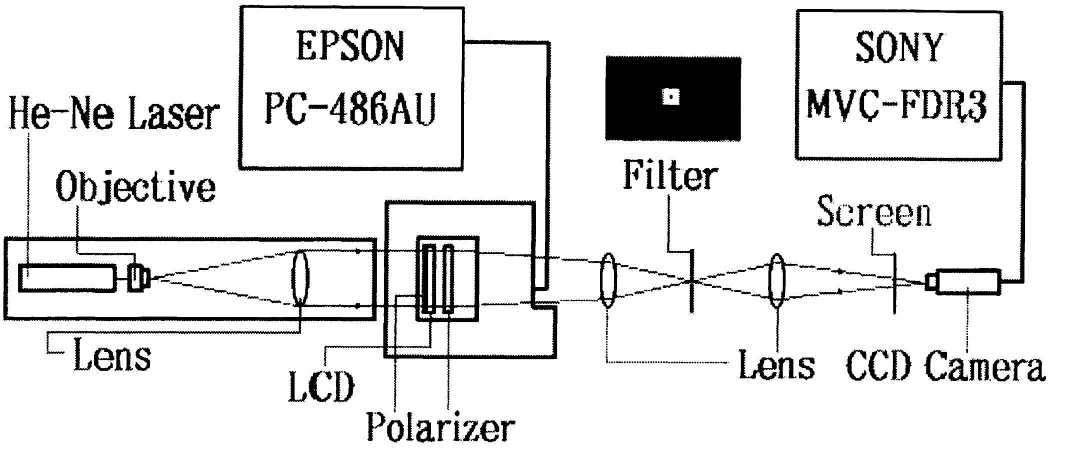
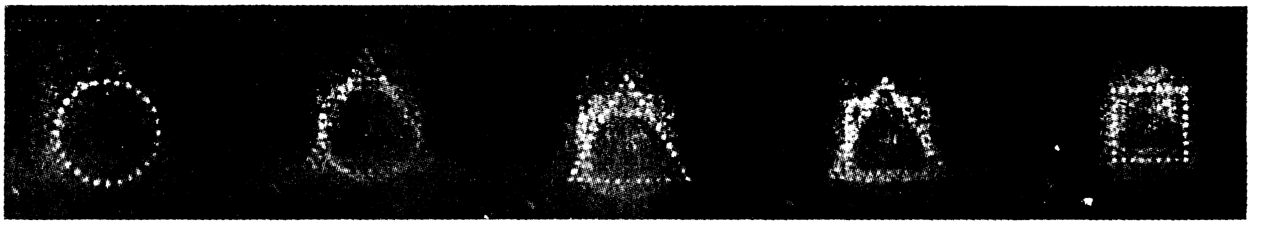


Fig.3.Holography system using LCD and filter system

Figure 4 shows the displayed image focused on the screen, which is moved from z' = 1100 mm to 700 mm, which corresponds to z = 700 mm to 300 mm. The image has no ghost images nor higher order images. The circle, the triangle, or the square is displayed at each correct position clearly. When the screen is moved to the intermediate position, each image becomes vague. It shows that each real image is reconstructed three dimensionally.



z=700mm z=600mm z=500mm z=400mm z=300mm

Fig.4 z-dependence of displayed patterns.

We also tested gray-scale images, but they could not be displayed clearly, so we do not show them.

Conclusion

In spite of the bad resolution of LCD, the images were clearly reconstructed by the hologram pattern displayed on the LCD. When the position of the screen is moved, each of three patterns appeared clearly at each position. It shows that the reconstruction was made three dimensionally.

References

1) K.Misumi, Y.Kashii, M.Mimura, *Mem. Fac. Eng. Osaka City Univ.* **40** (1999) 85.
2) T.Takemori, *HODIC Circular* **17** (1997) 13.