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Holographic Image Projection through Inhomogeneous Media

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This brief reports on an experimental test of a hologram technique that is capable of projecting undistorted images through inhomogeneous media. Coherent laser light and the hologram order that produces a conjugate image are used. The technique may be of interest in controlling wave transmission through inhomogeneous media for communication purposes, and it allows the scrambling or encrypting of texts, drawings, and similar messages for private communication.

In common holography there are two coherent waves incident upon the hologram or recording plate.[1] These are a signal wave S, originating from an object of interest, and a reference or background wave R. A recording is made of the intensity pattern

$$I = R.R^* + S.S^* + R.^*S + R.S^* \tag{1}$$

where R and S are the complex amplitude patterns of the two waves across the plate, and the asterisk denotes a complex conjugate. Illumination of the developed hologram produces waves of several orders. The order that corresponds to the third term in (1) reconstructs the original wavefront of S and produces a true image. The order corresponding to the last term in (1) produces a conjugate image. This latter hologram order is used in the present technique of image projection through inhomogeneous media.

The inhomogeneities of a lossless optical medium can be described by the spatial variation of the refractive index $n(\mathbf{r})$. For inhomogeneities of geometrical dimensions that are much greater than the wavelength the scalar wave equation

$$\nabla^2 u + k^2 n^2(\mathbf{r})\, u = 0 \tag{2}$$

is a good description of wave propagation in the medium.[2] Here $k = 2\pi/\lambda$ is the propagation constant in free space, and u is a vector component or potential of the wave field. A wave that propagates through the medium more or less in the z direction is represented by a solution of the form

$$u = S(\mathbf{r}) \cdot \exp(-j\beta z) \tag{3}$$

where S is a slowly varying (complex) function of $\mathbf{r}$. This solution of the wave equation (2) has a conjugate solution

$$u^* = S^*(\mathbf{r}) \cdot \exp(j\beta z) \tag{4}$$

which corresponds to a wave that travels in the opposite direction. The ray families associated with the two conjugate solutions have the same ray paths, which they follow in opposite directions. The intensity patterns $u.u^*$ of the two waves are the same.

An experiment was performed in which the wave S originating from an object was recorded on a hologram after it had passed through the inhomogenous medium. The return wave S^* was launched by means of the conjugate-image hologram order. In the original object plane the intensity pattern of the return wave reproduces the object, which was observed.

Fig. 1 shows the experimental arrangement. The object is a transparent text on an opaque background. In recording the hologram the object was diffusely illuminated by light from a 6328 Å gas laser. The

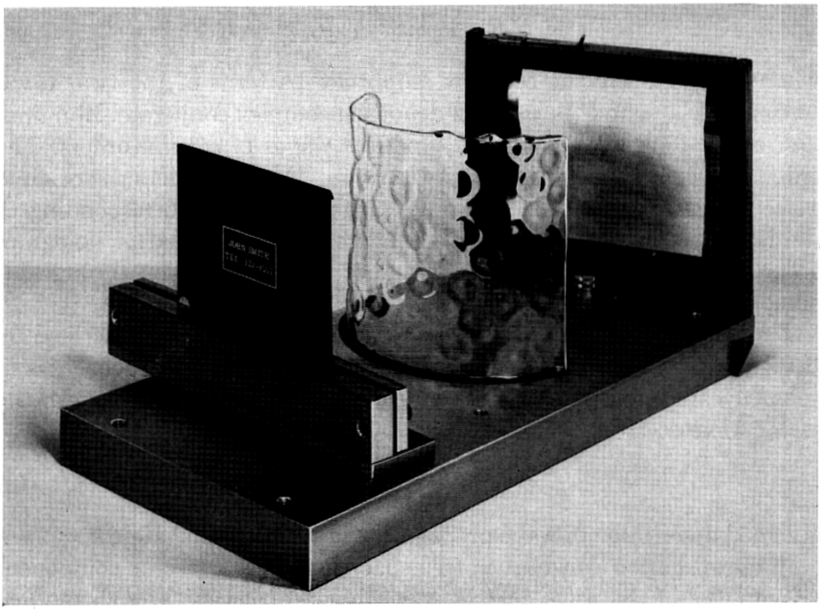

Fig. 1 — Experimental arrangement with transparent object text on the left, distorting warped glass in the middle, and hologram plate on the right.

light from the object passed through a warped glass plate which represents the inhomogeneous medium. The hologram was recorded on a Kodak 649-F spectroscopic plate in the presence of a coherent plane reference wave[3] incident at an angle of about 50 degrees of arc with respect to the rays from the object.

Fig. 2 gives an indication of the distortions introduced by the warped glass plate. It is a photograph of the object text taken through the glass plate.

In Fig. 3 the original object is reproduced on the left. The text is framed by a transparent rectangle which measures $\frac{3}{4}$ by $1\frac{1}{2}$ inches. A photograph of the intensity pattern of the return wave in the object plane is shown in the middle of the figure. For easier focusing, a diffusing plate was inserted in the object plane (in place of the object). The return wave was produced by illuminating the developed hologram with a plane beam of laser light antiparallel to the reference beam used in recording. Care must be taken to preserve the relative positions of the warped glass plate and the hologram plate, and the direction of the illuminating beam had to be adjusted with a tolerance of about ± 10 minutes of arc to achieve a good reconstruction of the object. The pattern produced in the

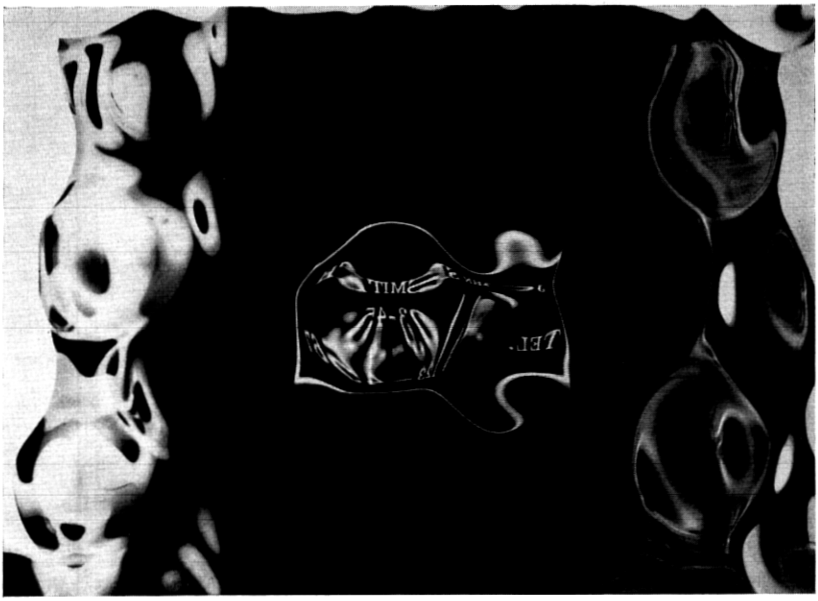

Fig. 2 — Object text photographed through warped glass plate.

(a) (b) (c)

Fig. 3 — (a) left — original text; (b) middle — reconstruction of text projected through warped glass; (c) right — scrambled reconstruction of text seen when warped glass is removed.

object plane when the same return wave is launched from the hologram with the warped glass plate removed is shown on the right in Fig. 3. The text is now scrambled and unreadable. It can be read only if the glass plate is reinserted in its original position.

REFERENCES

1. Gabor, D., Microscopy by Reconstructed Wavefronts, Proc. Roy. Soc., *A 197*, July, 1949, p. 454–487; Proc. Phys. Soc., *B 64*, June, 1951, p. 449–469.
2. Tatarski, V. I., *Wave Propagation in a Turbulent Medium,* McGraw-Hill Book Co., New York, 1961, p. 93.
3. Leith, E. N. and Upatnieks, J., Wavefront Reconstruction with Diffused Illumination and Three-Dimensional Objects, J. Opt. Soc. Am., *54*, November, 1964, p. 1295–1301.

Errata

In the October 1965 B.S.T.J., Fig. 21 on page 1600, the expression

$$P_R \simeq 8R \text{ for small } p$$

should read

$$P_R \simeq 8Rp \text{ for small } p.$$