COLLEGE OF ENGINEERING

REPORT # 137

College of Engr. Report # 137

Reprinted from

PHYSICS LETTERS

Volume 28A, number 3, 18 November 1968

A NEW CLASS OF OPTICAL IMAGING SYSTEMS ACHIEVING 'APERTURE SYNTHESIS' FROM NON-CONVENTIONAL OPTICS BY A POSTERIORI LENSLESS FOURIER-TRANSFORM HOLOGRAPHY *

G. W. STROKE
State University of New York, Stony Brook, New York 11790, *USA*

pp. 252–253

NORTH-HOLLAND PUBLISHING COMPANY
AMSTERDAM

A NEW CLASS OF OPTICAL IMAGING SYSTEMS ACHIEVING 'APERTURE SYNTHESIS' FROM NON-CONVENTIONAL OPTICS BY A POSTERIORI LENSLESS FOURIER-TRANSFORM HOLOGRAPHY *

G. W. STROKE
State University of New York, Stony Brook, New York 11790, *USA*

Received 15 October 1968

The difficulties of constructing adequately perfect conventional focusing systems for some applications (e.g., X-rays and ultrasonic imaging, space applications, etc.) may be solved by a posteriori holographic synthesis.

The well-known difficulties of constructing or even of conceiving adequately perfect *conventional* focusing systems, e.g., using mirrors and lenses, for some imaging problems (e.g., X-ray astronomy) have again been recently stressed [1,2]. For example, a solution has long been sought [1,2] which could somehow permit one to synthesize into one single image the multiplicity of incoherently recorded images formed by such *non-conventional* systems as an aperture pierced by a large number of randomly disposed 'pinholes' [1-4] and others [5, pp. 127-137]. Dicke [2] and Underwood [1] stressed that the required image 'synthesis' for the X-ray astronomy application could be readily achieved a posteriori, with coherent light, in an optical Fourier-transforming arrangement [5], provided that an 'appropriate phase- and amplitude-correcting plate' [2] could somehow be devised. We now show in a general way that such a 'correcting plate' for this and a family of comparable applications may in fact be best realized in the form of a lensless Fourier-transform hologram [6] and the desired image synthesis in an 'extended-source lensless Fourier-transform' holography arrangement [5,7]. Image 'deblurring' methods [7], at first sight formally comparable, have heretofore primarily implied 'sharpness' restoration in images imperfectly recorded with more or less 'perfect' *conventional* focusing systems, rather than being concerned with 'aperture respectively image-synthesis' of 'perfectly' recorded images, starting from suitable *non-conventional optics*, as we are here. Further analogies may be found in high-resolution X-ray crystallography [5] and radio-astronomy, among others.

Our experiments, described below, have fully born out the predicted perfection achievable with this new method of two-step imaging. Because of limitations of space, we give our theory together with the basic description of our results, used as a model for this and comparable situations. Further details will be given in ref. 4.

---

* Early aspects of this work were presented on 24 September 1968 by special invitation in Florence, at the International Commission for Optics Symposium on Applications of Coherent Light.

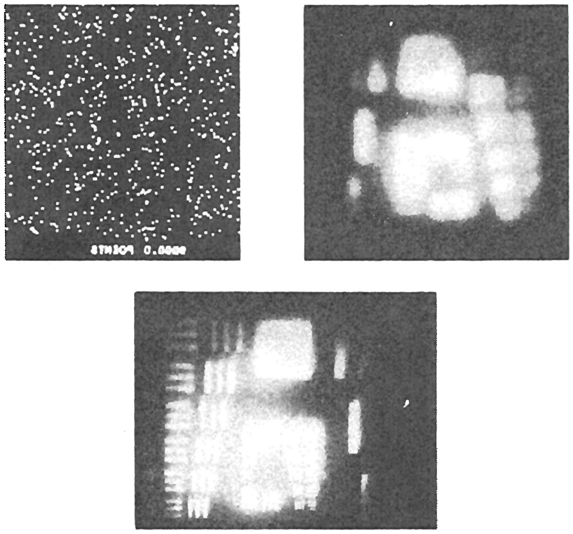

Fig. 1. A posteriori synthesis of a single image (c) from the multiple-image superposition (b) recorded with a random-array scatter-hole plate 'camera' (a) [see text]. [*Note* : (a) and (c) have been accidentally *printed* reversed with respect to (b)]. Further image improvement, to compensate for the finite 'pinhole' diameters may be achieved as in ref. 8.

Fig. 1a shows a 4×4 mm^2 enlarged section of the 17×17 mm^2 9 000 hole (0.046 mm diameter) array [3,4], having a geometrical 'projection' $h(x, y)$ in the image plane (when illuminated by a point source at infinity) and used to form the multiple images in incoherent light. Fig. 1b shows the image

$$g(x', y') = \iint_{-\infty}^{+\infty} f(x, y) h(x' - x, y' - y) \, \mathrm{d}x \mathrm{d}y = f \otimes h$$

of a test-bar target [geometrical image $= f(x, y)$, about 40×40 mm^2 outside] which would be obtained using the pinhole array in place of a good focusing system. Because of obvious optical diffraction disadvantages resulting from diffraction at optical in comparison to X-ray radiations, as used in the optical simulation with the small pinholes, the image fig. 1b shown was actually reconstructed with point-source illumination from the lensless Fourier-transform hologram 'equivalent' to [5]

$$I(u, v) = 1 + |\bar{G}|^2 + \bar{F}\bar{H} + \bar{F}^*\bar{H}^* ,$$

and obtained by using the multiple-pinhole array h as the 'extended' reference source $h(x, y)$ in place of the point source in recording the hologram of the 'desired' image $f(x, y)$. We have the Fourier-transform relations

$$\bar{G}(u, v) = \iint_{-\infty}^{+\infty} g(x, y) \exp[2\pi \mathrm{i} (ux + vy)] \, \mathrm{d}x \, \mathrm{d}y ,$$

and similarly for $\bar{H}$ and $\bar{F}$, using the usual normalization [5]. By the suitable choice of $h \star h^* = \iint_{-\infty}^{+\infty} h(x, y) h^* (x + x', y + y') \, \mathrm{d}x \, \mathrm{d}y \approx \delta$ (a delta function), illumination of the hologram with light from the point-spread function h (here the projection of the aperture) used as the reconstructing source, indeed permits us to synthesize a single very good image $f(x, y)$, as shown in fig. 1c, from the superposition (convolution) of the multiplicity of images of fig. 1b.

The author gratefully acknowledges the most fruitful comments of Professor D. Gabor, the kind experimental assistance of C. Puech, the generous assisting support of the National Aeronautics and Space Administration (Grant NGR-33-015-068) and the kind collaboration [4] of Dr. J. H. Underwood and Dr. R. B. Hoover, respectively in providing ref. 1 and 2, and the remarkable computer-generated random scatter-hole plate used.

References

1. J. H. Underwood, private communication to G. W. Stroke (July 1968), also in Science 159 (1968) 383.
2. R. H. Dicke, Astrophysical J. 153 (1968) L101.
3. R. B. Hoover, J. Opt. Soc. Am. 58 (1968) 721.
4. G. W. Stroke, J. H. Underwood and R. B. Hoover, being submitted to Astrophys. J.
5. G. W. Stroke, An introduction to coherent optics and holography (Academic Press, New York, 1966).
6. G. W. Stroke, Appl. Phys. Letters 6 (1965) 201.
7. G. W. Stroke, Phys. Letters 27A (1968) 407.
8. G. W. Stroke, G. Indebetouw and C. Puech, Phys. Letters 26A (1968) 443.

* * * * *