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OPTICAL APERTURE SYNTHESIS USING SUCCESSIVE EXPOSURE OF A SINGLE PHOTOGRAPH AND SPATIAL-FILTERING "LOW-FREQUENCY REDUNDANCY" SUPPRESSION

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A high-resolution "full spatial-frequency range" optical image may be synthesized by superposing in a single plate a suitable set of low-resolution partial frequency-range photographs, obtained separately or simultaneously, with "low-frequency redundancy" suppressed by spatial filtering.

There has arisen a considerable interest in an optical synthesis of a full spatial-frequency range, high-resolution photograph, I_{synth}, "equivalent" to that

$$I_{\mathrm{OC}}(x',y') = \iint O(x,y)\,h_{\mathrm{OC}}(x'-x,y'-y)\mathrm{d}x\,\mathrm{d}y = $$
$$= O(x,y) \circledast h_{\mathrm{OC}}(x,y)$$

which would have been obtained by a high-aperture (high ratio of aperture to focal length) optical system, in cases when only smal-aperture low-resolution optical systems are realizable or available. [$O(x,y)$: desired full-frequency range image; $h_{\mathrm{OC}}(x,y)$: the corresponding point-image "spread function" produced by the "complete" aperture.] The author recently proposed theoretically and verified experimentally [1] that the synthesis of the high-resolution image could be realized in optics, in incoherent light, by directly superposing in a single photographic plate the sum $\sum_n I_{0n}(x,y)$ of the component, partial frequency-range, low-resolution photographs, each produced by suitably chosen sets of small-aperture optics. The synthesized image is

$$I_{\mathrm{synth}} = \sum_n w_n[O \circledast h_{0n}] \ ,$$

where h_{0n} are the spread functions [2] of the component images. The "weighting" factors w_n may be readily realized, in part by exposure-time duration and suitable photographic processing, and, in part, by suitable spatial filtering of the component photographs, before (or during) superposition (for instance by partially attenuating their "low-frequency" region in the spatial Fourier-transform domain, e.g. as in fig. 8, page 102, ref. 2). In the original experiment [1], carried out as a model, we verified the new optical image-synthesis principle (also known as "optical aperture synthesis") with the aid of a "one-dimensional" varying frequency test chart. We have now successfully verified: 1) that two-dimensional image synthesis is readily achievable with available photographic methods [1], notably with "half-tone" scenes, 2) that the "low-frequency" "background" (redundancy) associated with each of the component photographs can be readily removed by spatial filtering, when necessary. The theoretical basis of our method was given in our ref. 1, together with its relation to the well-known radio-astronomical Sir Martin Ryle "aperture synthesis" method, using electronic computers [3], and with complete references [4]. Our new experimental results obtained as a model are shown in figs. 1 and 2. [The television half-tone test object was kindly supplied by Prof. D. Gabor and CBS Laboratories.] As in ref. 1, we simulated the exacting positioning requirements of the component aperture systems by placing suitable aperture "masks" in front of a large-aperture photographic lens. Complete theoretical and experimental details, and obvious extensions and applications, including astronomy, acoustical imaging and spectroscopy, will be given in our ref. 5.

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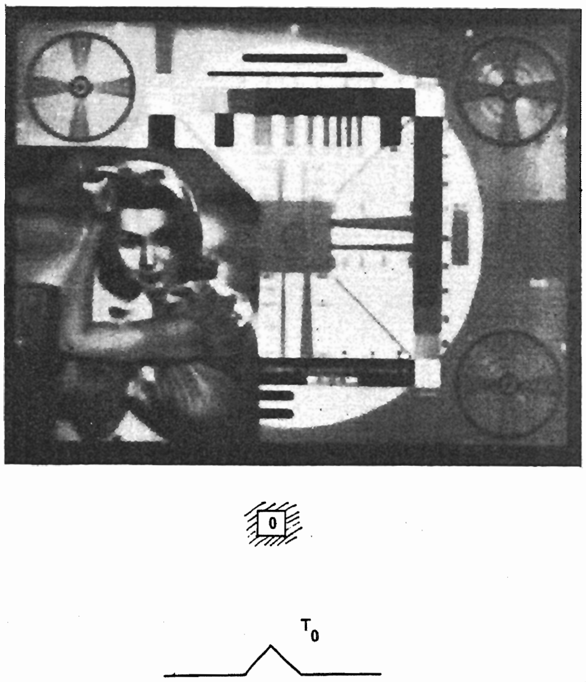

Fig. 1. Photograph of test object through component $[1 \times 1\ mm^2]$ aperture. The corresponding (MTF) "modulation transfer function" T_0 is equal to the auto-correlation function of the field produced by a monochromatic point source in the exit pupil of the aperture [1,2]. The image, about 13 mm wide, was obtained in ordinary incoherent light from the 90 mm wide object, using an $f = 240$ mm Schneider lens [1].

fruitful conversations, is also gratefully acknowledged, as is the partial support from the National Aeronautics and Space Administration and the National Science Foundation.

References

1. G. W. Stroke, Optics Commun. 1 (1969), to be published.
2. G. W. Stroke, An introduction to coherent optics and holography. Second ed. (Academic Press, New York, 1969).
3. M. Ryle, A. Hewish and J. R. Sheakeshaft, IRE Trans. Antennas Propag. 7 (1959) Suppl. p. 120.
4. Synthetic-aperture optics, Proc. of the Aug. 1967 Woods Hole Summer study, Vol. I and II (U.S. National Acad. Sciences, Washington, D.C., 1968).
5. G. W. Stroke and M. Halioua, Optica Acta (in preparation).

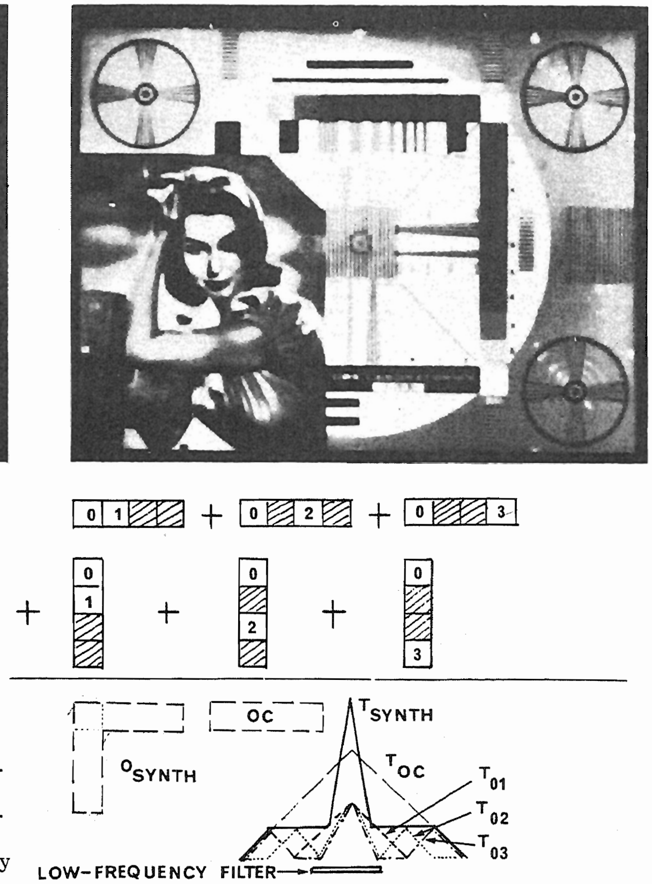

Fig. 2. Synthesized image obtained by exposing a single photographic plate successively through the sets of pairs of component apertures, [0+1, 0+2, 0+3] horizontal + [0+1, 0+2, 0+3] vertical, such that *not one* of the small apertures was larger than that used to obtain the "low-resolution" photograph of fig. 1' The MTF functions T_{01}, etc. shown correspond to the horizontal components. The "low-frequency filter" (shown schematically in position in the spatial frequency domain [1,2]) was not needed in the synthesis shown. In practice, the component photographs may be taken simultaneously (or successively) by separate, suitably pre-set component systems. The synthesized aperture O_{synth} (sufficient in this case for illustration of the new principle with the horizontal and vertical bars in the test chart) and the aperture OC are shown for comparison, and the MTF functions are drawn separated for clarity.

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