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G. W. STROKE

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A NEW HOLOGRAPHIC METHOD FOR A POSTERIORI IMAGE-DEBLURRING RESTORATION OF ORDINARY PHOTOGRAPHS USING "EXTENDED-SOURCE" LENSLESS FOURIER-TRANSFORM HOLOGRAPHY COMPENSATION

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

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By using the image of the blurred instrumental spread function in place of the recording point source to illuminate the lensless Fourier-transform hologram of a blurred ordinary incoherent-light photograph, one extracts a greatly enhanced sharpened image.

There has appeared an increasing new interest in the possibilities of "optical computing" image restoration methods [1-5] (for complete references see e.g. ref. 5), notably in view of their very considerably greater speed, compared to digital-computer Fourier-transform processing [6]. Previously described "optical computing" methods [1-5] notably those using holography [2-5] made use a Fourier-transform division, in the spatial frequency domain, which, under ideal conditions, results in perfect deconvolution, notably for such spatial frequency transfer functions [8] which can be made to have no zeros.

The new method which we describe here makes direct use of $h(x,y)$, the "blurred" image of a point in object space (i.e. the "spread function"), to extract the de-blurred image directly from a simply-obtained lensless Fourier-transform hologram [9] of the blurred transparency.

Fig. 1 b shows a sharpened image $f(x,y)$ which we have thus obtained, using the new method, by a posteriori holographic image-restorting compensation from the out-of-focus photograph $g(x,y) = f(x,y) \otimes h(x,y)$, where $\otimes$ indicates a spatial convolution. The original out-of-focus photograph, reproduced in fig. 1 a, was a NASA $55 \times 55\ \mathrm{mm}^2$ photograph, taken on the U.S. Satellite Gemini XII flights by Astronauts Lovell and Aldrin, with a Hasselblad camera, using a 90°-field ($f = 38$ mm) Zeiss Biogon lens, accidentally out-of-focus (unlike the other most beautiful photos from that flight). The aim of this work, upon the kind initiative of H. A. Tiedemann of the NASA Manned Spacecraft Center in Houston, was to devise some scheme to extract the valuable significant small geological units (e.g. mountain hogbacks), as we have, from the blurred photos, where they had appeared irretrievably lost to normal observation, before restoration!

The principle of the method used for holographic image restoration may be described in simple terms. We first record a "lensless Fourier-transform" hologram [9] of the blurred transparency photograph $g(x,y)$, using a point-source reference, to obtain the hologram $I = 1 + |\overline{G}|^2 + \overline{G} + \overline{G}^*$, which may be written as $I = 1 + |\overline{G}|^2 + \overline{F}\overline{H} + \overline{F}^*\overline{H}^*$, where $\overline{G}$, $\overline{F}$ and $\overline{H}$ are the spatial Fourier transforms of g, f and h [8]. By now replacing the hologram into its recording position, and by illuminating it with light from the spread function h (e.g. as recorded on a photographic transparency), the imaging wave $\overline{F}^*\overline{H}^*\overline{H}$ transmitted through the hologram immediately gives by Fourier transformation (i.e. in the focal plane of a lens following the hologram) the restored image f [8, pp. 127-137]. The restoration is "perfect" to the extent that $\overline{H}\overline{H}^* = 1$, i.e. $h \times h^* =$ "delta function", where $\times$ indicates a spatial correlation, noting that the Fourier transform of $\overline{F}^*\overline{H}^*\overline{H}$ is $f^* \times (h \times h^*)$. In the example shown, the spread function h had a pentagonal shape with 0.2 mm maximum dimension. The image sharpening obtained here may be considered as due to the change of an approximately rectangular function to the corresponding triangular function obtained by auto-correlation. Clearly the new method may be used in conjunction with previous methods, when appropriate.

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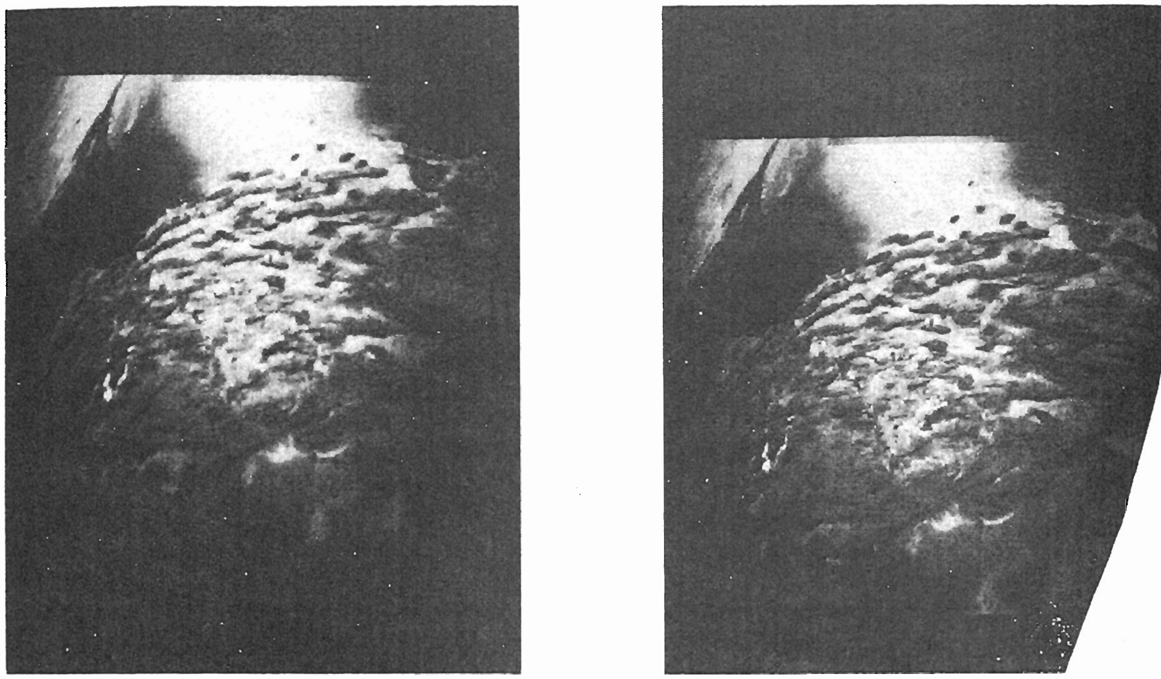

Fig. 1. a. Blurred out-of-focus NASA photograph from Gemini XII satellite. b. Sharpened photograph, using meth described in text. [For faithful comparison, the blurred photograph is reproduced using point-source illumination hologram of original photograph in place of spread-function illumination, used for compensation.]

perimental results is acknowledged with much gratitude, as is the generous assistance of the National Aeronautics and Space Administration under Grant NGR-33-015-068 in support of this work.

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