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A NEW HOLOGRAPHIC IMAGE DEBLURRING METHOD

G. W. STROKE and M. HALIOUA
State University of New York, Stony Brook, N.Y. 11790, *USA*

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A hologram of a deblurred image is obtained in a single step from a blurred photograph by recording through a tranparency transmitting: [amplitude of Fourier transform of spread function]$^{-1}$, using blurred photo and spread function as object and reference.

Optical image deblurring may be used to extract greatly sharpened "deblurred" images from imperfect photographs, "blurred" by imperfect focus, motion, atmospheric turbulence and image-system imperfactions, among other causes. Methods using the holographic Fourier-transform division filter of Stroke and Zech [1] have proven to be equally successful in the spatial-frequency [2-4] and in the spatial (laser scanning) model [5]. In contract with electronic computer methods, the deblurring filter $1/H$ is generated directly from the experimental point-spread function $h(x,y)$, in the form of a two-component "sandwich", so far realized in the form H^*/HH^*, consisting of a hologram and a transparency, transmitting respectively H^* and $1/HH^*$, with $H(u,v) = \iint h(u,y) \exp[2\pi i(ux+vy)] dx\ dy$ according to [1]. Two key photographic parameters determine the successful realization of the filter. One is the appropriate use of the relation $|E_T| = I^{-\gamma/2}$ between the exposure I and the electric field amplitude $|E_T|$ transmitted through a transparency upon unit-amplitude illumination, with γ-slope of the H-D curve. The other is the linear recording over an adequately large dynamic range, which may be realized using suitable "masking" [3]. for the case when the hologram $H^* = |H| \exp[-i\varphi_H]$ is realized in the form $\exp[-i\varphi_H]$, The amplitude component $1/|H|$ of the filter may be obtained from the photographic exposure $1/|H|^2$ by using $\gamma = 1$. This has now permitted us to record a considerably larger dynamic range than in our previous scheme using $\gamma = 2$ [3]. Our new experimental verifications are shown in fig. 1b and in fig. 2, where the ideal condition was simulated by using a reference beam with an amplitude approximately equal to the mean $|H|$ amplitude.

Our new method also uses the $1/|H|$ transparency (fig. 1d), however not any more for the recording of a spatial-frequency filter, but rather for the recording of an image-forming hologram, which may be directly used to produce the de-

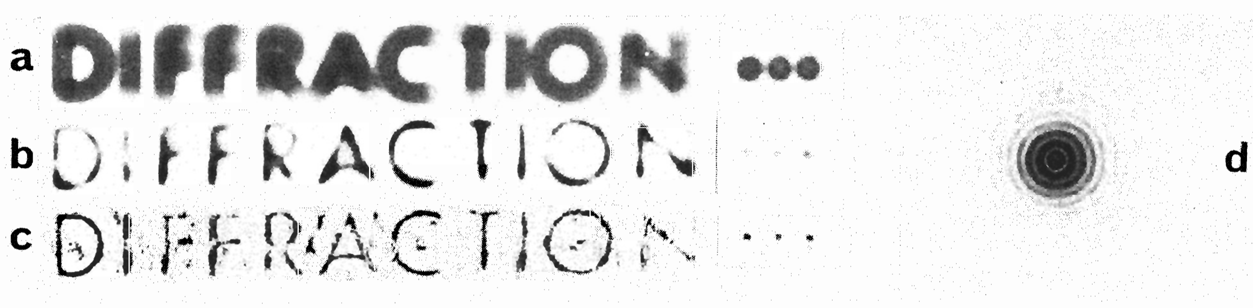

Fig. 1. a. Deliberately blurred out-of-focus photo. Three spread functions $h(x,y)$ shown on right (blurr circle diameter = 1 mm, with f = 240 mm lens). b. Deblurred photo extracted from fig. 1a using the holographic Fourier-transform division method according to refs. [1] and [3]. Deblurred images of spread functions are on right. c. Deblurred photo extracted from fig. 1a using new "deblurred-image hologram" method of text. d. Photo of $1/|H|$ amplitude-weighting transparency used for recording of "deblurred-image hologram", from which the sharp image of fig. 1c was reconstructed by simple plane-wave illumination.

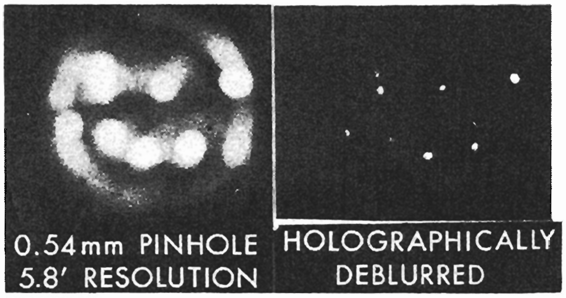

Fig. 2. Deblurring of large-pinhole (0.54 mm diameter at 400 mm from plate) x-ray photo of Sun, using method of refs. [1] and [3], to increase signal-to-noise ratio, compared to small-pinhole image. The pinhole-camera photo on left was obtained in the 44–70Å range on May 20, 1968 from an Aerobee rocket by K. Fredga, W. S. Muney and J. H. Underwood, and deblurred during the summer 1969 by us at Stony Brook.

blurred image $f(x, y)$ with simple plane-wave illumination. Indeed, by using the blurred transparency $g(x', y') = \iint f(x, y)h(x'-x, y'-y)\mathrm{d}x\, \mathrm{d}y$ as the "object" and the spread function $h(x, y)$ as the "reference" in a Fourier-transform hologram recording arrangement, and by recording the hologram through the $1/|H|$ transparency (fig. 1d) placed right in front of it, the wave illuminating the hologram is $(G+H)/|H|$, and the corresponding image-forming term $GH^*/|H|^2 = FHH^*/|H|^2 = F(u, v)$, from which the deblurred image $f(x, y)$ is obtained directly by Fourier transformation. Experimental verification is shown in fig. 1, where fig. 1c was thus extracted from the "deblurred-image" hologram recorded with a transparency of fig. 1a as the "object" and a transparency of the blurred point (spread function) such as one of those shown in fig. 1a next to the word "DIFFRACTION", used as "reference". Even though our new method appears to display more residual "interference" noise in this early test, than our well-refined Fourier-transform division method, we also note that the "deblurred-image hologram" produces a considerably sharper and more faithful deblurring. Other advantage, theory and noise considerations will be discussed in future publications. It may be of interest to note that our new method may be considered as providing a generalization for our for our method of ref. [6], for the cases where the auto-correlation function of $h(x, y)$ is not any more necessarily sharply peaked.

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