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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 referen-
ces 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" meth-
ods [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 func-
tions [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 func-
tion"), to extract the de-blurred image directly
from a simply-obtained lensless Fourier-trans-

Fig. 1 b shows a sharpened image \( f(x, y) \) which
we have thus obtained, using the new method, by
a posteriori holographic image-restoring com-
ensation 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 x 55 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 (\( f=36\text{mm} \)) Zeiss Biogon lens, acciden-
tally 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 holo-
graphic 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 \( I = 1 +
|G|^2 + G + G^* \), which may be written as \( I =
1 + |C|^2 + F H + F^* H^* \), where \( C, F \) and \( H \) 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
\( F^* H H \) transmitted through the hologram imme-
diately 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 rest-
oration is "perfect" to the extent that \( H H = 1 \),
i.e. \( h \times h^* = \) "delta function", where \( \times \) indicates
a spatial correlation, noting that the Fourier
transform of \( F^* H H \) is \( f \times (h \times h^*) \). In the ex-
ample shown, the spread function \( h \) had a penta-
gonal shape with 0.2 mm maximum dimension.
The image sharpening obtained here may be con-
sidered as due to the change of an approximately
rectangular function to the corresponding trian-
gular function obtained by auto-correlation.
Clearly the new method may be used in conjunc-
tion with previous methods, when appropriate.

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