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LASER-LIGHT SPATIAL-DOMAIN SCANNING DECONVOLUTION OF BLURRED PHOTOGRAPHS USING THE GENERAL HOLOGRAPHIC DEBLURRING FILTER

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Spatial-domain (scanning) deconvolution of blurred photographs may be realized in laser light using the experimental point-spread function with the aid of the 1967 Stroke and Zech holographic Fourier-transform division filter

Recent experiments have shown that direct incoherent-light deconvolution may be used to 'deblurr' photographs in the spatial (x,y) domain in some special cases (e.g. imperfect focus, motion blurring) [1-3]. The required scanning function $s(x,y)$ used to illuminate the blurred photograph

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

for the special cases was generated either by photomechanical means [1,3] or by suitable masking of a lens [2]. The scanning 'deblurring' function $s(x,y)$ was noted to be all real, without a formal mathematical proof for the general case. Two orthogonally polorized beams were used to generate respectively the positive and negative parts of the all-real function $s(x,y)$ in the two comparable arrangements [2,3], with $h(x, y)$ being the point spread function and $f(x,y)$ the desired "diffraction-limited" image as usual [4]. Heretofore the required scanning function $s(x,y)$ was generated by Fourier-transform or comparable computation.

In view of the great simplicity which scanning spatial-domain deconvolution arrangements (using suitable scanning and photo-electric components) may present, as compared to alternate methods, it appeared essential to us: 1) to show that the scanning function $s(x,y)$ used for 'deconvolution' of the blurred photograph, according to the equation $s \otimes g = s \otimes f \otimes h$, is always a *real* function, having the property $s \otimes h \approx \delta$-function, i.e. $SH \approx 1$, where S and H are the Fourier transforms of s and h, and 2) to show that the scanning function $s(x,y)$ may be readily generated (realized) in the general case directly from the experimental point-spread function $h(x, y)$.

We find that the holographic Fourier-transform division filter-generating method described by Stroke and Zech in 1967 [5,6] happens to be ideally suited to generate the desired scanning function $s(x, y)$ by Fourier transformation from the Fourier-transform division filter $1/H = H^*/|H|^2$, in as much as $s = T[1/H]$, where

$$T[\dots] = \iint_{-\infty}^{+\infty} [\dots] \exp[2\pi \mathrm{i}(ux + vy)] \, \mathrm{d}x \, \mathrm{d}y$$

is the usual spatial Fourier transformation, and $H = T[h]$.

First we show that the spatial-domain deblurring scanning function $s(x, y)$ used to scan the blurred photograph $g = f \otimes h$ in incoherent light is necessarily a *real* function in the general case. Indeed, since $h(x, y)$ is real (i.e. an intensity distribution) its Fourier transform $H = T[h]$ is hermitian, i.e. $H(u, v)^* = H(-u, -v)$. It follows that $[1/H(u, v)]^* = [1/H(-u, -v)$ and therefore, since $S(u, v) = T[s(x, y)]$, we also have $S^*(u, v) = S(-u, -v)$. Accordingly, the deblurring scanning function $s(x, y) = T[S(u, v)] = T[S(u, v)] = T[1/H]$ is *real*! However, it will in general be partly negative, so that this conclusion is of limited interest in view of practical implementations, in the general case.

In further thinking about general ways of realizing the positive and negative parts of the scanning function, it suddenly became clear to us that there was in fact no need to separately realize the two parts, as appeared necessary according to the previous methods, using incoherent light. Rather, by shining a collimated beam of laser light through the $1/H$ filter "sandwich" of Stroke and Zech [5], the scanning function $s(x, y)$ is directly generated as an aerial image in the focal plane of the lens following the filter [4]. By scanning the blurred image $g = f \otimes h$ in front of s in one of the suitable scanning arrangements [3,7], the amplitude of the electric field transmitted through the photograph is equal to the desired convolution $f \otimes h \otimes s \approx f$, with the condition $h \otimes s = \delta$-function. The deblurred image is generated by scanning, and recorded either by "contact printing", reimaging or via photoelectric devices. The final photograph is thus equal to f, using well-known photographic precautions [6]. It is essential to note that the imaging part of the process is spatially *incoherent*, while using the advantages of intense laser light. Accordingly, the method circumvents the considerable imaging imperfections "coherent phase noise" which characterize the imaging part in conventional (non-scanning) coherent image-filtering systems. Correspondingly, the general holographic Fourier-transform division filter [5] thus turns out to be not only the key to the laser-scanning image-deconvolution method, but it also may be used in a more perfect way than in the holographic image deblurring methods [5,6] for which it was created in the first place. The results of experimental verification of the proposed method will be reported in a future publication. Extensions to general "spatial filtering" applications are obvious.

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