ANALOG IMAGE PROCESSING IN TWO DIMENSIONS BY OMNIDIRECTIONAL SCANNING

In their article Nahara, et al (*1*) give entirely too much credit to me and not enough to others in discussing scanning rasters for two-dimensional image manipulation.

The reference in my original article (*2*) indicated that the most detailed and now classical treatment of this subject was given by L. S. G. Kovasznay and H. M. Joseph in 1955 (*3*). These two investigators show that two-dimensional isotropic scans "can be performed in several ways":

1. The central portion of a Lissajous figure formed by two sine waves may be employed. However, the requirements are approximately satisfied over only a small central portion.
2. An interlacing raster of curves such as cycloids or spirals.
3. A conventional television scan rotated 90 deg after each frame is completed.
4. Symmetrical triangular waves of slightly different frequencies for horizontal and vertical deflections. The resulting Lissajous figure consists of straight lines and, if operated slowly, has the appearance of a slowly varying rectangle.

The authors have obviously rediscovered Method 4 while what they call "Gregg's method" is really Method 3. At the time my paper was presented, I emphasized a slight variation of Method 3 because of its potential for producing apparent live-time manipulations utilizing short-time integration by the eye. On the other hand, Methods 1 and 4 as used to date have required long-time (photographic) integration to produce a usable image. In spite of the authors' criticisms concerning the lack of raster rotation in "Gregg's method", Method 3 will still produce an isotropic scan. In fact, all methods previously discussed should give the same results if performed properly.

In their original paper, Kovasznay and Joseph also showed images processed by Method 4 while R. W. Brainard and G. N. Ornstein reported on Method 1 in 1965 (*4*). Method 1 is also the raster used in the commercial Logetronic system.

Regardless of the lack of proper credits, the authors are to be congratulated for presenting a well-detailed working analog system for rescanning of scintiscans. It is most interesting that they also confirm the necessity of a fair amount of initial smoothing (spatial averaging or blurring) prior to image manipulation presumably because of the low signal-to-noise levels in the original data. Comments by the authors as to the amount of blurring necessary to subsequently deblur would have been most welcome.

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THE AUTHORS' REPLY

We appreciate the remarks concerning the author's credits for the related works. We regret that we have omitted Kovasznay and Joseph's paper (*3*) from our references due to the simple reason that Dr. Gregg introduced their classical work quite well in the process of scintigraphic images.

The second point of Dr. Gregg's comments is concerned with his statement that the two-dimensional isotropic scan can be performed by their methods, for instance, the Method 3 in his comments, without raster rotation. We do not feel it is reasonable, however, to make the statement without clarifying the assumption on which the statement is based since the Method 3 is "isotropic" only for a special type of processing, as described precisely in the original paper (*3*).

According to the paper, letting f(x,y) and F(x,y) be the original and the processed image, respectively, they assumed that the resultant image F depends only on the behavior of f in the infinitesimal neighborhood of point (x,y). Then an isotropic operation is expressed by

$$F(x,y) = Af(x,y) + B\nabla^2 f(x,y) + C\nabla^4 f(x,y) + \cdots \quad (1)$$

where

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}.$$

Restricting further their attention to the case where only the first two terms of Eq. 1 are kept, they stated that the isotropic operation is realized by averaging scan data in four directions along two orthogonal axes. Under these assumptions their process will be isotropic.

Our concern is, however, with a more sophisticated two-dimensional process to meet requirements in the recent progress on scintigraphic image processing. The generalized linear and shift-invariant process is expressed by

$$F(x,y) = f(x,y) * g(x,y) \quad (2)$$

where $g(x,y)$ is the certain filter function and the symbol * denotes the two-dimensional convolution operation. When $g(x,y)$ is circularly symmetric, i.e., $g(x,y) = g'(\sqrt{x^2 + y^2}) = g'(r)$, the process should be called "isotropic" in our sense. The isotropic process in our sense is realized by the omnidirectional scan but not by the four-directional scan without rotation.

We believe that omnidirectional scanning is particularly important for the process of scintigraphic image because the images are generally associated with statistical noise, the spatial frequency of which extends to a much higher frequency region than that of the signal, and accordingly a derivative or Laplacian operation is not practical due to excess enhancement of noise. Even in the case where F can be determined from f in a small region around point (x,y) in the process such as smoothing or deblurring (resolution enhancement), omnidirectional scanning will yield a better signal-to-noise ratio in the obtained image due to the averaging effect for noise in all directions.

As to the last comment on the amount of smoothing in "deblurring operation," we should like to record the following. Suitable filter response for deblurring, including smoothing, has been discussed by several authors and summarized by Kirch and Brown (*5*). The typical response has a peak at a suitable frequency with sharp cutoff at the high-frequency side. Such a response can be approximately realized by, in our system, the combination of a high-frequency enhancer (electronic filter) and a low-pass filter (defocusing the beam of the flying spot tube) having sufficiently sharper cutoff characteristics than the response of the enhancer. The cutoff frequency of the low-pass filter has to be appropriately higher than the turnover frequency of the enhancer. Adjustment of the overall response is made both by tuning the turnover frequency and gain of the electronic enhancer and by suitable defocusing of the beam such as looking at the processed image on a cathode-ray tube.

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REPLACEMENT FOR ^{131}I ROSE BENGAL. IS IT REALLY?

The July 1974 issue of the *Journal of Nuclear Medicine* carried an article by Lin and associates (*1*) entitled "A ^{99m}Tc-labeled replacement for ^{131}I-rose bengal in liver and biliary tract studies." Their data are presented in three figures. The first figure shows ^{131}I-rose bengal and ^{99m}Tc-labeled mercaptoisobutyric acid-stannous chloride complex (Hepatobiliary Scintigraphin) blood clearance in one dog. The second shows the body tissue distribution of ^{99m}Tc-mercaptoisobutyric acid-stannous chloride complex in rats. The third shows scintigraphy of the liver and gallbladder in a dog. The authors do not list any references. The article appears to give the reader the impression that ^{99m}Tc-mercaptoisobutyric acid-stannous chloride complex is the first ^{99m}Tc-labeled compound that is concentrated by the liver and gall-