ANALOG IMAGE PROCESSING IN TWO DIMENSIONS BY OMNIDIRECTIONAL SCANNING

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A new method of two-dimensional image processing by analog techniques is introduced. The original image stored on a film is rescanned by a flying spot scanner with a special raster, so-called omnidirectional scanning, by which the film is scanned in any direction with constant speed and with uniform scan-line density. The extracted image information is fed through an electronic filter to a display CRT. The asymmetric impulse response of the filter can be canceled out by superposition of video signals in all directions on the screen of the CRT. Therefore two-dimensional image processing can be accomplished with the one-dimensional filter. The preliminary processor was constructed and tested for phantom images obtained with a scintillation camera.

The quality of images obtained by scintigraphic devices is limited because of poor statistics and the finite resolving power of the devices and collimators. Thus processing of the image data such as smoothing, image enhancement, etc., might improve information transfer to the human viewer. Digital computers are generally adopted to aid in the display and manipulation of scintigrams. The most prominent feature of digital computer techniques is its flexibility. One can easily modify the method of data processing by simple modification of the programs and can select a multitude of display modes. Numerical interpretation of the data is also feasible.

Several groups have studied techniques other than digital computer techniques. Hall and Massey (*1*) adopted an optical method and Stroke, et al (*2*) adopted a holographic technique. Gregg (*3*) investigated an analog computer, which has several advantages over digital computer techniques for routine use. The image data can be processed quite rapidly, e.g., in the time comparable to one TV frame time, i.e., about 1/30 sec. With Gregg's method, information from scintigraphic devices is stored in a photographic film, the film is rescanned by a flying spot scanner, and the extracted information is routed to an analog computer and then fed to appropriate display devices.

The major difficulties encountered in analog processing based on scanning arise because the scanning is inherently one-dimensional so that the information perpendicular to the scan line is not extracted and because the impulse response of any electronic filter is asymmetric with respect to time origin. It has been reported that in the one-dimensional case it is feasible to symmetrize in effect the impulse response of the filter by means of a technique called "bidirectional processing" (*4*) in which the image information from a scintillation scanner is first recorded on magnetic recording tape and then the recorded data are processed in back-and-forth directions. This method may be suitable for processing the data obtained from scintillation scanners but is not applicable to data from scintillation cameras.

Gregg (*3*) suggested a scanning raster where each point is scanned in four directions along two orthogonal axes which enables symmetric processing along two axes. However, this raster does not scan each point in all directions so that two-dimensional response of the filter will not be isotropic. If rotation is applied to this raster, each point will be scanned in all directions so that the data processing can be accomplished isotropically.

This article describes a new analog processing method with so-called omnidirectional scanning

Received Oct. 2, 1973; revision accepted April 18, 1974.

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which enables isotropic scanning where the resultant two-dimensional point response of the electronic processor is axially symmetric.

If two triangular signals of different repetition frequencies are applied to the x and y deflection electrodes of a rescanning device, say, a flying spot scanner, the resultant trace of the beam spot forms an asynchronous Lissajous-like pattern. It uniformly covers the entire area of the rectangle as schematically shown in Fig. 1, provided that the repetition frequency of one triangular signal is slightly different from that of the other, the ratio of which is not a simple rational number. Thus in the course of time any point in the rectangle will be scanned back and forth along two axes, which are slanted by an angle of $\Pi/4$ rads with respect to the x or y axis. The merits of this raster of the asynchronous Lissajous are that the fly-back of the spot is not necessary and that the number of scan lines is infinite in principle if the ratio of the two frequencies is an irrational number.

This Lissajous-like raster is rotated at a constant angular velocity as shown in Fig. 1. The angular frequency of the rotation is much lower than the repetition frequencies of the triangular waves so that the angle of rotation can be regarded as constant during the periods of triangular waves and each scan line can be regarded as nearly straight. This forms a remarkable contrast to the conventional TV scanning or Gregg's method.

Let $X_0(t)$ and $Y_0(t)$ denote the triangular wave signals and let $X(t)$ and $Y(t)$ denote the rotated signals of $X_0(t)$ and $Y_0(t)$, respectively. Then $X(t)$ and $Y(t)$ can be expressed as

$$\begin{aligned} X(t) &= X_0(t)\cos\phi t - Y_0(t)\sin\phi t \\ Y(t) &= X_0(t)\cos\phi t + Y_0(t)\sin\phi t \end{aligned} \quad (1)$$

where t and ϕ are the time and the angular velocity of the rotation, respectively. Equation 1 involves multiplication of two time-dependent variables, that is, the triangular wave and the sinusoidal wave, which is generally very difficult to realize with electronic circuits. The product of the sinusoidal wave and the rectangular wave, the derivative of the triangular wave, was first produced with the help of analog switches, and the obtained signal was integrated by use of an operational amplifier to yield the signal expressed by Eq. 1.

With this scanning technique, any point within the circle inscribed in the rectangle can be uniformly scanned rectilinearly and isotropically in the course of a rotation. The resultant image processed by this scanning is equivalent to that processed with a two-dimensional filter the point response of which has axial symmetry.

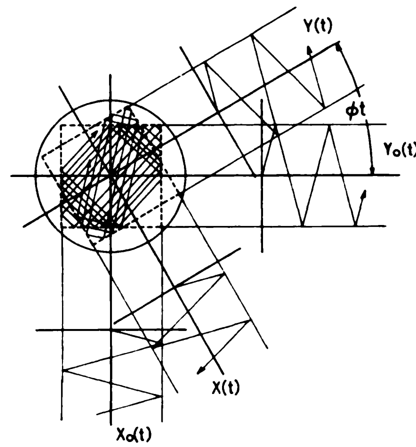

FIG. 1. Schematic diagram of asynchronous Lissajous-like raster driven by two triangular waves $X_0(t)$ and $Y_0(t)$, and raster driven by $X(t)$ and $Y(t)$, which is rotated by angle ϕt with respect to former.

The point response is expressed as

$$f(r) = h(r)/r \quad (2)$$

where r is the distance from the point in the image and h(r) the impulse response of the electronic filter because each point in the image is scanned in all directions and the scan-line density is inversely proportional to r.

The Fourier transform of Eq. 2 is also expressed as

$$\begin{aligned} F(\omega) &= \frac{1}{2\Pi}\int_0^\infty r dr \int_0^{2\pi} f(r) e^{i\omega r\cos\theta} d\theta \\ &= \int_0^\infty h(r) J_0(\omega r) dr \end{aligned} \quad (3)$$

where ω is the radial component in frequency domain, θ the angle, and J_0 the zero-order Bessel function of the first kind. These equations may be helpful in theoretical considerations and design of the electronic filters.

APPARATUS

To realize the principle described, a flying spot scanner was used for the image processing with the omnidirectional scanning (Fig. 2). It consists of a flying spot tube, two optical lens systems and film holders, two photomultipliers, an electronic processor including an electronic filter, a display CRT, and a raster generator. An original radioisotope image stored on a 35-mm standard film is set in the film holder. A 5CN-P16 tube (Toshiba Electric Co. Ltd.) was adopted as the flying spot tube because of its high spatial resolution (100 lines/cm at the center of the screen) and because of its short fluorescent decay time (0.12 μsec from peak to 10% of the peak intensity). The nominal nonuniformity of the tube is less than 5% over the entire surface of the screen (127 mm in diameter). The beam spot of the

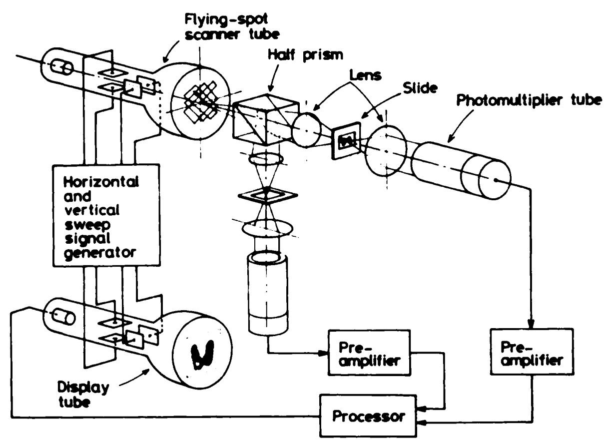

FIG. 2. Schematic diagram of analog image processing system with omnidirectional scanning.

tube is deflected in the way described before. The repetition frequencies of two triangular waves are about 5 kHz and rotation frequency is about 5 Hz.

Fluorescent light emitted from the beam spot is focused onto the film. The light transmitted through the film is collected with the photomultiplier tube by means of condenser lenses so that the optical density of the film is converted to a video signal. The video signal is amplified and fed to the electronic processor. The processed signal is consecutively fed to the display CRT.

The processor consists of an electronic filter and an analog processing unit in which the processed image signal is manipulated to provide the various displays of the image. Blurring of the image can be performed either by defocusing the beam spot of the flying spot tube or by defocusing the optical system. Blurring can also be done with a suitable electronic low-pass filter. The former method is chosen for its simplicity. Deblurring is performed with the filter which consists of two successive high-pass RC circuits of equal cutoff frequencies. The signal passed through the filter is mixed with the normal video signal at variable mixing ratio. Various modes of display such as normal contrast image, shaded view, volumetric view, cross-sectional view, and isocount contour map are added to this equipment. The shaded view gives a more volumetric impression of the image by casting light the direction and zenith angle of which can be varied at will. Light is cast by adding the differentiated video signal to the normal video signal applied to the grid of the CRT, while the raster spot moves in a particular direction with broad angle. Various parameters of these display modes can be adjusted with the corresponding variable resistances or switches so that the close examination of suspected lesions is feasible with various modes of display and adjustment of the display parameters.

RESULTS

Some preliminary results of analog image processing by the apparatus based on the proposed principle are shown in Figs. 3 and 4. The object in Fig. 3 is a test pattern for the spatial resolution of the scintillation camera. Figure 3A shows a simple reproduction of the original image and Fig. 3B shows a blurred image. Figure 3C is a deblurred image of the original image and Fig. 3D is a deblurred image of the defocused image. In Fig. 3C the finest lines are discernible but the image is rather noisy. In contrast, the noise is suppressed in Fig. 3D whereas the finest lines are still clearly discernible.

Examples of various display modes are shown in Fig. 4. The object of the scintigram under test is a liver phantom containing about 700 μCi ^{99m}Tc and two cold spots of 2-cm diam and three cold spots of 1-cm diam as schematically shown in Fig. 4A. Figure 4B is a simple reproduction of the original image. Accumulated counts of the scintigram are 250K counts. The shaded view is shown in Fig. 4C in which light is cast from top of the figure. One can perceive small irregularities in this mode of display, which can hardly be perceived in Fig. 4B. Figure 4D is the volumetric view and Fig. 4E is the volumetric view with contrast modulation. Figure 4F is the volumetric view with shade in which light is cast from top of the figure. The irregularity on the periphery is clearly discernible in these modes, especially in the shaded view mode, but the determination of the absolute location of lesion is somewhat uncertain. Therefore the location should be ascertained in other modes. An isocount contour map is shown in Fig. 4G in which 10 isocount contour lines are shown by 10% increments from background level to peak optical density. The level can be set with a ten-turn helical potentiometer, so that one can ascertain by

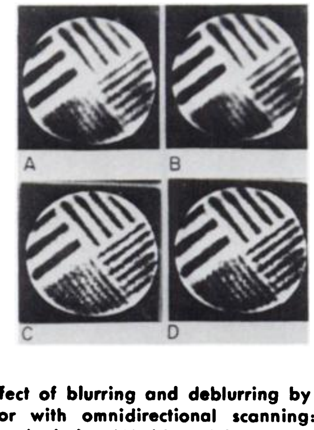

FIG. 3. Effect of blurring and deblurring by means of analog image processor with omnidirectional scanning: normal contrast view without manipulation (A), blurred image (B), deblurred image (C), and deblurred image of defocused image (D). Phantom used is test pattern for spatial resolution of scintillation camera. Both spacing and width of bars are 12, 9, 6, and 4.5 mm.

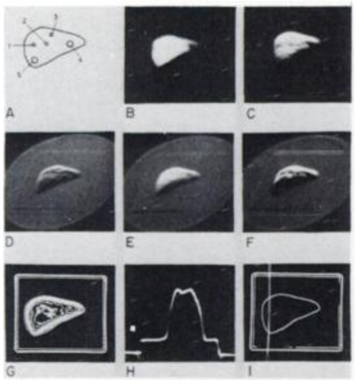

FIG. 4. Various display modes available with test apparatus; schematic diagram of liver phantom (A) which has three 1-cm-diam cold spots [shallow (1), middle (2), and deep (3) in phantom], and two 2-cm-diam cold spots [shallow (4) and deep (5)]; simple reproduction of original image in normal contrast view mode (B); shaded view (C) in which light is cast from top of figure; volumetric view (D); volumetric view with contrast modulation (E); volumetric view with shade (F) in which light is cast from top of figure; isocount contour map (G); cross-sectional view (H); and line of cross section of (H) along with periphery of object (I). In these figures, images are smoothed by defocusing flying spot tube.

adjustment of the potentiometer whether the "island" in the map is a cold or hot spot. A cross-sectional view is shown in Fig. 4H and the corresponding line of the cross section is shown in Fig. 4I along with the periphery of the image. In this mode of display, small cold spots may be clearly discernible even near the periphery of the image with suitable choice of location of cross-sectional line.

CONCLUSION

The omnidirectional scanning method which provides two-dimensional image processing in analog is presented in this article. The proposed scanning has the following prominent features.

1. A two-dimensional symmetric filter can be obtained by one-dimensional electric filter.
2. The raster has the possibilities of yielding various display modes, such as a shaded view and a cross-sectional view in an arbitrary direction because it includes scan lines in all directions.
3. Picture elements are quite dense provided that the ratio of the repetition frequencies of the triangular deflection signals does not form a simple rational number.

An important problem encountered in the present method lies in the design of the electronic filter but the design theory of an electronic filter will be available in communication technology by which the design of a filter with almost any response is feasible with multipole approximation (*5*). Although the electronic filter adopted in this article is a simple one, the test apparatus showed the usefulness of the filter in the image enhancement. The test apparatus also showed the validity of the principle of omnidirectional scanning for the analog processing of the scintigraphic images.

The proposed scanning method is applicable to rescanning devices other than the flying spot scanner, e.g., an image orthicon-TV system, an image storage device (e.g., Lithocon tube, Princeton Electronic Products, Inc., North Brunswick, N.H.), and an electron microscope.

ACKNOWLEDGMENTS

The authors are indebted to Tadashi Hashizume and Takeshi A. Iinuma for their valuable discussions and to Yoichiro Umegaki for his incessant encouragement. The authors are also grateful to Toru Matsumoto and Mitsuhiro Kuchiki for their kind collaboration in the preparation of the original scintigraphic images. The work was supported in part by a grant from the Ministry of Health and Welfare of the Japanese Government.

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