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IMPROVEMENT OF SCINTIGRAM RELIABILITY BY ISOCOUNT SCANNING AND MULTILEVEL ANALYSIS

Jun Ikebe and Oscar A. Nawa

Tokyo Institute of Technology, Tokyo, Japan

Given the target source conditions and the detector parameters, the isocount scanning uses optimally the available observation time by maintaining the statistical reliability of each measurement in the composition of a scintigram and by devoting all the observation time to the region of interest through logic circuits which allows quick skipping of the background region. The multilevel analysis is an effective enlargement of the dynamic range of the displayer screen density characteristics that emphasizes small uptake ratios in any density level. It also makes the feature extraction very easy by producing an animated sequence of pictures of the observed organ on the screen. The detectability of small uptake ratios significantly improved, specially in regions of low counting rate where the fluctuation of data severely degrades the picture quality in the conventional constant speed scanning method.

Several methods of computer processing have been tried that aim not only at extracting larger amounts of information from scan data but also prepare for automatic interpretation of scintigrams (*1,2*). It is known, however, that no information can be added to the original data by any retrospective processing and this stresses the importance of gathering the original data with maximum care.

This paper presents a new scanning mode that yields uniform reliability of data over the entire picture, devoting almost all the available observation time to the region of interest by minimizing useless observation of the background region. Moreover, by producing an animated sequence of pictures of the observed organ instead of a single static scintigram, the feature extraction is facilitated because human sensors are very sensitive to movements.

RELIABILITY OF DATA AND ISOCOUNT SCANNING

It is well known that the imaging pulses normally used to form the scintigram of an observed organ constitute a Poisson process. Provided that the conditions of the target source and detector parameters are given, the statistical fluctuations of data can be calculated as a function of the observing time τ. The efficient use of available scanning time in order to gather highly reliable data for scintigram composition is our main concern.

From the statistical viewpoint, a small uptake ratio is detectable only if the deviations of data from their expectations are small enough. Moreover, in regions of low counting rate, the statistical fluctuation must be proportionally small in order to keep detectability above a certain level. Taking these facts into account, the coefficient of variation, defined as the ratio of the standard deviation to the expectation of a random variable, is adopted here as a measure of data reliability, i.e., the smaller this coefficient, the greater the reliability.

For the conventional constant-speed scanning, the coefficient of variation is calculated by using the Poisson probability distribution form and is given by

$$\epsilon(n) = \sigma(n)/E(n) = 1/\sqrt{\tau\lambda(x,y)} \qquad (1)$$

The estimation of the counting rate λ is supposed to be done through the number of counts n in a time interval τ during which the detector actually moves a distance $\Delta L = \tau v$, where v is the scanning speed.

Solid curves in Fig. 1 were plotted for v = 250 cm/min and 100 cm/min with ΔL = 4 mm, resulting in an observation time τ = 96 msec and 240

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For reprints contact: J. Ikebe, Research Laboratory of Precision Machinery and Electronics, Tokyo Institute of Technology, 2-12-1, Ookayama, Meguro-ku, Tokyo 152, Japan.

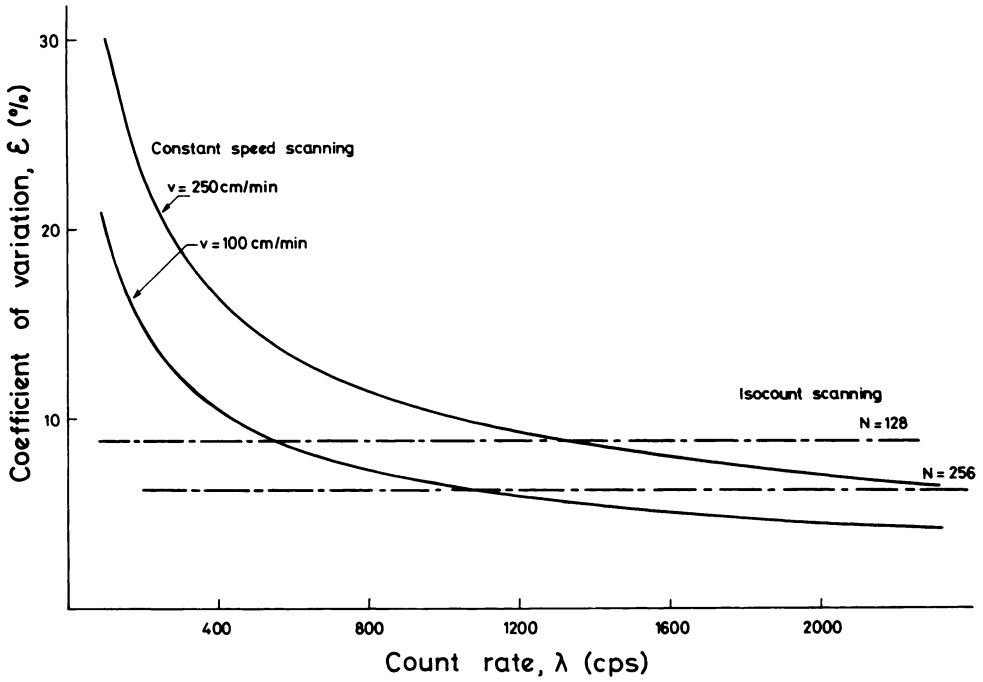

FIG. 1. In constant-speeding scanning, statistical fluctuations increase sharply in relation to counting rate when this becomes low whereas it is kept invariable in isocount scanning.

msec, respectively. The curves show a sharp increase of the statistical fluctuation in places where λ is small relative to the value of the counting rate, degrading the picture quality. The coefficient of variation decreases slowly with increasing λ.

The conventional constant-speed procedure, therefore, yields a picture in which fidelity varies from point to point. This is an especially serious drawback in brain scanning because an abnormality may arise in a region of low uptake ($\lambda = 150$ cps) as well as around the border of the cerebrum where the counting rate may go up to 1,000 cps.

This situation may be remedied by allotting a different observation time for each point instead of scanning every point with the same speed. The observed plane should be sectioned into small square picture elements; the detector is stopped directly over each of these elements in succession. At each observation point, the imaging pulses are counted during the time T necessary for the number of these pulses to reach a preset value N. The observed counting rate $R = bN/T$ is then calculated electronically and a flash of light proportional to R constitutes the picture element on the film. At the same time, the value of R is recorded on paper tape to be transferred to the displayer memory. The parameter b is a constant introduced by the circuits in the determination of R.

After finishing these operations, the detector is moved to the next observation point and the same steps are repeated. The preset number N is maintained constant during the entire scanning; this suggests the name "isocount scanning" for this method.

The time T is also a random variable and its probability density function $p_N(T)$ is given in the appendix.

$$p_N(T) = \lambda^N T^{N-1} \exp(-\lambda T)/(N-1)! \quad (2)$$

From Eqs. 2 and A-3, the probability density function p(R) of the counting rate $R = bN/T$ is determined

$$p(R) = (b\lambda N)^N \exp(-b\lambda N/R)/[(N-1)!\, R^{N+1}]. \quad (3)$$

The expectation E(R), the standard deviation $\sigma(R)$, and the coefficient of variation $\epsilon(R)$ are given respectively by:

$$E(R) = bN\,\lambda(x,y)/(N-1) \quad (4)$$

$$\sigma(R) = bN\,\lambda(x,y)/[(N-1)\sqrt{N-2}] \quad (5)$$

$$\epsilon(R) = 1/\sqrt{N-2} \simeq 1/\sqrt{N}. \quad (6)$$

In contrast to the constant-speed scanning, $\epsilon(R)$ becomes independent of the observed point and it may be arbitrarily adjusted by choosing a convenient value of N. Broken lines in Fig. 1 indicate the coefficient of variation of two typical values of N: 128 and 256.

THE CONTROLLER AND DATA PROCESSOR

The controller and data-processing circuits, shown schematically in Fig. 2, were inserted between the

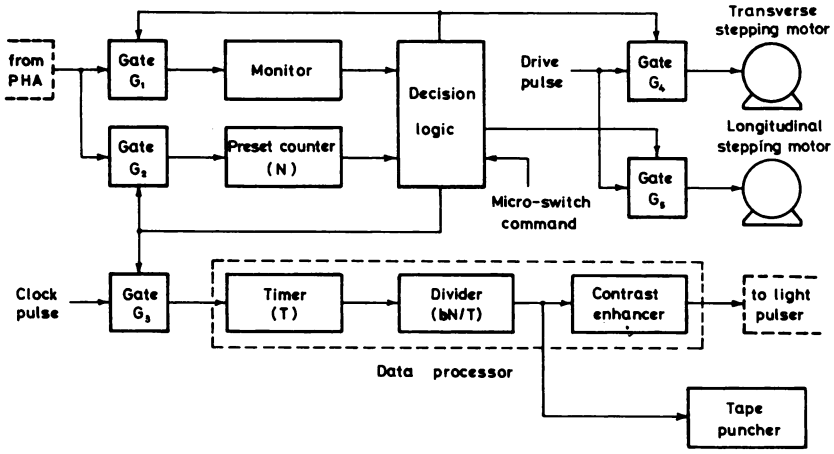

FIG. 2. Isocount scanning controller and data processor: output of pulse-height analyzer (PHA) is fed to controller which produces control signals and new processed imaging signal sent to light pulser.

pulse-height analyzer and the light pulser of a conventional scanner (RSL-1B, Hitachi Medical Co.). The input pulses to the controller are those used hitherto as imaging pulses. A new processed signal is used for imaging and analysis purposes.

Two stepping motors, one for transverse and another for longitudinal movement, receive the drive pulses and execute the move and stop sequence.

The monitor circuit consists of a counter that makes a rough observation of the input pulse rate during the transition from one observation point to the next and tells the decision logic circuit whether the detector is outside the region of interest. When this happens, the probe is quickly moved to the next observation point without a careful measurement. This is an important function in the procedure of optimizing the available scanning time; that is, to examine carefully the region of interest and avoid useless and time-consuming observation of the background region.

At each observation point, the gates G_2 and G_3 are opened simultaneously so that the timer is activated while the preset counter is adding up the input pulses. These gates are closed as soon as the number of input pulses reaches N and then the digital divider performs the division $R = bN/T$. This result is recorded on paper tape for posterior analysis on the displayer and the imaging process takes place after a convenient contrast enhancement.

As soon as the recordings are finished, gates G_1 and G_4 or G_5 are opened, the corresponding stepping motor is activated, and the detector is moved to the next observation point or to the next scan line, respectively.

MULTILEVEL ANALYSIS

Due to the small dynamic range of monochromatic film density curves or cathode-ray tube (CRT) displayer screen characteristics relative to the numerical range of scan data, it is very difficult to record clearly every detail at different levels of counting rate on a single static picture.

In the present study, the scan data are transferred to the memory of a display system that produces monochromatic scintigrams and also allows the multilevel analysis on the screen of a standard television set. The picture elements are produced by converting each value of the counting rate R to a convenient brightness on the screen synchronistically with the horizontal sweep signal. If the entire data range is displayed on the screen, a monochromatic scintigram is obtained.

On the other hand, the multilevel analysis proceeds by setting two reference levels L and $(L + k)$; each value of R is read out from the memory and compared with these values. If R is smaller than L, it is replaced by zero, producing a white picture element on the screen; if R happens to be larger than $(L + k)$, the greatest available value is assigned to that element, producing a black elemental picture on the screen. To each value of R between L and $(L + k)$, a gray level proportional to $(R - L)$ is assigned to it so that k different gray levels may be present.

The reference level L is changed sequentially, and any detail at every level is easily visualized. It was found experimentally that $k = 8$ to 10 is suitable for liver scanning and that this is in accordance with the number of gray levels clearly distinguishable by the human eye on a monochromatic film. For brain scanning, the counting rate range is not so wide and interest lies in enhancing small uptake ratios. On the other hand, human sensors are very sensitive to movements, so that in making $k = 0$, and varying the slice level with a suitable speed, a kind of silhouette appears on the screen that changes its form in a manner similar to that of an animation picture. This makes the feature extraction very easy. With the isocount method the fluctuations of data remain

relatively low in regions of low uptake, making this kind of analysis worthwhile.

RESULTS

Preliminary experiments with phantoms were conducted in order to verify the quality of the resulting scintigram for different values of N. As the scanning time is nearly proportional to N, it is desirable to keep N as small as possible.

It was verified that practically useful values of N are around 128–256, for which the coefficients of variation $\epsilon(R)$ are 8.8% and 6.3%, respectively. These levels are indicated in Fig. 1. On the other hand, it was verified that by increasing N from 512 to 1,024, with $\epsilon(R) = 4.4\%$ and 3.1%, respectively, the improvement of picture quality is not remarkable and the increased time for scanning is probably not worthwhile. This result is in accord with the slowly decreasing value of $\epsilon(R)$ when N is greater than 200 or 300. For $N = 32$ and 64, with $\epsilon(R) = 17.7\%$ and 12.5%, respectively, the resulting photoscintigrams become poor due to deformations in the shape of hot spots caused by large statistical fluctuations.

Figure 3 shows a case of liver metastasis: (A) is a monochromatic photoscintigram, the result of isocount scanning; (B) is a corresponding photoscintigram composed by conventional constant-speed method; and (C) is a sequence of pictures for different reference levels L, indicated below each frame, and with $k = 8$. About the same amount of time was spent in both methods: isocount scanning and the conventional constant-speed scanning.

Details of the sternum and spinal column, which are almost invisible in (A) and (B), are enhanced in (C)-a, as indicated by the arrows. The shape of liver and spleen, as well as the contour change of the defective portions [arrows in Fig. 3 (C)-e] for different reference levels are clearly seen with multilevel analysis.

A case of metastatic carcinoma of the brain is shown in Fig. 4; (A) is the left lateral view composed by isocount method, (B) is the corresponding picture due to constant-speed scanning, and (C) is a sequence of silhouettes that actually produces an "animated sequential scintigram" on the screen. Figure 4(A), with the top of the head slightly cut off by technical failure, reveals only a tumor in the parietal region; the multilevel analysis (C), however, succeeded in demonstrating not only this but also another tumor in the posterior temporal region [as shown by the arrow in Fig. 4 (C)-i], which was later

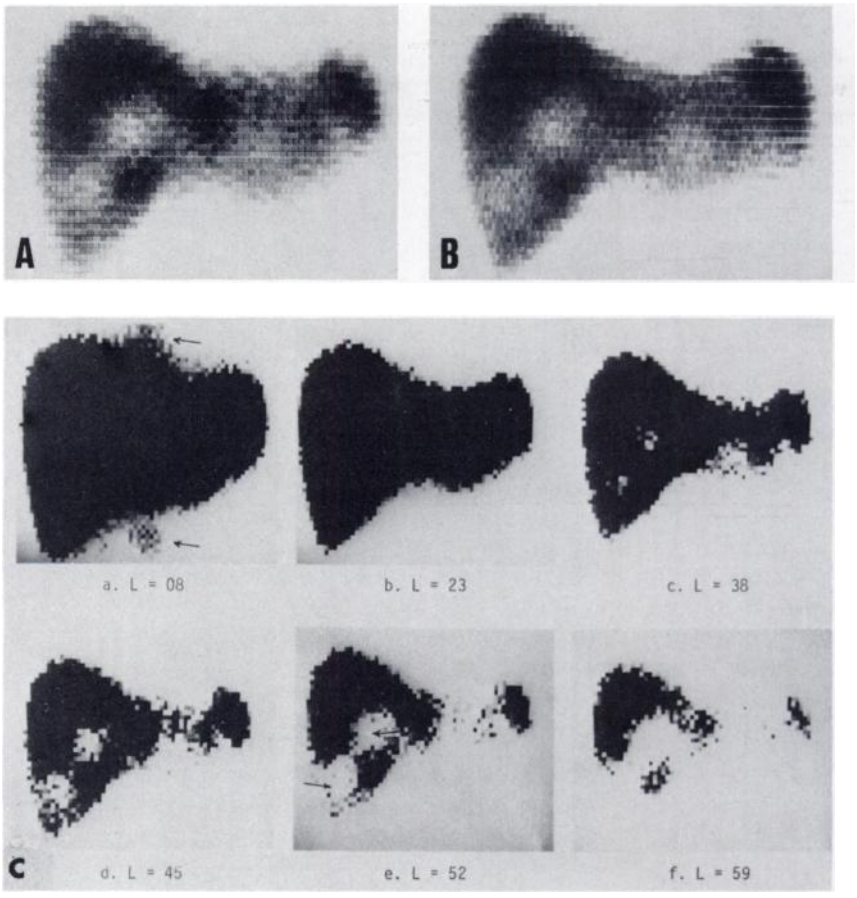

FIG. 3. Case of liver metastasis. (A) monochromatic photoscintigram produced by isocount scanning and (B) photoscintigram resulting from constant-speed scanning. Multilevel analysis (C) enhances details not clearly visible on (A) and (B).

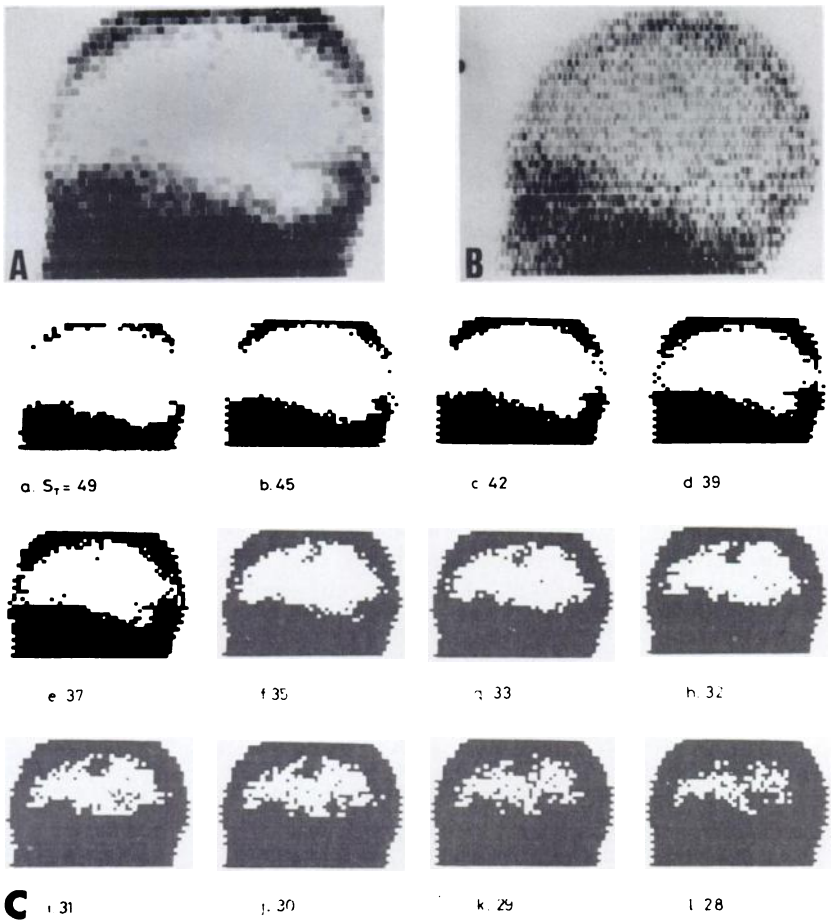

FIG. 4. Left lateral view of metastatic carcinoma of brain. Isocount scintigram (A) clearly shows tumor in parietal region blurred by statistical fluctuation in constant-speed scintigram (B). Multilevel analysis (C) shows another tumor in posterior temporal region.

confirmed by autopsy. On the other hand, it is very difficult to identify clearly these abnormalities in Fig. 4(B).

The evolution of silhouettes of normal cases with the reference level has a rather uniform pattern: first, the posterior fossa is delineated and disappears; then, the central cold area or supratentorial portion of the brain shrinks gradually in the posteroanterior direction. The anterior portion of the cerebrum remains white until the last phase, although it is narrowed by the expansion of the surrounding areas.

DISCUSSION

Some merits in scanning with "preset count" have been pointed out by Shepers and Winkler (*3*) but the real effectiveness of the isocount method was not clearly demonstrated because retrospective computer-processing masked it.

The coefficient of variation is introduced as a measure of statistical reliability of data and it is shown that with constant-speed scanning, the picture quality is severely degraded when the uptake is low. With isocount scanning, the degree of reliability of each observation may be appropriately set beforehand, yielding a picture with uniform fidelity independent of the counting rate at each point of the observed organ.

Automatic decision logic is incorporated in the control circuits in order to avoid useless and time-consuming observation of the background region. This allows an efficient allotment of the total available scan time to the region of interest.

This scanning method, associated with multilevel analysis, has proved to be an excellent one from the standpoint that it aids in lesion detection and therefore significantly increases diagnostic ability.

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APPENDIX

Calculation of $p_N(T)$ and p(R). For a Poisson process, the probability $p_N(T)\ \Delta T$ is equal to the probability of occuring N — 1 events in a time interval T, followed immediately by one event in an incremental time ΔT:

$$p_N(T)\,\Delta T = P_T(N-1)\,P_{\Delta T}(1) \quad \text{(A-1)}$$

Due to the Poisson characteristics of the process,

$$P_T(N-1) = (\lambda T)^{N-1}\exp(-\lambda T)/(N-1)! \quad \text{(A-2)}$$

Taking the limit with $\Delta T \to dT$, then $P_{\Delta T}(1) \to \lambda dT$, and from Eqs. A-1 and A-2, $p_N(T)$ in the text is obtained.

By using the random variable transformation formula, the following relation is set:

$$p(R)\,dR = p_N(T = bN/R)\,|dT/dR|\,dR \quad \text{(A-3)}$$

Substituting Eq. 2 in the text into the righthand side of Eq. A-3, Eq. 3 is obtained.

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