TEACHING EDITORIAL

The Impact of Digital Technology on the Scintillation Camera

Digital technology invades such common items as toys and automobiles, and it is also beginning to have a profound effect on the Anger scintillation camera. As the switch to digital electronics occurs, it is necessary to distinguish among changes that are strictly for cost saving, or the fashionable changes with marketing appeal, and those that offer true benefits in clinical utility. Indeed it is necessary to rethink old concepts, which have become accepted as gospel truths, and examine whether the increased power offered by digital processing can be used to overcome inherent limitations built into analog processors used in the Anger camera. The article by Genna, Pang, and Smith (*1*) in this issue describes an approach in which even the basic Anger arithmetic summing network has been replaced by digital electronics.

A number of technological changes have opened up possibilities in information processing that were inconceivable only a few years ago. At the same time, a new generation of electronic devices is making the transition from the research laboratory to the manufacturing stage, which indicates that the present trends will continue for some time to come. For example, digital memories are being developed with higher densities, with faster access times to increase processing speeds, and with lower power requirements to avoid cooling problems. Nuclear medicine image-processing systems now routinely contain 256 K words of image memory, and the progression to large memories is not so much a question of cost but rather of utility. Microprocessors are becoming ever more powerful and faster due to a change from 8-bit to 16-bit word length with 32-bit word length soon to come. Microprocessor-based systems now use an architecture that results in capabilities and characteristics that rival minicomputers. However, this last statement requires qualification: Microprocessors perform well when used to execute a single well-defined task but generally are inferior to minicomputers in a multi-tasking, general-purpose environment.

Now that we have stated the generally accepted fact that digital systems of the future are (almost) all-powerful, we must examine their potential role in nuclear medicine imaging instrumentation. The most apparent impact is in image formation and storage. Rather than displaying each scintillation on a cathode-ray tube as a dot and using film to form a dot-density image in real time, it is advantageous to store the image in a digital memory for subsequent display and film recording. This method assumes that the acquisition system does not compromise the image quality—the data preferably are accumulated in a 256 × 256 matrix and displayed with a minimum of 64 gray levels. This mode of image recording avoids repeat patient studies caused by film exposure problems, allows multiple copies to be made without compromising image quality, permits after-the-fact manipulation of background and contrast, and thus improves reliability and reproducibility. If the digital image recording is made an integral part of the data acquisition on the scintillation camera, then subsequent digital data processing can be performed off-line after completion of the patient study. Rather than extending our examination of the impact of digital technology to the potential uses of subsequent *data processing* to perform such calculations as ejection fraction or the reconstruction of longitudinal or transverse sections, I would like to discuss the impact on *data acquisition* instead and, in particular, the limitations of the analog Anger camera.

The light emitted in an Anger camera after a scintillation spreads in all directions and finally reaches the plane at which the photomultipliers detect the light and convert it into electronic signals. In that plane the light intensity has a bell-shaped distribution with its center directly above the point of scintillation. The photomultipliers sample this distribution at discrete intervals. As the photomultipliers are moved closer to the crystal, the bell-shaped distribution becomes narrower, but at the same time the number of samples decreases. Since the limiting factor in spatial resolution—at least for a gamma-ray energy of 140 keV—is the statistical accuracy of the signal from each photomultiplier tube, bringing the photomultipliers closer to the crystal results in larger, more accurate signals. The basic analog Anger positioning circuit finds the centroid of the samples taken by the photomultipliers. It has two inherent shortcomings:

1. The centroid of the *samples* taken by the photomultipliers does not necessarily correspond to the centroid of the *light distribution* resulting in mispositioning of the event and in general compression of the counts toward the centers of the photomultipliers (*2*).

2. Each signal is treated as if it carried equal position information, thus summing the contributions from the photomultipliers in a less than optimum manner (*3,4*). Although analog methods can overcome these limitations to some degree (*5–7*), digital techniques give additional flexibility in processing the information contained in the photomultiplier signals.

In the last five years, we have seen the introduction of sophisticated and accurate uniformity correction methods, and these have all been implemented digitally. The early methods (*8*) used count "skimming" or adding to correct for flood-field irregularities. More recent methods of uniformity correction (*1,2,9,10,**) recognize that the primary sources of nonuniformities are local fluctuations in energy signal amplitude and in positional linearity (*11*) and correct for these inherent problems rather than mask them by count adding or subtracting.

The basic causes of nonuniformity were understood more than 10 years ago (*12*), and methods for overcoming these problems were formulated at that time (*13*); however, it has been only through recent technological advances that the price, speed, and size of the necessary digital processing electronics have improved to the point that these methods could be applied in commercial instruments. An indication that the "time was right" for this next step is the fact that three companies introduced similar systems within approximately one year.† To understand the necessity for these systems, it is important to realize that each crystal/photomultiplier tube assembly has unique characteristics due to small variations from crystal to crystal and in photomultiplier tube characteristics. In analog systems, it may be necessary to choose a lightpipe for a particular crystal/photomultiplier combination or to add numerous adjustments to compensate for these variations. For example, a scintillation camera manufactured by Picker Corporation contains 222 individual adjustments (six for each of 37 photomultipliers) to assure good flood-field uniformity. Instead of performing numerous interrelated analog adjustments, it is equally valid to "look up" the correct position and energy amplitude in a memory (*2,9,10*). Digital methods of energy and linearity correction remove a major design restraint and permit the use of thinner lightpipes. Thus they result in better spatial resolution as well as good uniformity and energy resolution.

Designers of cameras have realized that intrinsic spatial resolution can be improved by giving different photomultiplier signals different weights, by such means as nonlinear preamplifiers (*5,7*). Ueda et al. (*3*) have calculated these optimum weights theoretically, and Hiramoto et al. (*6*) implemented delay-line techniques to overcome some of the limitations imposed by the Anger centroid-generating arithmetic network. They concluded that by better weighting of the signals, approximately a 20% improvement in intrinsic spatial resolution can be obtained. These findings are generally supported by Gray and Macovski (*4*). Genna, Pang, and Smith (*1*) describe a one-dimensional scintillation camera in which each photomultiplier signal is digitized, and the centroid of the sample is determined after giving each sample a "reliability weighting factor." This factor accounts for not only the statistical uncertainty of the signal but also the amount of position information carried by the signal, thereby overcoming the second shortcoming of the analog positioning circuit. Ultimately, the achievable intrinsic resolution is still limited by the light distribution in the photocathode plane. Obtaining a good light distribution *before* the photomultipliers convert this distribution into a limited number of electronic signals remains a major design task in building high-resolution scintillation cameras.

Since the all-digital approach is "obviously" superior to analog approaches, one might be tempted to judge its significance by the results reported. The authors (*1*) achieved an average spatial resolution of 4.2 mm FWHM and a uniformity of approximately ±6% maximum deviation after smoothing. Although this performance is not superior to that achieved with state-of-the-art commercially available Anger cameras, such a comparison is unfair, since it not only compares dissimilar systems (a one-dimensional camera with a 12.5 mm crystal with a two-dimensional camera with a thinner crystal), but it also compares the effort of a small group of investigators with the efforts and results achieved after years of refinement by large teams of physicists and engineers.

In general, as the scintillation camera is improved further, the complexity increases. For the analog approaches, improvement results in complicated circuitry, such as the dynamically variable integrators described by Tanaka (*14*) or the use of hundreds of adjustments. For the digital approaches the number of generally expensive analog-to-digital converters increases significantly as the position signals are digitized closer to the photomultipliers. Time, however, favors the digital approaches. As digital devices become more powerful and cheaper, they become a cost-effective alternative to the analog approaches, and offer increased design flexibility that can be translated into improved performance.

In summary, completely digital approaches to the design of scintillation cameras, as described by Genna, Pang and Smith, when coupled with good optical designs in the crystal/photomultiplier interface should provide improved performance and increased reliability. Rapid progress in digital components is likely to make them cost-effective within the foreseeable future.

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FOOTNOTES

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† Medical Data Systems, Siemens Gammasonics (ZLC camera), Elscint (Apex camera).

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