Published in final edited form as:

IEEE Nucl Sci Symp Conf Rec (1997). 2008 October ; 2008: 4091–4094. doi:10.1109/NSSMIC.

2008.4774181

Data-Processing Strategies for Crossed-Strip Gamma-Ray Detectors

Heather L. Durko [Student Member IEEE],

Center for Gamma-Ray Imaging, College of Optical Sciences at the University of Arizona, Tucson, AZ 85724 USA

Benjamin S. McDonald [Student Member IEEE],

Institute of Imaging Science, Department of Radiology and Radiological Sciences and the Department of Physics and Astronomy at Vanderbilt University, Nashville, TN 37232 USA

Sepideh Shokouhi [Member IEEE],

Institute of Imaging Science, Department of Radiology and Radiological Sciences at Vanderbilt University, Nashville, TN 37232 USA

Lars R. Furenlid [Member IEEE],

Center for Gamma-Ray Imaging, Department of Radiology at the University of Arizona, Tucson, AZ 85724 and the College of Optical Sciences at the University of Arizona, Tucson, AZ 85721 USA

Harrison H. Barrett [Fellow IEEE], and

Center for Gamma-Ray Imaging, Department of Radiology at the University of Arizona, Tucson, AZ 85724 and the College of Optical Sciences at the University of Arizona, Tucson, AZ 85721 USA

Todd E. Peterson [Member IEEE]

Institute of Imaging Science, Department of Radiology and Radiological Sciences and the Department of Physics and Astronomy at Vanderbilt University, Nashville, TN 37232 USA

Heather L. Durko: hdurko@email.arizona.edu; Benjamin S. McDonald: ben.mcdonald@vanderbilt.edu; Sepideh Shokouhi: sepideh.shokouhi@vanderbilt.edu; Lars R. Furenlid: furen@radiology.arizona.edu; Harrison H. Barrett: barrett@radiology.arizona.edu; Todd E. Peterson: todd.e.peterson@vanderbilt.edu

Abstract

Crossed-strip gamma-ray detectors are an attractive option for small-animal SPECT imagers due to their high space-bandwidth product. In systems with independent triggering of the two sides of the detector, advanced data-processing techniques are required to accurately determine gamma-ray interaction locations and energy deposition. Optimal detector operation further relies on rigorous detector characterization in order to achieve detector triggering uniformity and best timing resolution and to permit position and energy estimation with maximum-likelihood methods. We describe algorithms and methods developed for calibrating and characterizing a recently fabricated system based on 1024-strips-per-side 1-mm-thick silicon detectors.

I. Introduction

The use of crossed- or double-sided strip detectors (DSSDs) in small-animal SPECT systems provides the benefit of a large number of pixels without a correspondingly large number of individual pixel bonds. We are currently working with a DSSD in which the n (ohmic) and p (junction) sides trigger independently on an absorption event; these independent triggers must be combined with coincidence timing data to determine position and energy deposition information.

The silicon crystals used in the DSSD were fabricated at SINTEF in Norway [1]. Each detector is composed of a 60 mm $\times$ 60 mm $\times$ 1 mm slab of crystalline silicon with 1024 20- μ m-wide conducting strips on each side at a 59- μ m pitch. The strips on one side are oriented orthogonally with respect to the strips on the opposite side of the detector, resulting in 1,048,576 “virtual” pixels; this detector is therefore the first true megapixel gamma-ray detector to be used in small-animal SPECT imaging. A photo and schematic of the DSSD are shown in Fig. 1.

The readout of these strips is accomplished with application-specific integrated circuits (ASICs), the VATAGP6, manufactured by Gamma Medica-Ideas, also in Norway [3]. Each ASIC is responsible for reading out events from 128 strips. Each readout channel within the ASIC is composed of a preamplifying stage connected to two processing branches which are responsible for triggering on and reporting the resulting deposited charge, as shown in Fig. 2. The first branch of the ASIC contains a gain stage followed by a fast shaper amplifier, high-pass filter, and a level-sensitive discriminator. If the signal from the high-pass filter is greater than a specified threshold voltage, the FPGA activates the sample-and-hold circuitry and initiates readout of the detected amplitude.

When polled, an ASIC returns the digital address of the triggered channel and a pair of analog voltages corresponding to the deposited charge. A pair of analog-to-digital converters digitize the analog signal, and the FPGA generates a series of 32-bit list-mode data packets containing the channel address, energy-dependent ADC values, and a fast time stamp generated from a 40-MHz clock. Data from adjacent channels may also be read out to evaluate charge-sharing effects between channels. Data packets are sent to an external FPGA-based coincidence read-out board (CROB), which periodically inserts a 1-kHz slow time stamp into the data stream to complete the timing information. The CROB pushes the event data and their associated time stamps to a National Instruments DIO card in the acquisition computer. Since the n and p sides operate independently, two CROB ports are required to read event data from one detector. The resulting data stream is a concatenation of data from independent triggers from the two sides of the detector. In order to extract event information such as 2D position and deposited energy, it is necessary to use the fast and slow time stamps to identify events which are coincident between the n and p sides of each detector.

The silicon DSSDs were designed to perform within an operating range of 10–60 keV. While the detection efficiency of silicon diminishes quickly with increasing energy, it is

possible to increase detection probability by stacking detectors to collect a greater proportion of incident photons [4].

II. Data-Processing Strategies

The detector configuration and ASIC readout characteristics present a unique set of challenges:

- Photon event locations must be determined by matching independently occurring trigger events from opposite sides of the detector based on time stamps associated with each list-mode data event.
- Noisy channels will degrade detector uniformity and compete with true trigger events, resulting in misreported locations of photons in the projection image.
- The characteristics of the fast shaper branch of the ASIC determine the level at which each channel reports a trigger event. However, these characteristics cannot be measured directly and must be inferred from trigger rates and the output of the slow shaper branch.

These detector characteristics determine the methods which must be implemented to achieve optimal interpretation of the list-mode data stream. The following sections describe our work to date in extracting and interpreting these data.

A. Achieving triggering uniformity

Triggering uniformity is essential to optimal detector operation: it allows for uniform sensitivity across the detector and permits a lower global detection threshold to better trigger on low-energy gamma rays [2], [4]. We have developed an iterative routine to measure and adjust the triggering characteristics of each channel in order to achieve uniformity.

It is important to recognize that while the fast branch of the triggering detection circuit determines whether an event has occurred, its output is not available to the end user. As such, it is necessary to monitor the trigger rate of the detector on a channel-by-channel basis as the global threshold voltage is lowered to determine the level at which each channel triggers on its own baseline noise. This voltage can be locally modified by adjusting four-bit trim DACs at each channel. In these VATAGP6 ASICs it is, however, necessary to balance trim adjustments across the channels to maintain a current-neutral operating condition.

The iterative trigger-level adjustment algorithm is as follows:

- The trigger rate of each channel is individually monitored as the global trigger threshold is lowered to determine at what level it begins to trigger on its own baseline noise.
- Channels that begin triggering more than two standard deviations above the mean of the detector side are designated noisy. These channels are removed from subsequent mean calculations, and no effort is made to adjust their local trigger thresholds.

- Trim DAC values are calculated to shift each active channel's trigger threshold towards the mean value of the results from the previous iteration. Noisy channels and global (ASIC) DACs are assigned values which compensate for any current imbalance arising from DAC settings of active channels.
- This process is repeated until trigger thresholds converge.

Fig. 3 illustrates the detection uniformity achieved through this iterative process.

B. Optimal coincidence detection

Since the location of an absorbed photon is determined by matching the time stamps associated with two independent channel triggers, it is important to determine an appropriate coincidence window which maximizes the number of true events while minimizing the number of misassigned coincidences. Fig. 4 demonstrates the difference between an appropriate and a too-wide coincidence window. A mask consisting of two diagonally oriented circular holes was placed in front of the detector, which was illuminated with an ^{125}I source. A large coincidence time window can pair n and p events originating from separate mask holes, creating ghost events (a), while an optimal coincidence window reduces these artifacts (b).

We have experimentally evaluated the effect of coincidence window on proper event-location assignment. The data from the n and p sides of the detector used to generate the images in Fig. 4 were processed with coincidence time windows varying from 25 nsec to 10 msec. For each resulting coincidence image, the number of counts present in the correct circular regions was compared to the number of counts present in the square regions resulting from mismatched n and p events. Random noise-induced events occurring in all other regions of the detector were not included in the analysis. Fig. 5 displays the results; optimal event assignments occur for coincidence windows ranging between 2.5–25 μsec . Increasing the source activity will increase the rate of trigger events and increase the probability of event mismatch. The chosen window should be as narrow as possible to reduce the number of misassigned event locations.

C. Removing artifacts

Noisy channels whose trigger thresholds cannot be brought below the global trigger threshold will overpower the image with misassigned coincidences and must be disabled. In order to minimize artifacts in reconstructed images, it is necessary to replace the missing data. In Fig. 6, a flood image (a) is used to mathematically identify inactive channels; the values of inactive pixels are replaced by the mean of the surrounding pixel neighborhood (b) [5].

D. ADC statistics

Current and future work includes analyzing the energy deposited as measured by individual detector channels. Fig. 7 illustrates our work to date in calibrating photon energy from the digitized pulse peak information. Data acquired from the n side of the detector during an ^{241}Am flood exposure were analyzed and histogrammed to display ADC statistics across the entire detector (a). It is evident in the expanded graph that each ASIC is subject to channel-

dependent gain variations (b). Slices through the histogram map at either end of the seventh ASIC demonstrate the dependence of resolvable energy peaks on channel location (c), (d). Additional calibration steps will be required in order to develop a quantitative assessment of the energy-resolving capabilities of these detectors.

III. Conclusions

We have shown that variations in channel trigger levels can be compensated through iterative trim DAC adjustment, allowing uniformly low detection thresholds. Residual detector-specific artifacts in projection images can be minimized using information contained in flood images. Systematic gain variations across each ASIC present a challenge that must be overcome to achieve optimal energy calibration across the detector face.

Acknowledgments

Work at the University of Arizona was supported by NIBIB grant P41-EB002035: "The Center for Gamma-Ray Imaging." Work at Vanderbilt University was supported by NIBIB grant R33-EB000776 and the Burroughs Wellcome Fund.

References

1. SINTEF ICT. Microsystems and Nanotechnology. P.O. Box 124, Blindern, 0314 Oslo, Norway: <http://www.sintef.no/Home>
2. Shokouhi, S.; Durko, HL.; Fritz, MA.; Furenlid, LR.; Peterson, TE. Thick silicon strip detectors for small-animal SPECT imaging. IEEE; Nuclear Science Symposium Conference Record, 2006; Oct 29 2006—Nov 1 2006; p. 3562-3566.
3. Pettersen DM, Mikkelsen S, Talebi J, Meier D. A readout ASIC for SPECT. IEEE Transactions on Nuclear Science. Jun; 2005 52(3):764–771.
4. Shokouhi, S.; McDonald, BS.; Durko, HL.; Fritz, MA.; Furenlid, LR.; Peterson, TE. Performance characteristics of thick silicon double sided strip detectors. IEEE; Nuclear Science Symposium Conference Record, 2007; Oct 26 2007—Nov 3 2007; p. 1656-1660.
5. Papanestis A, et al. A radiographic imaging system based upon a 2D silicon microstrip sensor. Nuclear Science Symposium Conference Record, 2000 IEEE. 2000; 1:3/1–3/5.

Fig. 1. Silicon double-sided strip detector with 1024 conducting strips per side. Each ASIC controls 128 strips. Inset: schematic of the strip orientation on both sides of the detector bulk.

Fig. 2. Event-triggering circuit block diagram. The upper branch analyzes whether a triggering event has occurred; the lower branch samples the event for readout [2].

Fig. 3. Detector uniformity under ^{125}I flood illumination before (a) and after (b) iterative trim DAC adjustment. Images were processed to correct for inactive channels using techniques described in section II-C.

Fig. 4. A wide coincidence window introduces the possibility of mismatching n- and p-side triggers (a). An optimal coincidence window reduces this possibility while maximizing the number of true coincidences (b).

Fig. 5.

Number of total, true, and misassigned coincident events as a function of coincidence window. Optimal event classification for a $329 \mu\text{Ci } ^{125}\text{I}$ source occurs for a range of coincidence windows between $2.5\text{--}25 \mu\text{sec}$; choosing the narrowest possible window protects against event mismatch as source activity increases.

Fig. 6.

Raw flood image (a) used to determine unresponsive channels, which are used to remove artifacts from all projection images acquired with the same detector (b). Seven n-side channels and 15 p-side channels were deemed inactive in this example.

Fig. 7.

Histogram map of ADC values collected across the n side of the detector during a flood acquisition of ^{241}Am (a). An enlarged view of data from the seventh ASIC illustrates the effect of channel-dependent gain (b). Current operating conditions prohibit adequate discrimination between 13.9 keV and 17.8 keV peaks across a single ASIC (c), (d). Since the n and p sides collect holes and electrons respectively, their pulse polarities are opposite. On the n side of the detector, lower ADC values correspond to higher energies.