Impact of system resolution of image quality in PET imaging

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Abstract

Spatial resolution is one of the most controversial issues in nuclear medicine. With a relatively small number of collected events for a typical examination, the statistical significance of observed counts can be compromised if divided into cells too small.

Our group studies benefits of extending a standard PET ring with high resolution detectors called probes. The probes are normally placed inside the conventional detector ring, benefiting from proximity focus of the selected field of view. In such a setup, three different types of events are possible: **(1)** standard PET events with both interactions in the ring (ring-ring interactions) **(2)** mixed events with one photon interacting in the ring and the other in the probe (probe-ring) and **(3)** high resolution probe only events (probe-probe), which arise when probes surround the object under observation.

The three event types are recorded with significantly different spatial resolution. This prompted a study on impact of event resolution on final image quality. In absence of a particular application, variance-resolution curves similar to modified Cramer-Rao bound were used to quantitatively compare images reconstructed using different event types.

During initial studies, two-dimensional imaging of a single object slice was performed. Data simulated using point-spread-functions (PSF) extracted from point source scans was found to excellently agree with the measurements. Encouraged by the match, data from a state-of-the-art ring detectors (4 mm and 2 mm crystal size) was simulated. Even for such high-resolution detectors, the high resolution event types (probe-ring and probe-probe) still offer significant advantages over bare ring imaging.

1. Summary

Although seemingly beneficial there is no clear relation between improved spatial resolution and image quality [1] due to a relatively small event count.

We have recently tested a standard PET system extended with high resolution sensors (probes) to verify feasibility of the approach [2]. The setup consisted of:

- two arcs of antique BGO modules scavanged from a CTI 931 PET scanner, with crystals segmented to 6 mm circumferrentialy and 13 mm radially
- a pair of silicon sensors segmented to cubic voxels of 1 mm^3

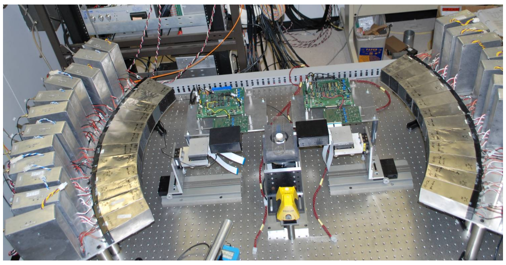

Figure 1: Photograph of the PET test bed with PET arcs of BGO sensors and two silicon probes on the opposite side of the object.

- lead collimator compressing the imaging volume to a single slice containing both silicon sensors.

Based on the location of interaction of each of the pair of the annihilation created photons, three event types can be discerned:

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- standard ring-ring or BGO-BGO events
- mixed probe-ring or Si-BGO events where one photon interacts in the ring and the other in the probe
- high resolution probe-probe or Si-Si events.

Clearly, each event type is recorded with different spatial resolution. A quantitative measure of relative image quality is required to compare images obtained for each event type.

The system was used to image mini Derenzo phantom with hot rods of diameters between 4.8 and 1.2 mm. The images were reconstructed using MLEM iterative method. Reconstructed images were post-smoothed using Gaussian kernels to assure spatially invariant resolution. Events were randomly split into 5 realizations with the prescribed event count (1 million, typically) to estimate variance of each pixel. When variance stabilized, iterations were stopped, typically at around 400 iterations for high resolution and as much as 10000 iterations for the low resolution, ring-ring data.

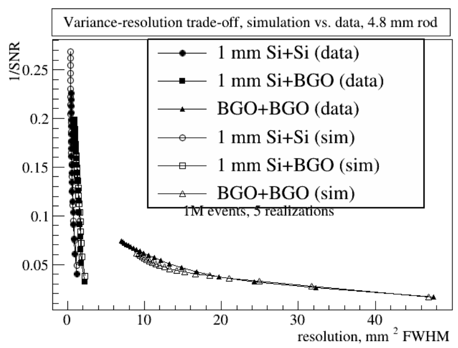

Figure 2: Variance-resolution curves for each of the three event types, solid markers for data, open markers for simulation.

In absence of a particular application, variance-resolution plots [3] were taken as a measure of image quality. Both parameters vary over image area and we limited ourselves to the region containing the largest (4.8 mm diameter) rod. Variance was estimated as the inverse of the pixel-wise SNR averaged over the region of interest. For image resolution, a virtual point source located at the center of the region was added to the sinogram during post-processing and reconstructed along the original sinogram. Images were subtracted to obtain reconstruction of the point source only, where area with pixel content exceeding half of the maximum content was taken as a resolution measure.

Measured data was compared to data simulated using point spread functions estimated during point source scans [4] and excellent agreement illustrated in Figure 2 was found.

Encouraged by the match, expected performance extending state-of-the-art rather than vintage detectors was estimated. We simulated 1000 mm diameter rings with both 4 mm and 2 mm sized crystals and compared performance of three event types. In both cases, probe-ring and probe-probe show significantly improved SNR irrespective of the resolution. The impact escalates at high resolutions, where as much as 100 times more ring-ring events are required for a matched SNR, inidicating great potential of PET probe imaging.

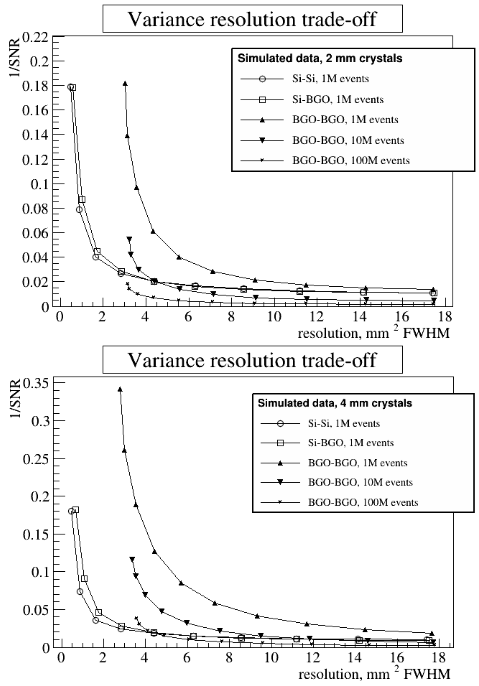

Figure 3: Data simulated for ring with a crystal size of 2 mm (top) or 4 mm (bottom) circumferrentialy. For ring-ring, number of events was varied between 1 and 100 million.

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