A novel image reconstruction algorithm to improve spatial resolution for scintillator-based gamma cameras.

Sai Vighnesh B[1], Koushik V[1], Sumukh Nandan R[1], S. G Singh[2,3], Shashwathi Sen[2,3], Murali Ravi[1*], Siva Sankara Sai S.[1]
[1]*Sri Sathya Sai Institute OF Higher Learning, Puttaparthi - 515134, INDIA*
[2]*Technical Physics Division, Bhabha Atomic Research Centre, Mumbai – 400085, INDIA*
[3]*Homi Bhabha National Institute, Mumbai- 400094, INDIA*
*. * email: muraliravi@sssihl.edu.in*

Introduction

Gamma cameras have been extensively used in the field of nuclear medicine [1] due to its unique capability of functional imaging. When compared with other medical imaging modalities like X-ray, ultrasound, etc. scintillator-based gamma cameras have low sensitivity, poorer spatial resolution and contrast.

Various algorithms like Anger logic, truncated centre of gravity (TCOG) and Raised to The Power (RTP) algorithms have been developed to improve the spatial resolution for scintillator-Position Sensitive Photomultiplier Tube (PS-PMT) based gamma cameras. They deliver high precision in event localization for monolithic and pixelated scintillators. These algorithms have drawbacks in terms of low localization accuracy, applicable for moderately high activity of the source for image reconstruction, and significant false positives as well as false negatives.

In order to overcome these drawbacks, our group has developed a probability distribution-based reconstruction algorithm with improved accuracy and flexible with variations in source activity. It reconstructs the image based on scintillation characteristics specific to the crystal in order to upscale the spatial resolution, unlike other algorithms that rely on bicubic interpolation for image reconstruction which are not advisable for medical imaging.

Drawbacks of existing reconstruction algorithms

Due to Anger logic, PS-PMT based gamma cameras have been able to achieve sub-anode size spatial resolution (limited by and equal to crystal pixel size). The algorithm attempts to precisely locate individual scintillation event based on centre of gravity of its spatial light spread over photocathode. For pixelated crystals, the intrinsic spatial resolution is limited by the crystal pixel size. As a consequence of polished edges, the spread of scintillated light is altered by internal reflection thereby leading to errors in scintillation localization. RTP algorithm [2] to some extent proved to be successful in reducing the spatial non-linearity caused by reflections in monolithic crystals. TCOG [3] algorithm subtracts a background ‘noise’ from the acquired data prior to performing RTP which reduces the contribution of stray radiation of lower energy.

The above algorithms may have good precision (based on their crystal pixel size in case of pixelated crystals) but have very low accuracy in cases of high-count rate**,** as they cannot handle localization of two or more simultaneous scintillation events. Especially for scintillators like CsI:Tl which have higher decay time and afterglow, these effects lead to degradation of image quality. They are precise but are not accurate in event localization and have a source activity range limitation, beyond which, they result in higher false negatives and false positives.

Probability distribution based reconstruction algorithm

The proposed novel image reconstruction algorithm does not attempt to locate individual scintillation events, rather, it attempts to plot a spatial probability distribution of scintillation events for a fixed number of counts per image (CPI). The algorithm i) acquires the data from the PS-PMT and bins the location of individual scintillation events to the location of corresponding anodes. ii) A matrix corresponding to the array of anodes is updated for every count until CPI counts have been detected. iii) The matrix dimensions are upscaled using nearest neighbour method (only for initial dimensional upscaling). Owing to the fact that scintillation light spread follows Poisson statistics [3], a Poisson distribution is plotted (values are sampled according to locations in the matrix) with the peak location at the centre of every pixel. The height of the peak equal to the counts at the corresponding anode and an FWHM equal to pixel size. iv) The matrix is then normalized and plotted.

Fig. 1 shows three phantoms imaged using 8x8 PS-PMT based gamma camera and their corresponding reconstructed images. We can clearly see the improvement in spatial resolution which is 49-fold (8x8 to 56x56) without use of interpolative methods. The phantoms are simulated in matlab and binned to 8x8 image. Small spots are lost due to multi anode binning.

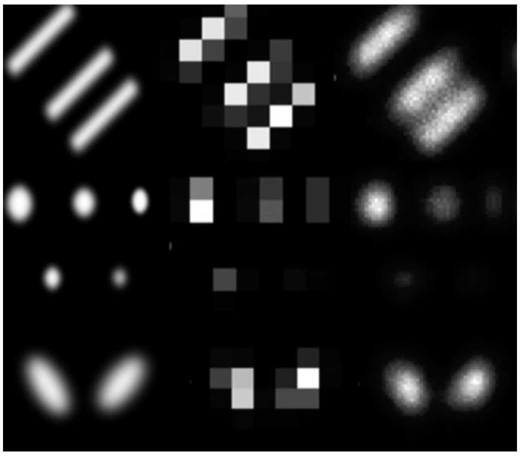

Fig. 1 Phantom images to the left, primary image developed based acquired data in the middle and reconstructed image to the right. (improved spatial resolution from 6mm to 0.85mm).

Shifting peak locations from the centre of pixel, based on counts detected at the adjacent anodes, further reduced the FWHM of lines spread function, thereby improving the spatial resolution. The limit of shift was set to lesser than half the crystal pixel size in order to maintain the accuracy of scintillation localizations. Fig.2 shows the reconstructed image and peak shifted image of a 6mm slant slit which reduced the image slit width from 13.6mm to 7mm(FWHM).

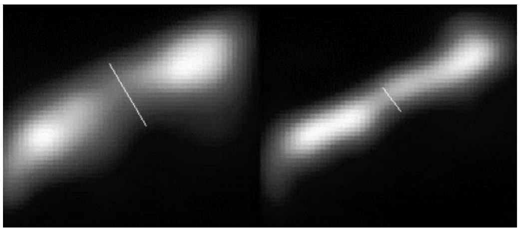

Fig. 2 A 5mm slant slit phantom reconstructed image to the left with width of 13.6mm (FWHM) and its peak shifted image to the right with slit width of 7mm.

In case of multiple events being detected simultaneously (a case of high instantaneous count rate with respect to count rate capabilities specific to the detector), the Anger, TCOG and RTP logic would result in detection of a single event located at the centroid of spatial distributions of scintillation events. This would yield a false positive at centroid and false negative at actual scintillation location. The novel algorithm, rather than locating the scintillation location at their centroid, plots the probable probability distribution at their respective individual locations, thereby being more accurate in scintillation localisation avoiding the false positives and false negatives at in cases of higher count rates.

It is a is applicable for gamma cameras with anode size, sub-anode size crystal pixels as well as monolithic crystals. However, the method of implementation may vary. It can be applied for single element as well as row column readout. Thus, the proposed non -interpolative super resolving algorithm provides flexibility with count rate as well as improved sensitivity and specificity.

References

[1] F. Yang, et.al, Int. J. Sci., vol. 4, no. 07, pp. 21–24, (2018)

[2] Pani, R, et.al, Nuclear Physics B - Proceedings Supplements, **197(1)**, 383–386, (2009)

[3] Pani, R., et.al, Journal of Instrumentation, 11 (2016).