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Crystal Identification in Positron Emission Tomography

Positron emission tomography is a radionuclide tomographic method of examining the internal organs of a person or an animal. It is an actively developing diagnostic and research method of nuclear medicine. This method is based on the possibility, with the help of special detection equipment (PET scanner), to track the distribution of biologically active compounds labeled with positron-emitting radioisotopes in the body. Modern Positron Emission Tomography (PET) detectors typically are made from 2D modular arrays of scintillation crystals. Their characteristic flood field response (or flood histogram) must be segmented in order to correctly determine the crystal of annihilation photon interaction in the system. Crystal identification information thus generated is also needed for accurate system modeling as well as for detailed detector characterization and performance studies.

The semi-automatic general-purpose template-guided scheme for segmentation of flood histograms was presented. It generates a template image that exploits the spatial frequency information in the given flood histogram using Fourier-space analysis. This template image is a lower order approximation of the flood histogram, and can be segmented with horizontal and vertical lines drawn midway between adjacent peaks in the histogram. The template is then registered to the given flood histogram by a diffeomorphic polynomial-based warping scheme that is capable of iteratively minimizing intensity differences. The displacement field thus calculated is applied to the segmentation of the template resulting in a segmentation of the given flood histogram. Then the scheme is evaluated segmentation scheme for a photomultiplier tube-based PET detector, a detector with readout by a position-sensitive avalanche photodiode (PSAPD) and a detector consisting of a stack of photomultiplier tubes and scintillator arrays. Further, the performance of the proposed method is quantitatively compared to that of a manual segmentation scheme using reconstructed images of a line source phantom.

For detailed characterization of PET detectors in a scanner and consequently, for accurate system modeling and image reconstruction, parameters like energy resolution, timing resolution and light collection need to be measured for each crystal in the system. This is because individual crystals even in the same detector array can have different detection efficiencies, varying energy deposition characteristics, and diverse optical photon collection properties.

Modern PET scanners typically have thousands of crystals. The most time consuming method for segmentation of flood histograms is to manually select the peaks by clicking at appropriate points on the computer screen and then use the binary file thus created (1 corresponding to pixels clicked and 0 otherwise) as an input to a standard segmentation method, e.g. the watershed method. A semi-automatic method where the manual process was replaced by background subtraction of the flood histogram followed by spatial filtering for noise removal and peak identification by intensity-based thresholding was developed by Mao. This method, however, was not robust for identification of edge crystals due to the hard thresholding condition and hence, considerable time was needed for manually correcting the segmentation. An approach using Gaussian mixture models (GMM) for segmenting flood histograms from multilayer GSO-based depth-of-interaction (DOI) capable detectors was proposed by Yoshida. Their approach performed well for complex flood histograms of individual blocks, but was impractical for the flood histogram of the whole detector because a large number of parameters for the GMM must be estimated.

The measured flood histogram was used to obtain the template then was registered to the target using fifth-order polynomial warping. Outcomes of the warping process are shown in Figure 1. The estimated transform was used to generate the modified target shown in Figure 1(a). Figure 1(b) shows the overlay of the estimated segmentation boundaries on flood histogram under consideration. After the segmentation process was repeated for another flood histogram obtained when the source was collimated at a depth of 18 mm from the PSPMT. The results in this case are shown in Figure 1(c). The flood histogram obtained from a singles mode measurement was also segmented and the results are shown in Figure 1(d). The procedure for segmentation for Figures 1(c) and (d) was the same as that for Figure 1(b), and hence, intermediate results are not shown. The computation time for obtaining the final segmentation in each case was around 47 sec for the (256 × 256) images. The proposed method indeed was able to segment all 196 crystals with reasonable accuracy in each of the three cases.

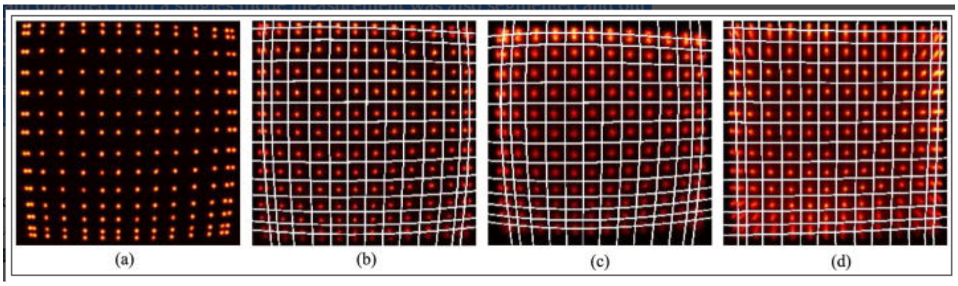

Figure 1- Segmentation of the PSPMT (multi-channel position sensitive with multiplexed readout, the X and Y positions)-based detector

The semi-automatic segmentation scheme presented here produced accurate delineation of crystals from flood histograms obtained from PMT-based and PSAPD-based PET detectors, including those with stacked detector geometries. While providing manual control necessary for exceptional cases, the scheme attempted to keep human involvement to the bare minimum. The adaptive method proposed for the generation of PSAPD flood histograms resulted in reduced spatial distortions and was found to be beneficial for crystal identification. The proposed segmentation method can easily be applied to a wide variety of PET cameras designs and potentially should facilitate accurate and accelerated system characterization.