Contribution ID: **17** Type: **Talk**

A novel DOI Positioning Algorithm for Monolithic Scintillator Crystals in PET based on Gradient Tree Boosting

Wednesday, 23 May 2018 11:20 (20 minutes)

Monolithic crystals are considered as an alternative for segmented scintillator arrays in positron emission tomography (PET). Monoliths provide good spatial, timing and energy resolutions as well as intrinsic depth of interaction (DOI) encoding. DOI allows reducing parallax errors (radial astigmatism) at off-center positions within a PET ring. This is especially important for high-resolution PET systems such as organ-specific applications (e.g. breast, neuro-imaging or total body PET). We present a new DOI estimation algorithm based on the supervised machine learning algorithm Gradient Tree Boosting (GTB). GTB builds a predictive regression model based on a set of sequential binary comparisons (decision trees). GTB models have been shown to be implementable in FPGA if the data usage fits the available memory resources. We propose two optimization scenarios for the best achievable positioning performance: One restricting the available data usage to enable a future FPGA implementation and one without any restrictions. The positioning performance of the GTB models is compared with a DOI estimation method based on an isotonic regression (IR) model of a DOI observable. The DOI observable is defined as the ratio of the highest photon count to the sum of the photon counts of neighboring sensor channels. The usage of a DOI observable is comparable to other methods presented in the literature. Among others, we calculate the spatial resolution (SR) as the FWHM, the bias vector and the 90-th percentile distance of the positioning error distribution to quantify the DOI positioning performance. A fan beam collimator coincidence setup was used to perform a side irradiate of a 32 mm x 32 mm x 12 mm large monolith wrapped in highly reflective Teflon tape. We achieved an averaged SR of 2.16 mm FWHM and 1.98 mm FWHM for the IR and GTB, respectively. In contrast to the IR models, the GTB models show a nearly uniform positioning performance over the whole crystal depth: The SR varies from 1.5 mm to 2.7 mm FWHM minimum to maximum for the GTB instead of 0.9 mm to 5.6 mm FWHM for the IR models.

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Session Classification: Session 11 - Instrumentation: detectors and electronics