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Pushing the limits of high resolution detectors based on monolithic scintillators for fast timing in PET with an AI-boosted 4D positioning algorithm

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In the framework of the UTOFPET project, a new TOF-PET detector prototype has been developed to provide uncompromised beyond-state-of-the-art performance. The proposed technology is based on a monolithic LYSO scintillator coupled to a matrix of 16 x 16 SiPMs which is well known to be capable of a high intrinsic spatial resolution but is typically not considered the best solution for providing excellent timing performance.

To solve this issue and make monolithic crystals suitable for time-of-flight PET we have processed, in real-time, the 256 signal outputs with a novel algorithm for estimating simultaneously and synergically the 4D event position coordinates (x, y, depth and time). The algorithm is based on a neural network (NN) and and it is trained with both experimental and Monte Carlo generated data. The NN has a computational complexity and a memory footprint low enough to allow a per-detector, real-time hardware implementation in modern, low-cost FPGAs.

In our implementation, the SiPM outputs are read by 16 HRFlexToT ASICs and are digitised by an array of TDCs implemented on FPGA. A SoC-FPGA on the back of the detector runs the NN that processes the outputs of the TDCs to generate the event position, time and energy at input rates that exceed 1 MHz. Event data are stored on a local memory and then transmitted to a host PC via Ethernet connection.

The results obtained with a 51.8 x 51.8 x 12 mm3 crystal indicate performance beyond the state of the art with an event positioning precision of 0.8 mm, a DOI of 1.4 mm, a CTR of 150 ps and an energy resolution of 11%.

This work reports a description of the UTOFPET detector with details on the algorithm and the method used for the training of the neural network together with the experimental results obtained.

Although the UTPFPET detector seems to have reached its limits, the proposed AI-enhanced methodologies may contribute to breaking the 100 ps limit in CTR when new fast materials become available.

Authors: CIARROCCHI, Esther (University of Pisa); BISOGNI, Maria Giuseppina; BELCARI, Nicola; SPORTELLI, Giancarlo (University of Pisa); MORROCCHI, Matteo (University of Pisa / Infn Pisa); CARRA, Pietro; ROSSO, valeria

Presenter: BELCARI, Nicola

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