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High Resolution Detectors Based on Continuous Crystals and SiPMs for Small Animal PET

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High performance detectors based on continuous crystals coupled to SiPMs have been assembled and tested for the development of a sub-millimetre resolution small animal PET prototype.
The prototype consists of two rotating heads, each made of a continuous 12x12mm LYSO crystal coupled to a monolithic, 64- pixel SiPM matrix from FBK-irst. Detectors with 5 mm and 10 mm thick crystals have been assembled and tested. A position determination method including depth of interaction (DOI) determination has been applied. The results of a detailed GEANT4 simulation including generation and transport of optical photons in the crystal has been satisfactorily compared with the experimental data. The intrinsic spatial resolution obtained in x and y with real data is 0.7 mm FWHM. DOI determination experiments with 5 and 10 mm thick crystals are being carried out.

In order to test the imaging capabilities of the detectors, tomographic data have been acquired rotating the detectors around the source. Different Na-22 radioactive sources have been successfully imaged demonstrating the feasibility of the detector concept. A list-mode image reconstruction algorithm has been employed to fully exploit the continuous nature of the data. The FWHM of the reconstructed point sources ranges from 0.7 to 1 mm FWHM, which provides confidence that sub-millimetre spatial resolution is achievable with this detector concept.

Optional extended abstract

High performance detectors based on continuous crystals coupled to SiPMs have been developed and tested for the construction of a high resolution PET prototype that has been assembled at IFIC Valencia, in collaboration with the University of Pisa and INFN Pisa. The prototype consists of two rotating heads. Each head is composed of a 12x12mm LYSO crystal coupled to a monolithic, 64 pixel SiPM matrix from FBK-irst. The MAROC2 ASIC is employed for readout and two detectors with two MAROC2 boards are set in time coincidence for the operation of the prototype.

The characterization of the detector heads shows an energy resolution of 15% FWHM at 511 keV with 5 mm thick crystals[1]. The determination of the interaction position is being conducted with a method based on the analytic model of the solid angle subtended by the interaction position in the crystal with the SiPM elements in the array. The method determines the interaction position in 3D, including depth of interaction (DOI) information[2]. The spatial resolution is around 0.7 mm FWHM in x or y both for 5 mm and 10 mm thick crystals. Tests are ongoing for the DOI determination with real data. Geant4 simulations have been carried out, modeling the production and transport of optical photons and varying the model of reflection of the photons on the sides of the crystal. The simulations successfully reproduce the detector response in both cases and can be used to predict the system response in different conditions.

In order to test the imaging capabilities of the detectors, tomographic data have been acquired with Na-22 radioactive sources, including one and two point sources, and a disc source. Data are taken with the detectors at 6 positions from 0° to 180°, with 30° steps, in order to cover the field of view. Images have been successfully reconstructed demonstrating the feasibility of the detector concept[3].

In image reconstruction from list-mode data, the simulated One-Pass List-Mode (SOPL) algorithm [4] has been applied to fully exploit the continuous nature of the data. SOPL is based on an analytical multi-ray method where the ray-end points are estimated in the continuous detector and the corresponding matrix elements are computed on-the-fly. In contrast with traditional multi-ray methods based on discrete data, improved spatial resolution has been observed in preliminary studies. The FWHM of the reconstructed point sources is 0.8 mm FWHM, which provides confidence that submillimetre spatial resolution is achievable with this detector concept.

[1] G. Llosá et al., Characterization of a PET detector head based on continuous LYSO crystals and monolithic 64-pixel silicon photomultiplier matrices. Phys. Med. Biol., 55, 7299-7315, 2010.
[2] Li Z. et al. Nonlinear least-squares modeling of 3D interaction position in a monolithic scintillator block. Phys.
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[3] G. Llosá et al. Development of a PET Prototype with Continuous LYSO Crystals and Monolithic SiPM Matrices. 2011 IEEE NSS MIC Conference Record. MIC18.M-020. P 3631-3634. CDROM. ISBN 978-1-4673-0119-0.
[4] J.E. Gillam et al. Simulated One-Pass List-Mode: A Highly Flexible Method of Image Reconstruction for PET. IEEE Nuclear Science Symposium Conference Record, 2011 MIC21.S-162. P 4206-4210.

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