High-Sensitivity PET using Optimised Continuous Cylindrical Shell Nanocomposite and Transparent Ceramic Scintillators

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Certificate of Authorship / Originality

I, Keenan Wilson declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Electrical and Data Engineering at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution.

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Abstract

Positron emission tomography (PET) systems typically employ 2D or 3D arrays of discrete monocrystalline rectangular prismatic scintillators, arranged in a ring around the imaging object. As PET systems have evolved towards higher spatial resolution and sensitivity, the number of crystals has increased while the dimensions of the crystals have decreased, leading to ever-increasing costs and complexity - particularly in total-body PET. At the same time, the need for optical isolation between crystals limits packing efficiency and hence achievable sensitivity. The chief alternative to discrete-crystal PET - monolithic scintillators with external photodetector arrays - introduces its own challenges, since producing large, high quality scintillator crystals is expensive and technically challenging.

Two new classes of scintillator have recently emerged as alternatives to monocrystalline scintillators for gamma detection - nanocomposites, which combine scintillating nanoparticles with an organic polymer binder - and transparent ceramics. Both are cheaper and easier to manufacture than monocrystalline scintillators, and can be more easily formed into complex shapes - however, they are also less transparent and, in the case of nanocomposites, less dense. Neither has previously been employed in PET systems to any significant degree.

In this work, a new PET system design is proposed which exploits the properties of these new scintillators. Instead of discrete crystals or flat monolithic slabs, the scintillator is formed into a continuous cylindrical shell, tiled on the inner and outer surfaces with silicon photomultiplier photodetectors. The design aims to achieve high sensitivity and competitive spatial resolution compared to similar discrete-crystal PET systems.

Five nanocomposite and four transparent ceramic scintillators are evaluated, and an optimisation method developed to maximise the probability of locating interactions between 511 keV photons and the scintillator within a given tolerance. A technique for localising the endpoints of the lines of response in a monolithic cylindrical shell is developed and evaluated for the best materials of both types. A coincidence detection method based on deconvolution and spatio-temporal partitioning of photon clusters is developed and evaluated. Finally, a simulated PET scan of several point sources inside the optimised scanner is performed, and images reconstructed using analytic and iterative algorithms; spatial resolution and sensitivity are evaluated.

The promising results obtained in this work establish the feasibility of the proposed design and confirm that the design objectives can be achieved. The design offers a markedly different design envelope to conventional PET, and suggests a new pathway to lower-cost total-body PET.

Dedication

For my wife, Yukti.

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