Vrije Universiteit Brussel
Interuniversity Institute for High Energies

ARTIFICIAL NEURAL NETWORK BASED POSITION ESTIMATION IN POSITRON EMISSION TOMOGRAPHY

Author
MATEUSZ WĘDROWSKI

Promotors
Prof. Peter Bruyndonckx
Prof. Stefaan Tavernier

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Doctoral examination commission:
Prof. Michel Defrise (AZ ULB) - chairman
Prof. Peter Bruyndonckx (ELEM VUB)
Dr Denis Schaart (TU Delft)
Prof. Stefaan Tavernier (ELEM VUB)
Prof. Gerd Vandersteen (ELEC VUB)
Prof. Karl Ziemons (FZ Jüelich/FH Aachen)

Summary

Gamma detection in nearly all commercial positron emission tomography (PET) scanners is based on the use of block detectors with a large number of small scintillator pixels. One of the important factors limiting the spatial resolution in PET scanners using this approach is the uncertainty of the exact depth of interaction of the gamma ray in the crystal. Using one large and undivided piece of scintillator where the position of the gamma interaction is extracted from the light distribution in the block, allows overcoming this limitation. At the same time, the sensitivity of the scanner can be increased by avoiding inter-crystal dead spaces. However this approach tends to produce poor results if simple minded methods, such as centre of gravity, are used to determine the position of the gamma interaction in the crystal block. On the other hand, if machine learning algorithms such as artificial neural networks are used, excellent performance is obtained. With the dramatic increase of computing power in recent years, this is now a realistic approach to real-time gamma detection in PET scanners.

Usage of avalanche photo diodes (APD) is an alternative to photomultiplier tubes (PMT). Generally a PMT is cheaper and has a higher output signal, so that in standard PET applications PMTs are still more common. Nevertheless, a PET scanner by itself, as a separate device, is getting less and less competitive with respect to integrated multi-modality solutions. In the case of PET coupled to magnetic resonance imaging (MRI) the detectors are exposed to intense magnetic fields. This excludes the usage of PMT and makes APD competitive. The recently developed silicon photo-multiplier (SiPM) detectors seem to have even more potential.

The goal of this thesis is to investigate the intrinsic detector spatial resolution behaviour of $20 \times 20 \times 10\,\mathrm{mm}^3$ monolithic Lutetium Orthosilicate (LSO) scintillator block PET detector based on Hamamatsu S8550 APD light sensor with the artificial neural network (ANN) applied as the estimating algorithm. The conditions of measurements and analysis are based on realistic scanner operation. The robustness of the neural network is studied on several parameters as the incidence beam angle, random fraction in data, APD high voltage and temperature fluctuations. Finally a comparison with alternative light sensors for a monolithic block detector design is done. The data from 64-multichannel PMT and 16-channel SiPM based detectors are studied individually to apply the same resolution reconstruction conditions.

The research is done in the framework of the Crystal Clear Collaboration in cooperation between CIEMAT Madrid/Spain, Forschungszentrum Jülich/Germany and Vrije Universiteit Brussels. The data from alternative detector designs are analysed by courtesy of the group from the University of Technology Delft and from The University of Science and Technology of China (UTSC).

In chapter 1 the basic physics processes and the main PET characteristics are explained. First the concept of tracers is explained. Then the PET principles as annihilation detection with other effects are described. In the later part of the chapter, the most important PET factors are looked into i.e. spatial resolution, sensitivity, noise and energy resolution.

In the first part of chapter 2 the scintillator material is described, its characteristic, mechanism of operation and most common types. The second part is devoted to a discussion of light sensors such as PMT and photo diodes. The biggest emphasis is put on APD detector, its principles and main parameters. Promising SiPM detector is described.

Chapter 3 is the introduction to the presentation of the result. The advantages of the monolithic scintillator blocks based on APD design and the details of the aim of the project are explained. The detector set-up structure and signal processing idea are described and the artificial neural network algorithm is referred to.

Chapter 4 summarises the investigation done for APD based detectors. The first part describes the data structure and data acquiring process. All calibrations and preparation for measurement are specified. Then the ANN structures applied for the spatial resolution estimation are explained. The last part shows the result of the ANN robustness studies.

The comparison between data obtained with different detectors is presented in chapter 5. In this chapter, the first three sections present an analysis of the data obtained with obtained with with two detectors using of PMT and one detector using of SiPM. The last section presents conclusion from a comparison between these detectors.