Use of machine learning algorithms for gamma detection in positron emission tomography

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Dedicated Positron Emission Tomography (PET) scanners such as small animal PET, Positron Emission Mammography (PEM) or Brain PET scanners, all require high spatial resolution and high sensitivity. Most current designs use small scintillation crystals. The general approach to improve the spatial resolution in such designs is to decrease the crystal size. However, the decreased pixel size results in loss of sensitivity because of the increased dead space between the pixels. If the sensitivity of the PET scanner is insufficient, the obtained images have to be smoothed to reduce the image variance. Obviously, this results in a loss of image resolution and hence the potential of the system is not fully exploited. To obtain a maximum coincidence rate, the sensitivity of the detectors in the PET system has to be optimized. This can be achieved by increasing the thickness of the scintillators used to stop the 511 keV annihilation photons and by minimizing the dead spaces in the detector design. However, these design changes should not degrade the spatial resolution of the scanner.

To achieve this goal we developed detectors based on monolithic scintillator blocks that are read out by avalanche photodiodes (APDs). This increases the sensitivity due to the absence of optical separation material between the individual scintillation pixels used in current PET designs. The position information within the scintillator block is embedded in the shape of the scintillation light distribution. This principle of light spreading allows the scintillator block to be larger than the sensitive area of the photo detector, avoiding dead space due to the packaging of the photo detector. This again enhances the sensitivity. In this perspective, the detector module had to be based on new technologies. For the scintillator part, Lutetium Orthosilicate (LSO) was chosen because of its high light yield, good stopping power and short decay time. The S8550 APDs were chosen as photo detector. These presented a number of advantages relatives to position sensitive photomultiplier tubes (PSPMTs) in the applications of interest.

In this thesis, the characteristics and implementation of the monolithic LSO scintillator blocks in combination with a machine learning positioning algorithm were evaluated, via simulations as well as experimentally on a bench set-up and on a prototype scanner. First three different positioning algorithms were tested experimentally on the bench set-up. To this end, following positioning algorithms were evaluated: Levenberg-Marquardt Neural Networks (LM-NN), Neural Networks trained with an algebraic method (Alg-NN) and Support Vector Machines (SVM). The position information is extracted from the measured scintillation light distribution generated in monolithic LSO blocks of various shapes and read out by the Hamamatsu S8550 APD array.

The data acquired for the positioning algorithm evaluations were done on an “academic” bench set-up. In order to evaluate the block detectors in a real compact PET environment, a prototype PET demonstrator was built. The demonstrator consists of only two 20x10x10mm3 LSO detector modules. To simulate a full-ring scanner, the detector modules are mounted on separate rotating platforms which allow the movement of both detector modules, also relative to each other. In addition, since the detector characteristics may change in time, it is also appropriate to acquire new training data from time to time. The use of an auxiliary bench set-up for this calibration procedure implies the removal, calibration and re-mounting of all detector modules of the scanner. This would be a time consuming and tedious task. That’s why an automated acquisition method of training data for the positioning algorithm is investigated. The implementation and validation of this procedure was done on the demonstrator set-up.

A slight difference in the spatial resolution between the bench set-up and the demonstrator set-up was noticed. In order to study the origin of this difference and which instrumentation parameters limit the performance of the whole system, a GATE based Monte Carlo simulation was developed. Training data were simulated using the parameters that represent the experimental set-ups. After training, the NN was evaluated using simulated data generated with the same parameters except that the photon beam is assumed to be perfect now, i.e. a zero beam width. The resulting resolution will hence only reflect the influence of the detector components and the data acquisition method, i.e. it represents the intrinsic detector resolution.

Finally; the spatial resolution in 2D reconstructed images of the monolithic front-end detectors in combination with the trained LM-NNs is also examined. The radial and tangential resolutions as function of the radial source position were tested. To conclude, a mini-Derenzo phantom filled with FDG showed very encouraging results and corresponds with the expectations according to the outcomes of the studied point sources.