

A 2D Positioning Application in PET Using ANNs

Fernando Mateo

Universidad Politécnica de Valencia, Spain

Ramón J. Aliaga

Universidad Politécnica de Valencia, Spain

Jorge D. Martínez

Universidad Politécnica de Valencia, Spain

José M^a Monzó

Universidad Politécnica de Valencia, Spain

Rafael Gadea

Universidad Politécnica de Valencia, Spain

INTRODUCTION

Positron Emission Tomography (PET) is a radiotracer imaging technique based on the administration (typically by injection) of compounds labelled with positron emitting radionuclides to a patient under study. When the radio-isotope decays, it emits a positron, which travels a short distance before annihilating with an electron. This annihilation produces two high-energy (511 keV) gamma photons propagating in nearly opposite directions, along an imaginary line called Line of Response (LOR).

In PET imaging, the photons emitted by the decaying isotope are detected with gamma cameras. These cameras consist of a lead collimator to ensure that all detected photons are propagated along parallel paths, a crystal scintillator to convert high-energy photons to visible light, photo-multiplier tubes (PMT) to transform light signals into electric signals, and associated electronics to determine the position of each incident photon from the light distribution in the crystal (Ollinger & Fessler, 1997).

We have researched on how Artificial Neural Networks (henceforth ANNs or NNs) could be used for bias-corrected position estimation. Small-scale ANNs like the ones considered in this work can be easily implemented in hardware, due to their highly parallelizable structure. Therefore, we have tried to take advantage of the capabilities of ANNs for modelling the real detector response.

BACKGROUND

Traditionally, Anger logic (Anger, 1958) has been the most popular technique to obtain the the position of the *centroid*, or centre of the light distribution inside the scintillator crystal by means of a simple formula. The solution proposed by Anger involves connecting the PMT outputs to a simple resistor division circuit to obtain only four signals (X^- , X^+ , Y^- , Y^+). However, Anger logic introduces some important drawbacks in the detection process: non-uniform spatial behaviour, differences between each PMT gain or the deformation of the light distribution when it approaches the edge of the scintillator. These problems are alleviated by using correction maps.

However, the presence of all these phenomena in traditional detectors still reduces the intrinsic resolution and produces non-uniform compression artifacts in the image and the so called border effects. The main consequence is an unavoidable reduction of the *Useful Field Of View* (UFOV) of the PET camera, which usually covers up to 60% of each crystal dimension.

With other methods such as *Statistics Based Positioning* (SBP) or *Maximum Likelihood* (ML) positioning, this UFOV can be increased to approximately the 80% of each dimension of the crystal, but these methods involve a heavier computational cost (Joung, Miyaoka, Kohlmyer & Lewellen 2001)(Chung, Choi, Song, Jung, Cho, Choe, Lee, Kim & Kim, 2004).

These drawbacks have not been fully overcome yet. Therefore, our proposal to introduce ANNs in the detection process as good quality estimators is well-grounded.

Some previous research has been made in this area for PMT (A.M. Bronstein, M.M. Bronstein, Zibulevsky & Zeevi, 2003) and Avalanche Photodiode (APD) based (Bruyndockx, Léonard, Tavernier, Lemaître & Devroede, 2004) detectors using neural networks. In this work, the detectors are based on continuous scintillators and Multi-Anode PMTs (MA-PMTs) employing charge division read-out circuits (Siegel, Silverman, Shao & Cherry, 1996).

ANN APPROACH TO 2D POSITIONING IN PET

Materials and Methods

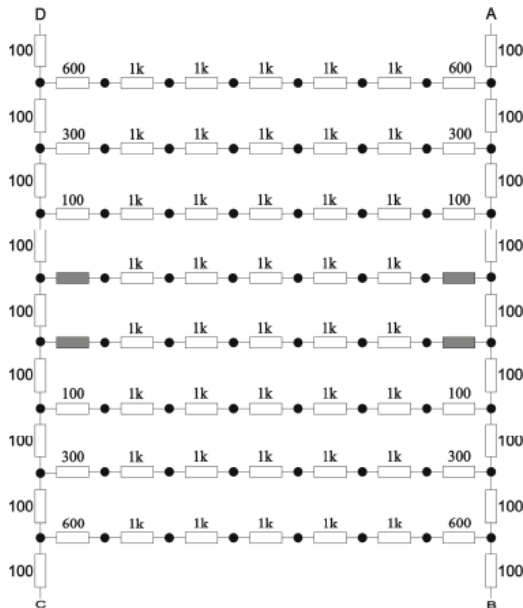
We have employed the GEANT4 (Agostinelli, 2002) simulation toolkit to model the detector and to generate realistic inputs for the NN. The electronic read-out of the resistor circuit was performed with SPICE analysis. The supervised training and validation of the ANNs have been carried out with the MATLAB Neural Networks

Toolbox (The Mathworks, Inc., 2004). We have chosen the RPROP algorithm (Riedmiller & Braun, 1993) because it proved to converge faster than the standard gradient descent algorithm and other variants such as the Levenberg-Marquardt algorithm. Radial basis (RB) networks were also considered but were discarded in the end due to their inferior performance.

Detector Characteristics

The model of the detector under study comprises a $49 \times 49 \times 10 \text{ mm}^3$ continuous slab of LSO scintillator crystal coupled to a Hamamatsu H8500 Flat-Panel MA-PMT. The read-out electronics is a conventional DPC-like resistive charge division circuit that proves to model Anger's logic accurately. Taking the resistor network pattern used by Aliaga et al. (Aliaga, Martínez, Gadea, Sebastián, Benlloch, Sánchez, Pavón & Lerche, 2006) as a starting point, we have designed a new resistor network based on the architecture proposed by S. Siegel (Siegel, Silverman, Shao & Cherry, 1996) (Fig. 1) that allows us to estimate the 2D positioning with better results. As in the previous design, all 64 channels (one per anode of the H8500) are coded into only 4 output lines, which are then fed into current sensitive preamplifiers. The current-ratio matrices A, B, C and D corresponding to each output were obtained from electronic read-out using SPICE analysis. The network was analyzed applying the superposition theorem for electric circuits.

Figure 1. Siegel's DPC diagram



Neural Networks

Given a collimated source S of γ photons with origin at (x_s, y_s, z_s) emitting perpendicularly to the detector surface, we can describe the interaction of a photon in the detector as a random variable $X \rightarrow \mathbf{A}$, being, \mathbf{A} a vector of elements a_i , the number of photoelectrons arriving at each anode of the MA-PMT. Thus, the elements of the vector \mathbf{J} are the inputs of the NN, which can be written as

$$J_k = \sum_i A_i \cdot G_i \cdot R_{i,k} \quad (1)$$

where J_k is the k th output of the charge division network, G the vector of pad gains of the MA-PMT (in our case randomly distributed between 1 and 3) and

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