Next Generation PET for Human Brain Study

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ABSTRACT

Conceptual design of the next generation PET with both high sensitivity and high spatial resolution has been performed. A detector unit using a depth encoding scheme was designed and constructed for trial. The unit consists of four Gd_2SiO_5:Ce crystal blocks in a 2x2x4 array coupled to a position-sensitive photomultiplier tube having metal channel dynodes and 4x4 multi-anodes. Our proposed detector is a very reliable and simple solution suitable for volume PET devices since the proposed depth encoding scheme does not need additional photo-detectors.

Keywords: Positron emission tomograpy, depth of interaction, scintillation detector, nuclear medicine.

1. INTRODUCTION

In PET scanners, thinner crystals are of great benefit for coincident events at the center of the field of view (FOV) to obtain better image resolution and sensitivity, while the resolution in the radial direction degrades toward the peripheral FOV because of the crystal penetration of obliquely incident gamma rays. This effect, commonly referred to as a parallax error, causes the radial elongation artifact that has long been recognized as an obstacle to high resolution PET in 2D data acquisition mode. Especially in full 3D data acquisition mode, the parallax error limits the system volumetric spatial resolution even in the central region of FOV with increasing the acceptance angle. The method for eliminating the parallax error without reducing sensitivity is to use the detector module that measures the depth of interaction (DOI) of incident gamma rays. A next generation PET using DOI detectors may perform both high sensitivity and high spatial resolution as shown in Fig. 1.

We are planning to construct a prototype PET scanner for human brain study with high sensitivity, high spatial resolution and high count rate performance. Our designed scanner has 25 cm axial filed-of-view and 38 cm detector-ring diameter. DOI detector, namely, 3D matrix detector unit, is most important key technology for the next generation PET and is now under development in our institute.

2. MATERIALS AND METHODS

The 3D matrix detector unit has been extremely successful in positioning performance and there is a distinct peak in the distribution for each crystal element in the block by flood source measurements[1]. Each crystal element can be easily distinguished, so that it allows accurate identification of the element in which a scintillation event takes place. This would be the principal advantage over a continuous block detector configuration for reliable operation and the daily checking of large numbers of detectors. A disadvantage of the detector unit comes from a large size of each PMT coupled to each small crystal element. In a practical application of the detector unit for PET, one-to-one coupling between a crystal and a PMT is apparently unsatisfactory for efficient optical coupling in a tightly packed crystal block array. A solution of this difficulty may be the use of a position-sensitive photomultiplier tube (PS-PMT).

A detector unit using a depth encoding scheme was designed. The unit consists of four Gd2SiO5:Ce (GSO) crystal blocks in a 2x2 array coupled to a PS-PMT having metal channel dynodes and 4x4 multi-anodes[2]. Figure 2 shows a schematic diagram of the detector unit. Element (i,j,k) represents the crystal segment which belongs to the i-th block and the j-th stage and is located on the k-th quadrant in a block. The four elements in the bottom stage in each block are optically coupled to the face plate of the PS-PMT, where each position of the sixteen bottom crystal elements in all the blocks corresponds to that of each anode segment. The position of a crystal element absorbing a gamma photon is detected by applying Anger-type position arithmetic to the output signals from PMT anodes. In each block, the crystal elements are coupled to each other with air gaps, various coupling compounds, or reflectors, so that the light sharing among elements can be optimized to identify each crystal element clearly in the positioning logic.

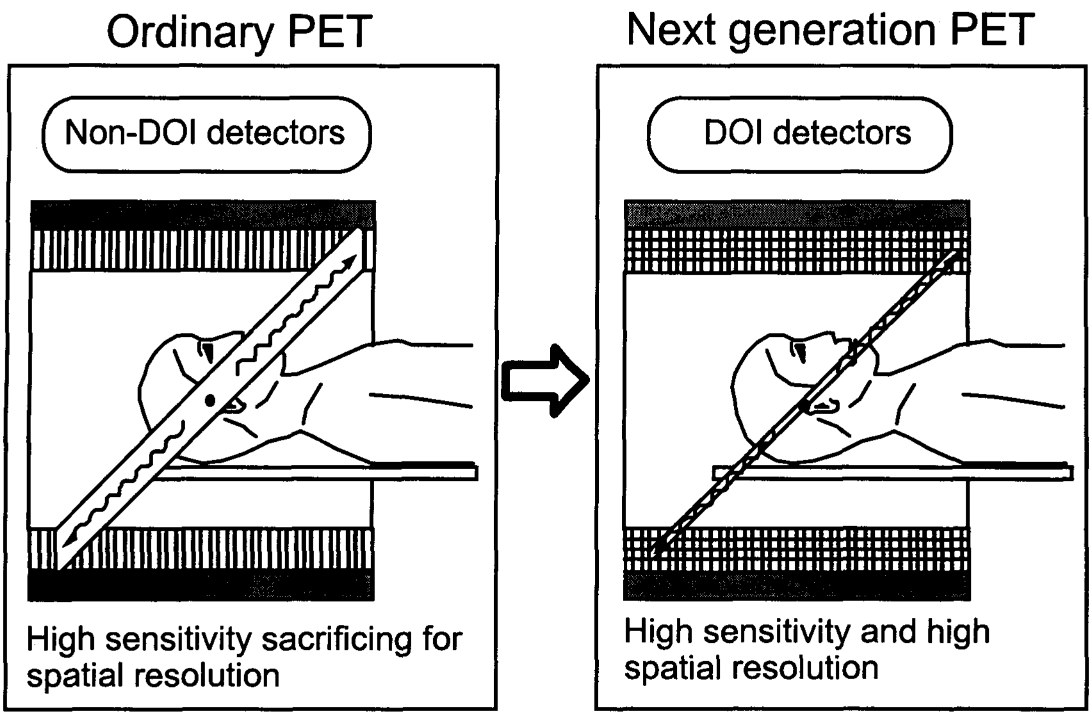

Fig. 1. Schematic drawing of an ordinary PET and a next generation PET.

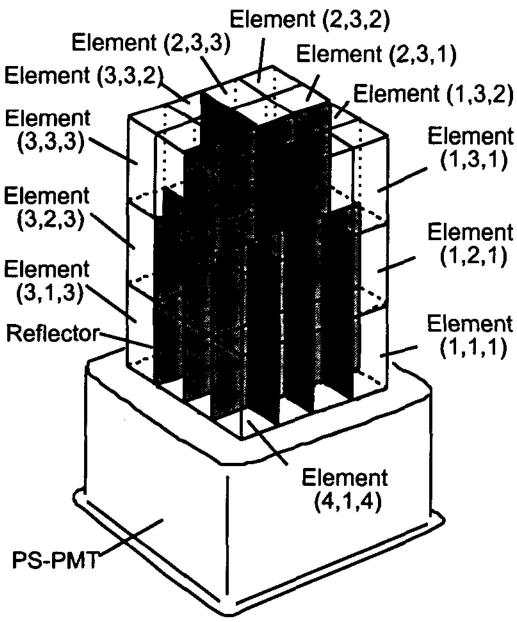

Fig. 2. Schematic drawing of the dept encoding detector.

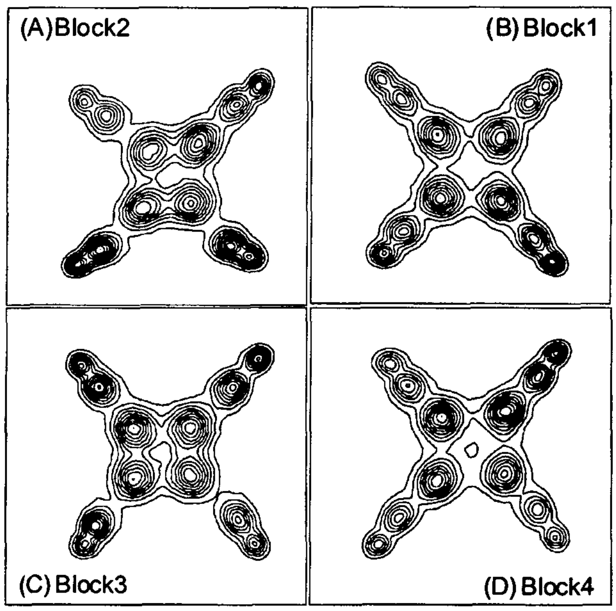

Fig. 3. Positioning contour image histogram for the three stage detector unit.

3. EXPERIMENTS AND RESULTS

The dimensions of GSO crystal elements used in the following experiments are 3.8 mm x 3.8 mm x 10 mm. All the surfaces of each crystal are mirror-polished. In a 2x2 array, each crystal element of the top stage was optically coupled to each other with air gaps, while each crystal element of the middle and bottom stages was optically separated from other elements in the same stage with two layers of 0.1 mm thick PTFE (polytetrafluoroethylene, Teflon) tape. Each stage of 2x2 array was wrapped with a 0.2 mm thick PTFE tape and stacked together to form a three-stage crystal block with Silicone oil (refractive index = 1.4). Four crystal blocks were coupled to a multi-anode PS-PMT (Hamamatsu R5900-M16).

A 3D matrix detector unit was assembled with the four (2x2) crystal blocks and the PS-PMT. Each crystal block was optically isolated from each other and was placed on each quadrant of the PS-PMT. A 0.1 mCi Cs-137 (662 keV) point source was used for gamma ray irradiation to examine the positioning performances. Figure 3 shows four 2D positioning histograms, (A), (B), (C), and (D), obtained with the anode signals in four individual quadrants of the PS-PMT, respectively. In this histogram, 48 peaks are clearly visualized corresponding to the individual crystal elements. The energy resolutions for the bottom, middle and top stages are 17, 21, and 21 % and the relative pulse height values for those stages are 1.0, 0.62 and 0.50, respectively.

The results obtained in the scanning slit source experiment in Figures 4 and 5 suggest that the light sharing method identifies the DOI with reasonable accuracy. More than 90 % of events are correctly assigned to a stage when the source beam falls onto the center of that stage. The results obtained in Fig. 6 also suggest that the row and column of the crystal array are recognized with reasonable accuracy. The deep valleys at the center of the responses correspond to layers of PTFE tapes among the crystal blocks. Our proposed detector should be a very reliable and simple solution suitable for volume PET devices since the proposed depth encoding scheme is constructed with all the same crystal elements and does not need additional photo-detectors nor a combination of different types of scintillators.

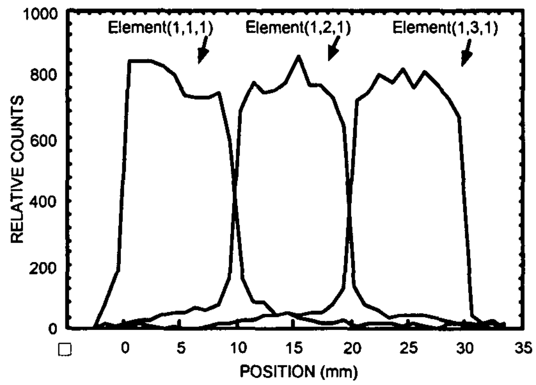

Fig. 4. Responses of the elements (1,1,1) (1,2,1) and (1,3,1) to a Cs-137 collimate beam scanned across the face of the detecto unit along depth direction.

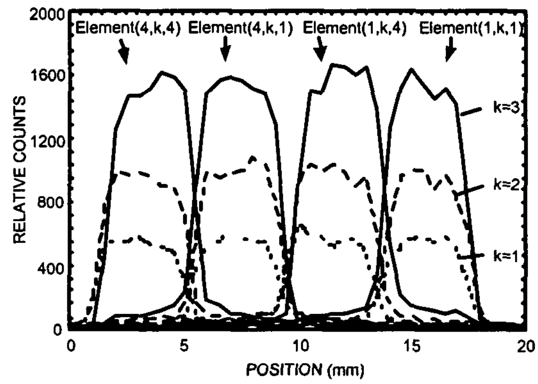

Fig. 5. Responses of the elements (1,k,1), (1,k,4) (4,k,1) and (4,k,4) to a Cs-137 collimated bea scanned across the face of the detector unit alon row direction (k = 1, 2 and 3).

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