Fundamental Research on a Whole Body PET Scanner Using 3D Position Sensitive Semiconductor Detectors

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論文内容要約

Chapter 1 Introduction

In current human whole body PET scanners, the axial field of view (FOV) is short (typically, ~20 cm) and large fraction of the body is outside the FOV. Moreover, scintillation detectors are used which limits the spatial resolution due to large detector size. On the other hand, semiconductor detectors are flexible in downsizing and fine arrangements and can provide a resolution of ~1 mm. The aim of this research is to study the performance of a large axial FOV whole body PET scanner constructed from 3D position sensitive semiconductor detectors in order to achieve high sensitivity and fine spatial resolution so that we can obtain information about metabolism and correlate each other. The objective also includes developing a technique for the reduction of calculation time of the system matrix as well as reduction of number of detector rings.

Chapter 2 Use of Positron to PET

In PET, positron-emitting radionuclides are injected into the patient intravenously. The distribution of the compound in tissues is determined by its biochemical properties. These tracer compounds can then be used to track biochemical and physiological processes *in vivo*. When the radioactive substance decays, a positron will be emitted with a certain kinetic energy and travels some distance (known as the positron range) and then combined with an electron before annihilation occurs. This puts a limitation on the spatial resolution of the PET scanner. Moreover, the positron and the electron are not at rest when the annihilation occurs and due to residual momentum the photons will not be emitted at exactly 180^0 rather with a deviation of $\pm 0.25^0$ (0.5^0 at FWHM). This effect is known as the non-collinearity and has an impact on the spatial resolution of the scanner. In the case of our whole body PET, the non-collinearity effect is estimated as ~1.32 mm. After the annihilation occurs, the photon emitted will interact with the surrounding materials (the tissues, detectors …).　The two major mechanisms by which the emitted photons interact with matter are: the photoelectric effect and the Compton scattering. In the PET systems, to avoid

Compton scattering effect, we set threshold energy for γ-ray detection. Threshold energy of 270 keV is usually adopted.

Chapter 3 Detectors for 3D whole body PET scanner

Factors that affect spatial resolution include the detector size and lack of depth of interaction (DOI) information. Current PET scanners use scintillation detectors, and downsizing scintillators to small elements is limited to 2 ~ 4 mm and hence the spatial resolution is affected. Moreover, it is difficult to obtain DOI information with scintillator coupled with photomultiplier tubes (PMTs). On the other hand, semiconductor detectors are flexible in downsizing and fine arrangements and can provide a resolution of ~ 1mm. Among semiconductor detectors, the material of choice for PET scanner is CdTe which has high sensitivity for 511 keV and can operated at room temperature. Downsizing of detector elements provides a high resolution. However, it reduces the packing fraction of the detector and hence the sensitivity decreases. To address this problem, a 2D position sensitive detector (2D PSD) is developed in Ishii-laboratory based on charge division method, and the 3D PSD can be formed by stacking the 2D PSD. The detection position of a 3D PSD is obtained as follows; transaxial position: determined by specifying a hit detector, axial position: determined by a hit strip, and DOI: is determined by calculating a hit position. The position resolution of our 3D PSD is Δx ~ 1mm, Δy ~ 1mm, and Δz ~ 1 mm.

Chapter 4. Design of whole body PET scanner and its basic performance

In the simulation, the whole body PET scanner is constructed as follows. The 2D PSD is composed of 16-strip Cadmium Telluride (CdTe) each with a dimension of $1 \times 40 \times 1.1 mm^3$ and arranged axially with a strip pitch of 1.2 mm. A module is formed by arranging four 16-strip 2D PSD axially with a pitch of 0.1 mm. A 3D PSD is formed by stacking 2D PSD module with a pitch of 1.25 mm. One ring of the scanner consists twelve 3D PSD blocks, and has a diameter of 600 mm and an axial FOV of 76.7 mm. There are 32 DOI layers in the radial direction each with 1.25mm pitch. This is obtained by applying charge division method. The radial detector thickness, number of rings and gaps between two adjacent rings were varied. By adjusting a 5-ring system, we can observe metabolisms in important organs and obtain correlation between them (Fig. 1). The point source and absolute sensitivity of the proposed scanner was estimated from a point source and line source respectively (Fig. 2). The noise equivalent count rate (NECR) was also estimated for various ring numbers. The comparison of the sensitivities (table 1) and NECR (table 2) of the proposed scanner with scintillation type detectors shows that the 3D PS CdTe detectors for PET scanners have a very good performance.

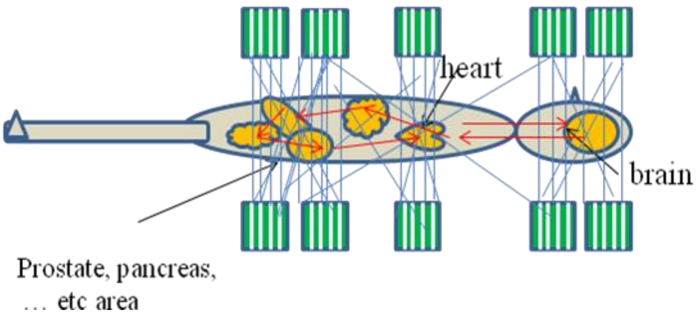
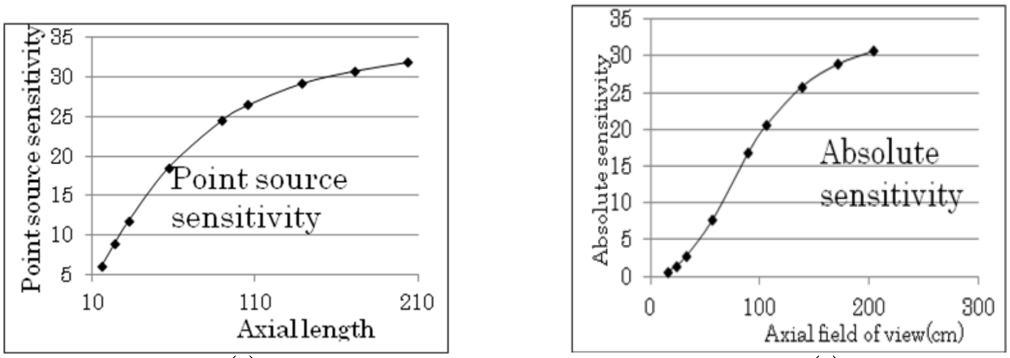


Fig. 1 5-ring system having different gaps between adjacent rings



(a) (b)

Fig. 2 (a) Point source sensitivity, and (b) absolute sensitivity of the 3D PSD based whole body PET scanner

Table 1 Comparison of sensitivities constructed from the 3D PSD and LSO detectors

Material type					
LSO*			CdTe		
Axial FOV (cm)	Sensitivity		Axial FOV (cm)	Sensitivity	
	Point source	Absolute		Point source	Absolute
16.4	0.067	0.0048	15.84	0.0603	0.0067
22	0.087	0.0085	24.01	0.0895	0.015
32.3	0.129	0.0186	32.18	0.117	0.027
55.6	0.199	0.0478	56.69	0.185	0.0776

Table 2 Comparison of NECR Scintillation detector based PET scanners

Detector material	aFOV (cm)	Peak NECR (kcps)
CdTe	15.8	53
LSO	16.2	61
BGO	15.2	28
NaI (Tl)	18	16
GSO	48	25

Chapter 5. Image Reconstruction for Whole Body PET Scanner

There are two types of image reconstruction algorithms: analytical and iterative image reconstruction. We used iterative image reconstruction algorithms, specifically list-mode image reconstruction algorithm, because it can model various physical phenomena, and improve the image quality. One of the basic components of iterative image reconstructions algorithm is the system matrix (SM) which relates the image domain to the measured data. In the SM, the detector response function (DRF) was modeled using analytical calculation method. Calculation of the SM is time consuming, and therefore, we developed a technique to reduce the calculation time. In this technique, we applied symmetry in which the total voxels are divided into 8 parts, and only one part is taken and further divided into a number of slices. The system matrices of individual slices are then computed by independent computers and then combined to generate the overall system matrix. By using this technique, the calculation time has been improved from ~5 days to ~5 hrs (~24 times). The SM was implemented in LMEM image reconstruction technique to reconstruct the image of two types of phantoms: spherical point sources and contrast phantom (Fig 3). In both case, the images were reproduced faithfully (Fig. 4).

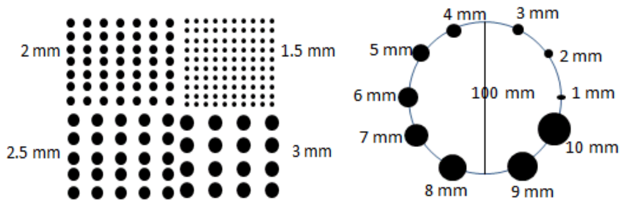


Fig. 3. Spherical point sources and contrast phantom

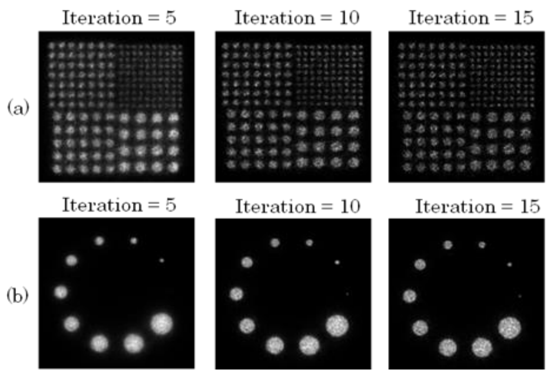


Fig. 4 reconstructed images

In both types of phantom studies, the images are seen clearly at 15 iterations.

Chapter 6 Conclusion

In this study, a 3D PS CdTe detector based large axial FOV PET scanner has been proposed and studied in order to increase the sensitivity and achieve high spatial resolution. The comparison of the sensitivity and NECR of the proposed 3D PSD whole body PET scanner with current whole body PET scanner shows that the 3D PSD has a very reasonable performance. By adjusting the gaps between rings in a 5-ring system, we can observe metabolism in important organs and obtain correlation between them.

A new technique for the calculation of system matrix (SM) was developed and the calculation time of the SM is significantly reduced. From reconstructed images, the spatial resolution of the scanner is ~1.2 mm

In the future, we are planning to study and develop an elliptical-shaped PET scanner which is expected to achieve higher spatial resolution and sensitivity (Fig. 5). A resolution of ~ 0.8 mm and high quality images are expected

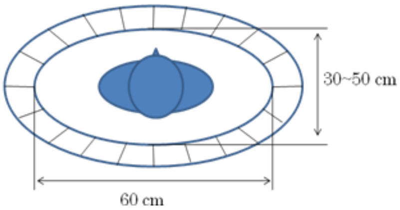


Fig. 5 Elliptical-shaped PET scanner