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# Development of a Method to Optimize the Geometrics of Positron Emission Tomograph 「PETの検出器の精密配置」

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# 論文内容要旨

Positron emission tomography (PET) is a very powerful method of nuclear imaging. This modality is widely used as a promising tool for various well-conducted studies such as oncology, cardiology, pharmacokinetics studies, and brain diseases like psychiatry, epilepsy and etc. PET consists of the systematic administration to the subject of a selected radiopharmaceutical labeled with one of physiological radionuclides (such as 11C, 13N, 15O or 18F), followed by the measure, as a function of time, of the distribution of the nuclides in the structure of interest. The method is based on the detection of the annihilation photons which are emitted from the radionuclides distributed in the organ of study.

As for other medical imaging techniques, a large amount of research is dedicated to improvement of the quality of the image obtained by PET scan. Improvement of the image quality can be made by improvement in either hardware and/or reconstruction algorithm. Hardware improvement deals with developing new radiation detectors, faster electronics and so on. On the other hand, improvement of reconstruction algorithm deals with developing more precise algorithms for reconstructing more accurate image that represents the imaged object in a better quality. It should be noted that improvement in one aspect is not enough; because best detector technology will not result in a better image quality unless the reconstruction algorithm is improved and vice versa.

Among many factors that may affect the image quality, the one that traditionally has not been taken into account is precise detector positioning in the gantry. This may not have been a very important and determinative issue for decades since the spatial resolution of PETs had not been better than 4 mm. But with the improvement of spatial resolution of the PET systems especially those dedicated to small animals, precise detector and detector block positioning should be considered as important factors. Another point that traditionally has been considered is assuming central part of detectors to be the most sensitive part to radiation. This is important when coincidence counts are recorded and located along LORs (line of response). The reason for its importance is that formation of sinograms in PETs is based on the coordinates of LORs and LOR coordinate is calculated based on detector coordinate. Thus, if by any reason, central part of detectors are not the most sensitive part to radiation, it will result in a different LOR coordinate. These are all contributing to geometrics of positron emission tomographs.

This dissertation discussed about the above mentioned issues. Thesis consists of the following chapters:

*Chapter 1,* A brief explanation about medical imaging, different modalities and finally positron emission tomography is introduced.

*Chapter 2,* Basic introduction to PET physics and instrumentation is given.

*Chapter 3,* This chapter deals with FinePET, a small animal PET developed at Tohoku University, as well as brief explanation to its detector structure, data acquisition system and detector block positioning method that was used.

*Chapter 4,* This chapter covers experiments to measure the coincidence events of opposite two detectors as a function of a point source position. This was done by moving a point radioactive source in front of detectors in opposed detector blocks and recording the coincidence counts for adjacent LORs as a function of source position. Coincidence measurement was performed at the intervals of 50 μm. Coincidence measurment time was 10 minutes for each position. Moving the point source on the line perpendicular to LOR and registering the coincidence counts as a function of source position will result in a curve representing a profile of detectors responding to source movement. After fitting a curve to the obtained data, we can find the distance between the peak position of each curve. If the distance between the two peaks equals to the detector pitch divided by two, then, our first assumption of considering the most sensitive part of the detectors to radiation in the center of the detectors was true. We confirmed this assumption

*Chapter 5,* A dual-purpose step-by-step method is explained where the developed method may be used to find center of the gantry in PETs and also to find detector misalignments due to imperfect detector positioning. All misalignments due to imperfect detector positioning are mathematically modified and used by image reconstruction program to reconstruct various images. This method is based on selecting a centered detector in each detector block of PET and measuring coincidence counts between the two centered detectors in opposite detector blocks to find the coordinates of LORs (Line of Response). Due to slight misalignment of detector positions, measured LORs may not intersect in a single point. On the basis of this method, the center of the gantry can be chosen and the coordinates of detectors can be measured in a very high accuracy. The results of implementation of our method to FinePET are introduced.

*Chapter 6,* Based on the modified detector coordinates, coincidence files of several experiments were used by filtered back projection image reconstruction method to compare between reconstructed images both before and after detector coordinate modification. A comprehensive explanation is given for each comparison. Since, the measured misalignments of detectors in FinePET are small (in the range of ±0.1mm), the spatial resolution of the reconstructed images were not changed significantly.

*Chapter 7,* This chapter concludes the dissertation.

*Appendix A,* A technique by using a laser-based apparatus for position calibration of the detector blocks of FinePET is developed. This technique is based on using a laser sensor to find the position of detectors in the scanner and hence finding any misalignment due to incorrect positioning of detector blocks. In this method a very fine dedicated holder for laser sensor is used to carry the sensor in to center of the gantry and scanning the surface of detectors. Then, a line equation for each detector block from the scan data of blocks' surface was driven. Comparing the obtained equation with ideal equation of each detector block resulted in finding misalignment of detector blocks' positions. This technique may be used to find misalignments of detector blocks or detector block movement in PETs with transformable gantry.

# 論文審査結果の要旨

本論文は、PET の空間分解能を決定づける検出器の精密配置のための検出器位置測定法の開発を行い、検出器位置を考慮した再構成画像により画質向上を目指したものである。

本論文は全 6 章で構成されている。

第 1 章は総論であり、本研究の背景及び目的を述べている。

第 2 章では、本研究の基礎となる PET の原理について述べている。

第 3 章では、本研究で開発した手法を適応した、東北大学で開発された FinePET について詳細に述べている。

第 4 章では、FinePET を用いて、LOR に対して線源を直角に 50μm 間隔で動かしながら同時計数を測定することにより、検出器の有感領域の中心を求めている。そして、FinePET の検出器の間隔が理論通りであることを示している。

第 5 章では、PET のガントリーの中心と検出器の位置を測定する手法について述べ、ガントリー中心と検出器の位置情報を再構成に組み込むことにより、ミスアライメントにより生じた画像のゆがみを、検出器を動かすことなく補正する手法について述べている。実際に FinePET のガントリー中心と検出器の位置を高精度で測定し、わずかなミスアライメントがあることを示した。

第 6 章は、実際に測定した FinePET のガントリー中心と検出器位置を再構成に取り入れて画像再構成を行い、取り入れない場合との画像の比較を行っている。そして、測定した検出器位置情報を画像再構成に取り入れることにより、画質の改善が図れることを示した。

第 7 章は総括であり、各章の成果をまとめている。

以上要するに本論文は、 1mm 以下の高空間分解能 PET を実現するために重要な、ガントリー中心と検出器位置を精密に測定する手法を提案し、実際に 1mm 以下の分解能を持つ FinePET のガントリーの中心と検出器のミスアライメントの精密測定を行っている。その結果、わずかなミスアライメントがあることを示した。そして、測定したミスアライメントの情報を再構成において考慮することにより、検出器の位置を変えることなく画質の改善を試み、画質が向上することを示している。

これまでに開発されている PET においては空間分解能が 4mm 程度であり、検出器の位置決めは重要ではなかったが、本方法は 1mm 以下の空間分解能の PET を実現する技術であり、今後のＰＥＴ開発に大いに貢献することが期待され、この技術開発は量子エネルギー工学の発展に寄与するところが少なくない。

よって、本論文は博士（工学）の学位論文として合格と認める。