Oral presentation | II. Radiation, Accelerator, Beam and Medical Technologies：202-2 Radiation Physics, Radiation Detection and Measurement

Fri. Mar 18, 2022 2:45 PM - 4:10 PM JST | Fri. Mar 18, 2022 5:45 AM - 7:10 AM UTC | Room B

[3B10-14] Photon Detection Technique 3

Chair: Mariko Segawa (JAEA)

2:45 PM - 3:00 PM JST | 5:45 AM - 6:00 AM UTC

[3B10] Development of gamma source identification by 4π Compton gamma imaging

(5)Identification and visualization of radiation source(s) considering static obstacles

*Hidetake Ebi[1], Atsushi Mukai[1], Kenji Shimazoe[2], Yusuke Tamura[3], Hanwool Woo[2], Fumihiko Ishida[4], Jun Kawarabayashi[5], Kosuke Tanabe[6], Kei Kamata[3], Hideki Tomita[1] (1. Nagoya Univ., 2. Univ. of Tokyo, 3. Tohoku Univ., 4. Natl. Inst. of Tech., Toyama College, 5. Tokyo City Univ., 6. Natl. Research Inst. of Police Science)

3:00 PM - 3:15 PM JST | 6:00 AM - 6:15 AM UTC

[3B11] Compton imaging system with SOI and Scintillator

*Zhihong Zhong[1], Kenji Shimazoe[1], Hiroyuki Takahashi[1], Lan Zhang[1], Mizuki Uenomachi[2] (1. UTokyo, 2. RIKEN)

3:15 PM - 3:30 PM JST | 6:15 AM - 6:30 AM UTC

[3B12] Characterization of Time of Flight Compton Camera for Radiation monitoring

*Agus Nur Rachman[1], Kenji Shimazoe[1], Hiroyuki Takahashi[1], Hideki Tomita[2], Eiji Takada[4], Yusuke Tamura[3], Jun Kawarabayashi[5], Kosuke Tanabe[6] (1. The University of Tokyo , 2. Nagoya University , 3. Tohoku University , 4. National Institute of Technology, Toyama College, 5. Tokyo City University , 6. National Research Institute of Police Science)

3:30 PM - 3:45 PM JST | 6:30 AM - 6:45 AM UTC

[3B13] Random and scatter noise reduction in PET imaging using entangled annihilation gamma photons with Compton PET pixel detectors

*Donghwan Kim[1], Agus Nur Rachman[1], Taisei Ueki[1], Kenji Shimazoe[1], Hiroyuki Takahashi[1] (1. The University of Tokyo)

3:45 PM - 4:00 PM JST | 6:45 AM - 7:00 AM UTC

[3B14] Simultaneous diagnostic and therapeutic radionuclides imaging with Compton-PET hybrid camera

*Mizuki Uenomachi[1], Kenichiro Ogane[2], Zhihong Zhong[2], Kenji Shimazoe[2], Kei Kamada[3], Hiroyuki Takahashi[2], Yang Wang[1], Hiromitsu Haba[1] (1. RIKEN, 2. UTokyo, 3. Tohoku Univ.)

4:00 PM - 4:10 PM JST | 7:00 AM - 7:10 AM UTC

Time reserved for Chair

全方向コンプトンイメージングに基づく放射線源可視化・定量法の開発
(5) 周辺構造物を考慮した線源同定と可視化

Development of gamma source identification by 4π Compton gamma imaging

(5) Identification and Visualization of radiation source(s) considering static obstacles

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全方向コンプトンイメージングを用いて、ガンマ線源の位置・線源強度を推定する手法の開発を行なっている。3 次元 LiDAR を用いて探知領域の環境地図を取り込み、線源周辺の構造物・遮蔽などを考慮して線源同定を行う手法について基礎検討を行い、^{137}Cs 線源を環境地図上に可視化できることを示した。

キーワード：コンプトンイメージング，線源探知，自己位置推定と環境地図作成

1. はじめに 検出器に入射するガンマ線の強度分布を測定するガンマイメージング法は、放射線源の検知に有用である。全方向コンプトンイメージングは、4 π 方向に視野を有するガンマイメージング法であり広範囲を同時に測定することができるため、複数の測定点でのガンマイメージと立体角を考慮することで、探知領域内の点状線源強度と位置を推定することができる[1]。本手法における探知領域内での測定位置の決定と移動経路の測定には 3 次元 LiDAR を用いた Simultaneous Localization and Mapping (SLAM)を利用することができるため、探知領域内の構造物の認識も可能である。そこで、本研究では、SLAM にて取得した検出器周囲の構造物を考慮した線源同定を行う手法について検討を行った。

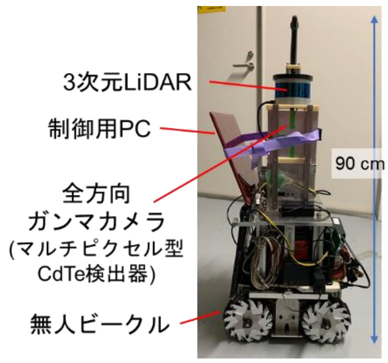

Fig. 1 放射線探知システム

2. 構造物を考慮した線源同定と環境地図上での可視化

Fig. 1 に示す放射線探知プロトタイプシステムを用いて、構造物の情報を考慮した ^{137}Cs 線源の同定を行う基礎実験を行った。無人ビークルに全方向ガンマカメラ（マルチピクセル型 CdTe 検出器）と 3 次元 LiDAR を搭載し、2 つの部屋をつなぐ通路に設置した ^{137}Cs 線源（2 MBq）の周囲の 4 つの測定位置（#1～4）で全方向コンプトンイメージを取得した。3 次元 LiDAR を用いた SLAM にて認識した環境地図と周辺構造物のデータをもとに、線源推定を行う 3 次元ボクセル空間上で構造物により遮蔽されるボクセルの重みを下げ、線源同定を行った。その結果、すべての測定点を用いても矛盾のない線源推定が可能であることを示した（Fig.2 参照）。今後、構造物による遮蔽のより詳細な検討を行う予定である。

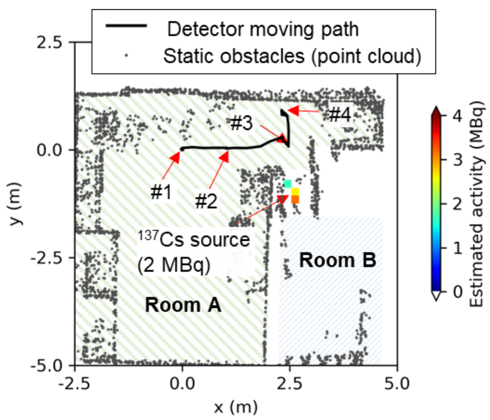

Fig. 2 周辺構造物と線源の推定結果 (z 軸=0.0 m)

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参考文献 [1] H. Tomita *et al.*, Proc. of 2020 IEEE/SICE SII, 18–21, (2020).

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Compton imaging system with SOI and Scintillator

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Abstract: In this research, an integrated system consisting of silicon-on-insulator (SOI) with scintillator array has been studied. The system shows an excellent energy measurement capability, which leads to high quality of reconstructed image. What's more, the pixelized SOI sensor enables the possibility of electron-tracking technique that would further increase the quality of Compton imaging.

Keywords: Compton imaging, SOI, Scintillator

1. Introduction

Compton scattering is the interaction that has the greatest cross-section between atoms and sub-MeV (102 keV~1MeV) photons. Compton imaging is a promising imaging technique. Without the necessity of mechanical collimation, Compton camera is lighter in weight, and it has larger angle of detection. It has been successfully applied in areas such as astronomy and nuclear powerplant site investigation. In our system, the SOI detector (XRPIX7) works as scatter, providing high energy resolution. GFAG array couple with MPPC works as absorber to ensure detection efficiency.

2. Experiment and results

2-1. Energy performance

The energy performance of SOI detector and GFAG array is illustrated in figure 1 and figure 2, respectively. On average, the SOI system has reached an energy resolution better than 9% for peaks lower than 20 keV. This result is ideal for scatterer in the Compton camera. In the image reconstruction, only the energy deposition in scatterer is used to compute the scattering angle.

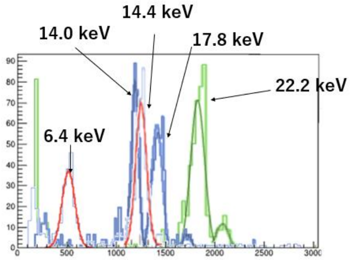

Fig. 1 Energy spectrum of SOI

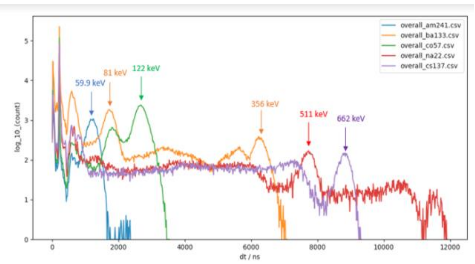

Fig. 2 Energy spectrum of MPPC

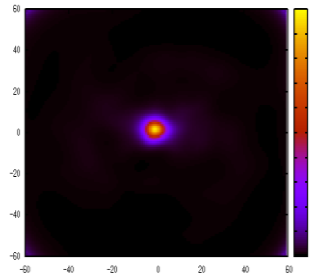

Fig.3 Reconstructed Image of ^{57}Co

2-2. Image reconstruction

A ^{57}Co sources is used to test the imaging capability of the system. The 122-keV gamma-ray is the target. MLEM (Maximum Likelihood Expectation Maximization) method is used for image reconstruction. Figure 3 shows the reconstructed image after 10 iterations. An ARM (angular resolution measure) of less than 10 degrees has been achieved.

3. Conclusion

The integrated SOI-GFAG system shows a great capability in terms of Compton imaging, thanks to the high energy resolution of SOI detector. The next steps include improving the performance for gamma-rays with higher energy (such as 662 keV), as well as applying the system into the Compton-PET architecture.

References

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Characterization of Time of Flight Compton Camera for Radiation Monitoring

* Agus Nurrachman[1], Zhong Zhihong[1], Donghwan Kim[1], Mizuki Uenomachi[1], Kenji Shimazoe[1], Hiroyuki Takahashi[1], Takuya Kishimoto[1], Hiroki Kogami[1], Atsushi Mukai[2], Shintaro Hara[2], Keita Yamagishi[2], Hideki Tomita[2], Yusuke Tamura[3], Hanwool Woo[3], Kei Kamada[3], Hidetake Ebi[4], Fumihiko Ishida[4], Eiji Takada[4], Hajime Asama[4], Jun Kawarabayashi[5], Kosuke Tanabe[6], Kenichi Tsuchiya[6]

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Abstract

Time-Of-Flight (TOF) is widely used in areas such as Positron Emission Tomography (PET). This technique can also be applied to other imaging systems such as Compton imaging TOF information helps to determine the interaction order on the detector. This information can improve the image quality from Compton imaging. In this study, we build the TOF Compton detector using GFAG Crystal and high time resolution front-end electronic circuit. In the TOF-PET system, we have achieved 400 ps time resolution. We expect the TOF technique can be applied in the Compton camera.
Keywords: Radiation measurement, Compton imaging, Time-of-flight, Time resolution

Introduction

Time-of-flight (TOF) technique has been used since 1980's in Positron Emission Tomography (PET) for medical application [1-2]. To build a TOF system combination of fast decay crystal with high density, fast photomultiplier, high time resolution front-end electronic is needed. We applied the TOF into the Compton camera to improve the imaging quality. The TOF information can helps to determine the interaction order on the detector. The aim of the present experimental studies is to examine the feasibility of using TOF measurement for Compton imaging and this result can be used for three-dimensional images in future experiments.

Compton detector experiment

An Application-Specific Integrated Circuit (ASIC) with 64 input/output is used to process the analog signal from the Multi-Pixel Photon Counter to the digital signal using the time over threshold method. A 2.5 x 2.5 x 5 mm 64 array Gadolinium Fine Aluminium Garnet (GFAG: Ce) crystal is used for the scintillator. GFAG is chosen because it has a fast decay time and high-density properties. It reported the GFAG crystal couple with 64 Ch MPPC array S13361-3050 from Hamamatsu can provide energy resolution of 622 keV energy from ^{137}Cs source and 511 keV energy ^{22}Na are consecutive 5.5% and 6.5%.

The Compton imaging experiment results are shown in Fig 1. The image reconstruction using the MLEM method. The spatial resolution from the reconstruction image is 8.6 mm.

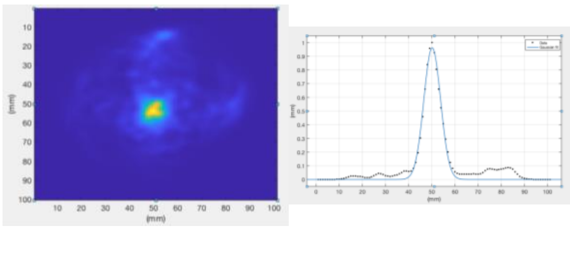

Fig. 1 Image reconstruction using MLEM method

Reference

[1] Y Nakamura et al. 2016 Phys. Med. Biol. 61 5837

Random and scatter noise reduction in PET imaging using entangled annihilation gamma photons with Compton PET pixel detectors

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Abstract
Random and scatter correction is important to quantitative PET imaging. There are many techniques including dual window method, scatter simulation method, delayed coincidence, estimation from singles, etc. for random and scatter reduction. In this study, entanglement characteristics of annihilation photons is used to reduce random and scatter.
Keywords: PET, Random Correction, Scatter Correction.

1. Introduction

Reduction of random and scatter events contributing to the background on the reconstructed image is important in PET imaging. Two gamma rays from annihilation of para-positronium containing anti-parallel spins are entangled and have orthogonal linear polarization. The orthogonal linear polarization in two correlated photons results in the difference between azimuthal scattering angles of two photons tend to be 90˚. Its correlation shows larger amplitude at polar scattering angle near 81˚. When two photons are not originated from the same annihilation event, which means the photons have no correlation, photons will show no preferred azimuthal angle difference. If one photon is scattered before reaching detectors, the correlation becomes much less or none. [1] In the experiment we take coincidence events from double Compton scattering whose azimuthal angle difference is near 90˚ to get larger proportion of true signals with reduced random and scatter events.

2. Methods

Experiment was conducted to characterize the distribution of azimuthal angle differences in double Compton scattering events with pixelated Ce:GAGG-SiPM detectors forming Compton PET scanner. Octagon shaped 8 arrays were used for the experiment. Figure 1 shows the experimental setup and schematic diagram of experiment. Measured azimuthal angle indicates strong difference intensity at around 90˚ and low intensity at 0˚ and 180˚ as expected from the theory. These correlations can be applied to the reduction of scatter and random coincidence events and the improvement in PET imaging will be reported.

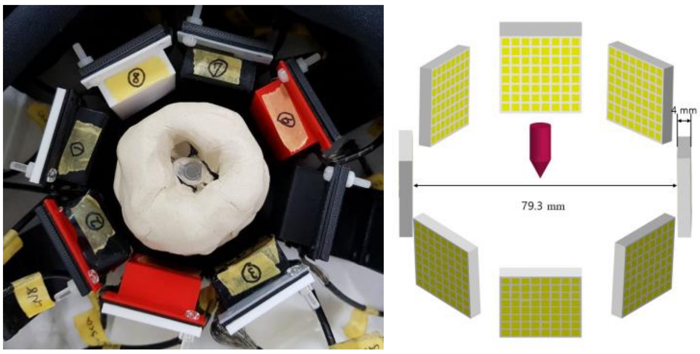

Figure 1 Photo of experiment setup and its schematic diagrams.

References

[1] D. P. Watts *et al.*, "Photon quantum entanglement in the MeV regime and its application in PET imaging," *Nat. Commun.*, vol. 12, no. 1, pp. 1–39, 2021, doi: 10.1038/s41467-021-22907-5.

Compton-PET ハイブリッドカメラを用いた診断治療核種同時撮像検証

Simultaneous diagnostic and therapeutic radionuclides imaging with Compton-PET hybrid camera

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キーワード： Compton イメージング、PET イメージング、多核種撮像、At-211

1. 緒言

近年、放射線治療の一種である内用療法では標的アルファ線治療が注目を集めており、^{211}At は将来有望な治療用アルファ線放出核種の一つである。一方、新規治療薬の開発において、核医学で用いられている診断核種と新規治療核種の同時撮像は、新規薬剤の体内での挙動や集積の適格性を評価する上で有用な手段となることが期待される。そこで本研究では、幅広いエネルギーのガンマ線イメージングが可能な Compton イメージングと高感度かつ高分解能な PET イメージングを組み合わせた Compton-PET ハイブリッドカメラ [1-3]を用いて治療核種(^{211}At)と診断核種(^{18}F と ^{111}In)の同時撮像の検証を行った。

2. 方法

本研究では厚さ 1.5 mm の散乱体および厚さ 9 mm の吸収体で構成されるコンプトンカメラを 8 台半径約 45 mm のリング状に並べたイメージングシステムを構築した。検出器はピクセルサイズ 2.5 mm×2.5 mm の 8×8 アレイ高分解能 GAGG シンチレータと Silicon photomultiplier (Hamamatsu, S13361-3050)から成り、ピッチサイズは 3.2×3.2 mm である。リングの中心に ^{211}At (11.84 MBq), ^{18}F (0.175 MBq), ^{111}In (0.88 MBq)を 10 mm ずつ離して並べ、12 時間撮像した。

3. 結果

図 1 に ^{211}At, ^{18}F, ^{111}In の Compton イメージング、^{18}F の PET イメージング結果を示す。Compton イメージングを用いてそれぞれの集積の可視化、および ^{18}F の PET イメージングに成功した。

4. まとめ

本研究では Compton および PET イメージングを同時に実行する Compton-PET ハイブリッドカメラを用いて治療核種の ^{211}At、診断核種の ^{18}F、^{111}In の同時撮像を行い、それぞれの可視化に成功した。本発表では更に ^{111}In、^{18}F の画像上のアーチファクト低減を目的とした二光子同時計測法によるイメージング結果も報告する。

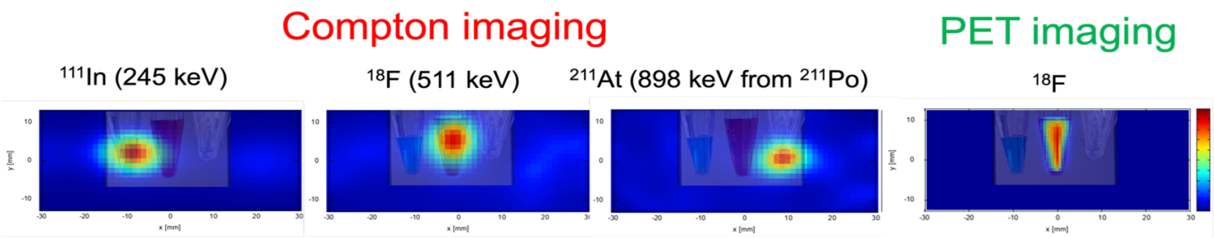

図 1：^{211}At, ^{18}F, ^{111}In の Compton および PET イメージング結果

参考文献

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