Simulation Study on SOI based electron tracking Compton camera using deep learning method

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Introduction
A Compton Camera is a promising gamma-ray imaging method based on Compton scattering kinetics because of high Compton scattering probability for sub-MEV or higher energy gamma-ray imaging [1]. Several researches show the great capability of detecting nuclides in the applications of nuclear medicine, astrophysics and decommissioning [2][3][4], however, there are still demands for improving signal-to-noise ratio in Compton imaging. The conventional Compton imaging suffers from the artifact derived from the Compton cones and it is known the detection of ejected direction of recoil electrons could improve the signal to noise ratio in the image [5][6]. Our group have been working on the fine-pitch silicon-on-insulator (SOI) based electron tracking Compton camera and shows the improvement of SN in the experiment. In this study the extraction of ejected direction of recoil electron by using deep learning method are simulated and analyzed with Monte Carlo simulation for faster processing of data.

Principle

**Compton Camera**
- Gamma-ray imaging
- Based on Compton scattering kinetics
- High detection efficiency (no collimator)
- Detection energy + position

**Conventional**: Low SN ratio caused by Compton cones

**Recoil electron tracking is one way to improve**

Conventional: Identify a position of source
- Draw some Compton cones → Identify a position of source

**SOI**

**Electron tracking in SOI pixel detector**

Fine-pitch SOI pixel sensor with trigger output capability is useful in electron tracking Compton imaging

*Figure: Electron tracking in SOI pixel detector*

Electron tracking with SOI detector improves the SN and angular resolution.

Investigation of direction extraction with automated deep learning method

Results
After teaching is finished the unknown images are used as input to estimate the direction in alpha and beta. Around 15 epoch is required for estimation.

*Figure: Simulation Study on SOI based electron tracking Compton camera using deep learning method*

Compton Image reconstruction (preliminary) is done with electron tracking and without electron tracking using simulated data. Electron tracking shows slightly better signal-to-noise ratio and spatial resolution.

Conclusions
- Deep learning method could be useful to estimate the direction of ejected recoil electron with SPD of a 58 degree and 36 degree in alpha and beta angle, which will accelerate the processing in et-Compton imaging
- Reconstructed image shows better SNR and resolution with e.t.
- Further investigation is required including the effect of noise in pixel.
- Silicon based et-Compton imager is in development

Experimental Setup

**Data Generation**

1. 662 keV gamma photons are injected to the center
2. 10 μm and 30 μm pixel
3. Deposited energy is recorded in 2D
4. Data are classified into 8 categories in alpha (horizontal) and beta (vertical) angle of scattering
5. Around 80000 data for teaching With Geant4 Monte Carlo simulation

Convolutional Neural Network

Deep learning with multi-layer
Combination of convolutional layer to extract the local characteristics and pooling layer to minimize the size

Evaluation

1. Around 40000 data are used to evaluation the accuracy of estimated direction in 8 categories
2. Using the unknown image as input to estimate the direction
3. Accuracy is defined by: (no. of correct forecast data)/(no. of all data)
4. SPD (Scatter Plane Deviation) is evaluated
5. Image is reconstructed with and without electron tracking

<table>
<thead>
<tr>
<th>Method</th>
<th>Pixel Size</th>
<th>α</th>
<th>β</th>
<th>SPD(α)</th>
<th>SPD(β)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNN</td>
<td>10 μm</td>
<td>61.76%</td>
<td>48.48%</td>
<td>57.5</td>
<td>36.3</td>
</tr>
<tr>
<td>CNN</td>
<td>30 μm</td>
<td>47.52%</td>
<td>49.51%</td>
<td>73.0</td>
<td>35.6</td>
</tr>
</tbody>
</table>

Comparison of 10 and 30 μm pixel

- α: Tables shows the accuracy of alpha and beta angle (one angle corresponds to 45 deg. in alpha and 22.5 deg in beta) with CNN
- b. 10 μm pixel shows the higher accuracy in estimation of alpha angle
- c. SPD (FWHM of accuracy) is around 36 degree in beta.

<table>
<thead>
<tr>
<th>SPD evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron SNR(%)</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Without 3.99</td>
</tr>
<tr>
<td>With 4.83</td>
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</tbody>
</table>

SNR and spatial resolution (FWHM) in reconstructed image

Reference