Estimating Depth-of-Interaction on Moholithic Crystal PET Detector using Wasserstein Distance-Based Embedding

Sangjin Bae[1,2,3,] Jae Sung Lee [1,2,3,4,5*]

1 Interdisciplinary Program in Bioengineering, College of Engineering, Seoul National Graduate School, Seoul, Korea (Rep. of)
2 Integrated Major in Innovative Medical Science, Seoul National Graduate School, Seoul, Korea (Rep. of)
3 Department of Nuclear Medicine, College of Medicine, Seoul National University, Seoul, Korea (Rep. of)
4 Department of Biomedical Sciences, College of Medicine, Seoul National University, Seoul, Korea (Rep. of)
5 Brightonix Imaging, Seoul, Korea (Rep. of)

Purpose

Monolithic crystal detectors used in positron emission tomography (PET) are able to determine the depth of interaction (DOI) of gamma rays based on the number of detected photons at a photosensor array (known as the light distribution or LD). Statistical methods, particularly those based on neural networks (NN), can accurately estimate the interaction position of gamma rays in terms of both spatial and DOI resolution. However, it is difficult to obtain a dataset with precise DOI information in an experimental setting. In this study, we introduced a new method called Wasserstein distance-based Locally Linear Embedding (W-LLE) for extracting DOI information from monolithic crystal detectors with row-column sum readout. To assess the effectiveness of the W-LLE method, simulation and experimental studies were conducted.

Methods

Locally Linear Embedding (LLE) is a technique for finding a lower-dimensional representation of a high-dimensional dataset, while maintaining the relationships between nearby points in the data. LLE typically uses the Euclidean distance to find the nearest neighbors in a dataset. The Wasserstein distance, on the other hand, is a measure of the difference between two probability distributions. In this study, the Wasserstein distance (also known as the Sliced Wasserstein Distance) was used to approximate the difference between probability distributions in high-dimensional space. Rather than selecting neighbors of each LD using the Euclidean distance, we used the Sliced Wasserstein Distance that was calculated using marginal distributions that row and column readout provide. To implement the W-LLE algorithm, we used the Scikit-learn v0.24.2 Python package for machine learning. We also compared the performance of the proposed method to the original LLE and a model-based method. In this study, an LYSO crystal (25.4x25.4x15 mm3) detector with a photosensor array of 8x8 (3x3 mm2) pixels was simulated and tested experimentally. The dataset was collected using a pencil beam, and the methods were evaluated using the true DOI information in the case of simulation, and by testing the performance of the methods on an dataset acquired with obliquely irradiated pencil beam in the experimental study.

Results

In the simulation setup, W-LLE showed the most robust performance in the perspective of dataset size, hyperparameter of the algorithm, and effect of the outliers.
In the experimental setup, the neural network trained with DOI estimated using W-LLE showed 1.33 mm FWHM x-direction resolution, and 1.84 mm FWHM DOI resolution.

Conclusion

The Wasserstein distance-based embedding method was effective in extracting DOI information from the row-column sum data.