Performance Evaluation of a Table-top Compton Camera for Various Detector Parameters

Se Hyung Lee[1], Hee Seo[1], So Hyun An[2], Jae Sung Lee[3], Chan Hyeong Kim[1]*

[1]*Department of Nuclear Engineering, Hanyang University, Seoul, Korea, *chkim@hanyang.ac.kr*

[2]*Korea Atomic Energy Research Institute, Daejeon, Korea*

[3]*Department of Nuclear Medicine and Interdisciplinary Program in Radiation Applied Life Science, Seoul National University, Seoul, Korea*

ABSTRACT

A prototype table-top Compton camera, composed of two small plane-type position-sensitive semiconductor detectors, is under development. The objective of this study was to find the optimal imaging conditions for the camera in order to maximize its performance in terms of imaging resolution and imaging sensitivity. To that end, the performance of the Compton camera was simulated varying several detector parameters (i.e., the photon energy of the source, the geometrical configuration of the component detectors, and the interaction position resolution of the absorber detector), using the GEANT4 detector simulation toolkit. The camera was found to show its highest performance for the photon energy of 364.5 keV (^{131}I), but also showed a relatively high performance for 511 keV (^{18}F) and 662 keV (^{137}Cs). The camera showed its highest performance also when the scatterer and absorber detectors were positioned in parallel, separated by 10 cm. Finally, it was found significantly beneficial to the imaging resolution to increase the interaction position resolution of the absorber detector to 0.3 cm x 0.3 cm in the planar direction and to 0.5 cm in the axial direction.

INTRODUCTION

- The Compton camera is a very promising gamma-ray imaging device, especially in the field of nuclear medicine and molecular imaging
- The Compton camera has many advantages over conventional gamma-ray imaging devices, which advantages include 3-D imaging capability from a fixed position, almost no limitation on the photon energy of the gamma sources, simultaneous multiple radioisotope tracing capability, and, in principal, high imaging resolution and sensitivity.
- Currently under development is a table-top Compton camera composed of small plane-type position-sensitive semiconductor detectors.
- The current version of the camera, however, does not show sufficient imaging resolution and sensitivity for medical imaging applications.
- The objective of the present study was to find the optimal imaging conditions for the table-top Compton camera in order to maximize its performance in terms of imaging resolution and imaging sensitivity.
- To that end, different imaging conditions were simulated using the GEANT4 detector simulation toolkit.

METHODS

- The table-top Compton camera is composed of two plane-type position-sensitive semiconductor detectors: a double-sided silicon strip detector (DSSD, 5 cm x 5 cm x 0.15 cm, 16 x 16 strips) as the scatterer detector and a 25-segmented germanium detector (25-SEGD, 5 cm x 5 cm x 2 cm, 5 x 5 segments) as the absorber detector (Fig. 1).
- The camera was simulated with the GEANT4 detector simulation toolkit.
- The performance of the camera for the photon energies of 140, 364.5, 511, 662, and 1332 keV, which represent ^{99m}Tc, ^{131}I, ^{18}F, ^{137}Cs, and ^{60}Co, respectively, was calculated.
- The considered geometrical configuration variables of the component detectors were the inter-detector distances (IDDs) of 3, 6, 10, 15, and 20 cm and inter-detector angles (IDAs) of 0, 30, 45, 60 and 90 degrees.
- Considering that the imaging resolution is limited mainly by poor interaction position resolution of the absorber detector, the camera's imaging resolution was evaluated also as a function of the interaction position resolution of the absorber detector.

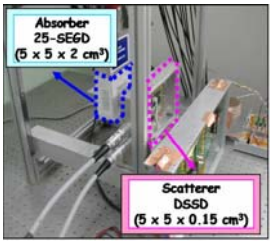

Fig. 1. Table-top Compton camera.

RESULTS AND DISCUSSION

- Figure 2 shows the imaging sensitivity, imaging resolution, and figure-of-merit (FOM) of the table-top Compton camera as functions of the photon energy of the source.
- Overall, the table-top Compton camera shows its highest performance (highest FOM) for the photon energy of 364.5 keV, but also shows relatively high performances for 511 keV and 662 keV.
- Figure 3 shows the performance of the table-top Compton camera as a function of the IDD and IDA for an ^{18}F point source 6 cm in front of the Compton camera.

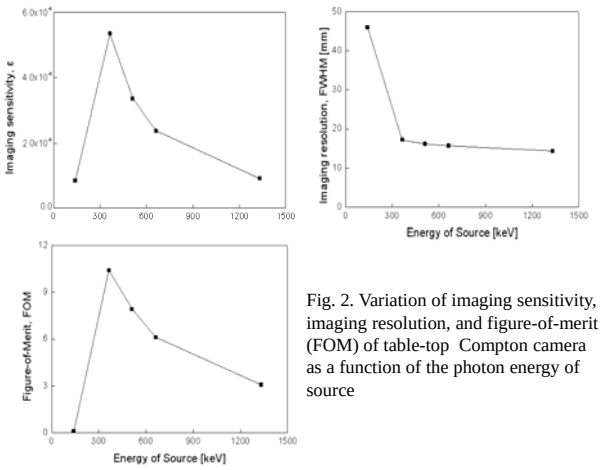

Fig. 2. Variation of imaging sensitivity, imaging resolution, and figure-of-merit (FOM) of table-top Compton camera as a function of the photon energy of source

- The highest performance (highest FOM) in the cases considered in this study was found when the IDD was 10 cm. The result also indicates that the table-top Compton camera shows its highest performance when the IDA is 0 degrees for all of the IDDs considered in this study.
- Figure 4 shows the variation of the imaging resolution as a function of the interaction position resolution of the absorber detector for an ^{18}F point source 6 cm in front of the Compton camera.

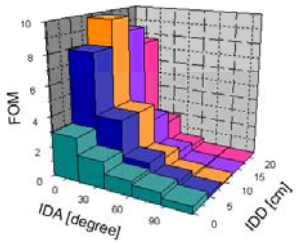

Fig. 3. Performance (i.e., figure-of-merit, FOM) of table-top Compton camera as functions of inter-detector distance (IDD) and inter-detector angle (IDA)

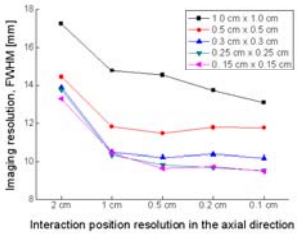

Fig. 4. Variation of imaging resolution of table-top Compton camera as a function of interaction position resolution of absorber detector

- The interaction position resolution of the current absorber detector is 1 cm x 1 cm in the planar direction and 2 cm in the axial direction.
- The result shows that it is significantly beneficial to the imaging resolution of the Compton camera to increase the interaction position resolution to 0.3 cm x 0.3 cm in the planar direction and to 0.5 cm in the axial direction: thereby, the imaging resolution is enhanced from 17.2 mm FWHM to 10.2 mm FWHM (Fig. 5).

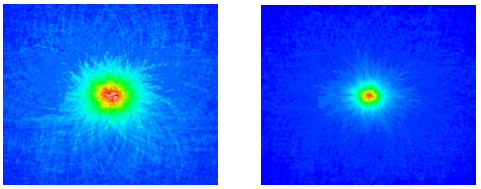

Fig. 5. Reconstructed images from Compton camera. Left: current system with position interaction resolution of absorber detector = 1 cm x 1 cm (planar direction) and 2 cm (axial direction). Right: a system with position interaction resolution of absorber detector = 0.3 cm x 0.3 (planar direction) and 0.5 cm (axial direction)

CONCLUSION

- The performance of a table-top Compton camera was evaluated as a function of various detector parameters in order to find the optimal imaging conditions.
- The camera showed its highest performance for the photon energy of 364.5 keV (^{131}I), but also showed a relatively high performance for 511 keV (^{18}F) and 662 keV (^{137}Cs).
- The Compton camera showed its highest performance when the scatterer and absorber detectors are positioned in parallel and separated by 10 cm.
- It was found significantly beneficial to the imaging resolution of the Compton camera to increase the interaction position resolution to 0.3 cm x 0.3 cm in the planar direction and to 0.5 cm in the axial direction: thereby, the imaging resolution was enhanced from 17.2 mm FWHM to 10.2 mm FWHM.
- This resolution is not very high, but will be appreciably enhanced by employing the expectation-maximization (EM) algorithm, currently under development for the table-top Compton camera.