Sharper Views of Invisible Threats: Optimizing Radiation Source Localization and Visualization in Compton Camera Technology

Prateek Gyanchandani[1], Dr. Mohit Tyagi[2], D. G. Parulekar[3], and Y. C. Shivkumar[4]
[1,3,4] *Technology Development Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA*
[2]*Technical Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA*

Introduction

Compton cameras offer a novel approach to visualizing and localizing radiation sources within facilities handling radioactive materials. By using electronic collimation, they provide a wider field of view than traditional gamma cameras. This study focuses on enhancing visualization and localization algorithms for Compton cameras, particularly using SBP (simple back projection) and LM-MLEM (list mode maximum likelihood estimation maximization). Mathematical simulations using a Cs-137 source carried to evaluate the algorithm's performance under various conditions.

The ability to precisely locate and identify radioactive sources is crucial for preventing radiation releases and ensuring safety in nuclear facilities. The Fukushima Daiichi Nuclear Power Plant incident highlighted the importance of such capabilities. However, Compton camera algorithms often have trade-off between computational speed and resolution [1]. In high-radiation environments like hot cells, efficient data processing and accurate real-time localization are essential. This study aims to improve both resolution and processing speed by developing advanced data analysis software and implementing optimized localization and visualization algorithms.

Methodology

The detector provides information about the energy deposition in detectors. Also, the detector provides the respective coordinates for these events.Using position & energy information Compton scattering angle θg by eqn.1[1] can be derived. c is speed of light, m_e mass of electron at rest. Position and θg can be used to form Compton cones. Their back propagation and coincidence give idea of position of source

$$cos\theta g = 1 - m_e c^2 \left(\frac{1}{Eabsorb} - \frac{1}{Etotal}\right) \quad \textbf{(1)}$$

The scattering angle obtained is used in image reconstruction in SBP algorithm and smoothened by sigmoid function [1]. The obtained image is used as initial values for LM-MLEM algorithm in eqn. (2) to obtain the final image after [1][2].

$$\hat{\lambda}j(l+1) = \frac{\hat{\lambda}j(l)}{sj} \sum_i \frac{tij}{\sum_k tik * \hat{\lambda}j(l)} \quad \textbf{(2)}$$

Where tij corresponds to a photon's probability to get emitted from the image bin j is detected as event i. Sj is sensitivity matrix estimation $\boldsymbol{\lambda}(\boldsymbol{l})$ obtained from the previous iteration[2]

The flow of whole process is provided in below figure

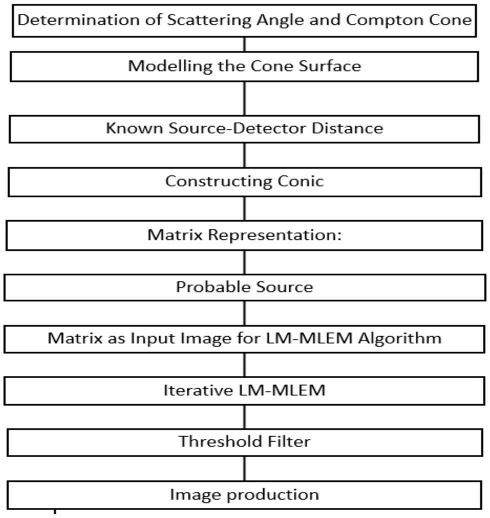

Fig 1: *Algorithm process flow*

Parameters for Modelling

1. Total Number of Events Captured= 1000.
2. Source = Cs 137 (662KeV)
3. Field of View = -30° to 30° in x and y axis
4. Distance of Source to Camera = 3 m
5. Detector size = 5cm x 5cm (5x5 pixels),
6. Distance between both detectors = 2.5cm
7. Type of collimation = Electronic

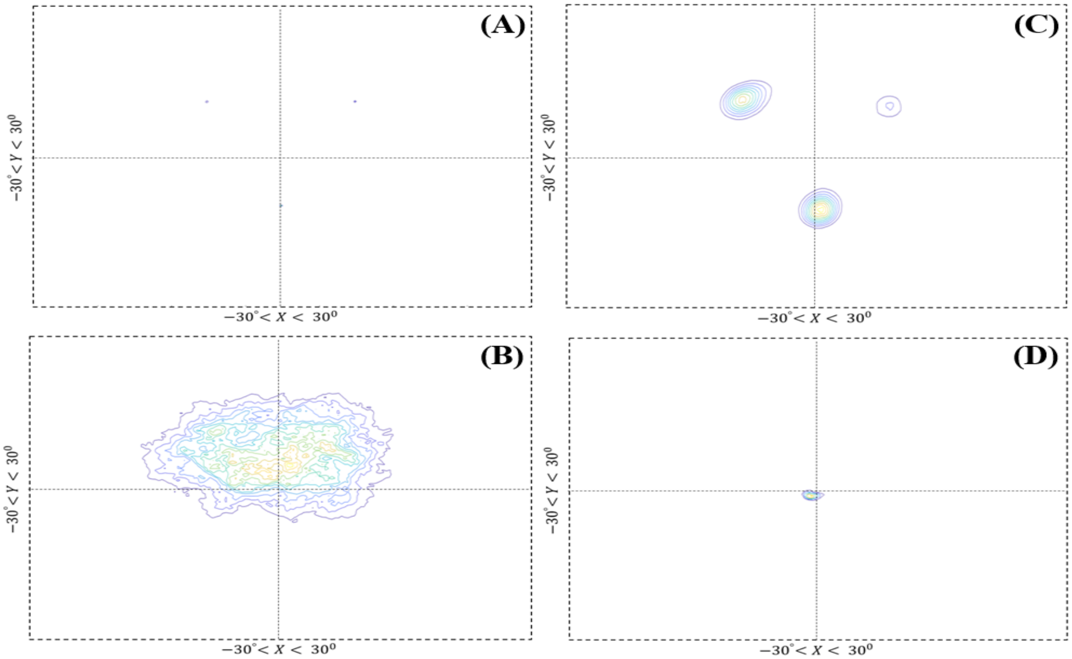

***Fig 2: (A)** Ideal 3 Point Source **(B)** 3 Point Source with 20% energy uncertainty & position binning, using SBP + Sigmoid & threshold filtering **(C)** 3 Point Source with 20% energy uncertainty & position binning, using SBP +Sigmoid, LM-MLEM &threshold filtering **(D)** Point Source with 20% energy uncertainty and position binning, using SBP + Sigmoid, LM-MLEM & threshold filtering*

Results & Discussions

The study was conducted on single, multiple point sources at various distance from detector. Fig 2 (A, B, C) shows three-point detection at 3 m distance. Fig 2 (D)show final detection using SBP + Sigmoid, LM-MLEM & threshold filtering for point source at 3m.

The obtained values of FWHM (Full width at half maximum ARM (angular resolution measure) for point source detection are) 1.51° & 1.73° respectively, which are comparable to the existing systems of Compton camera.

Compton camera imaging of a point source at 3 meters produced high-quality results despite uncertainty in energy deposition and position binning. The SBP method, incorporating a sigmoid function in image reconstruction and subsequent threshold filtering, enhanced both FWHM and ARM compared to conventional methods. Additionally, employing the LM-MLEM algorithm, initialized with an image matrix from SBP and sigmoid function instead of constant matrix, showed a significant improvement when the source was near the detector with fewer events captured. However, as distance or the number of events captured increases or number of iterations increase, the improvement in FWHM, ARM became less differentiable. Parallelization implementation showcased reduction in execution time drastically from 1028.3 sec to 18.46 sec. Study was also carried out in Geometrical aspects of detector for improved performance parameters

Future works will be focussed on implementing the same on hardware, addressing challenges with regard to Compton camera and comparative studies.

References

[1] R. K. Parajuli, "Development and Applications of Compton Camera -Review," Sensors 2022, MDPI, 2022.

[2] J. Zhang, "Prototype of an array SiPM-based scintillator Compton camera for radioactive materials detection," Radiation Detection Technology and Methods, 201