

GATE Simulation of Coded Mask Aperture for near field gamma ray imaging application

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Introduction

Coded Mask Aperture (CMA) technique [1] for producing images of radiating objects has been applied extensively in far field application problems of astronomy and space science [2-3]. In this paper we have modelled CMA for a Small Organ Imaging Gamma Camera (SOI-GC) which is a near field problem as the object to be imaged is not at infinity. Using CAM the sensitivity of the SOI-GC can be improved while retaining the spatial resolution. Thus the exposure time for generating SPECT images can be reduced. We have performed Monte Carlo simulations using GATE (Geant4 Application for Tomographic Emission) for a pixelated detector geometry model. The design of the mask involves choice of suitable mask pattern which is achieved using Shift Register Algorithm (SRA). We report here the initial results of the method and obtained shadowgrams along with energy resolution curve for the detector used.

I. Mask Pattern Design

In the design of a CMA for GC (Fig.1), the first challenge is to pick the mask pattern family that is best suited, and within it, the pattern of the right size. In view of the imaging performance, the autocorrelation function of the mask pattern should be a delta function [1]. This ensures that the System Point Spread Function is a delta function leading to reduction of artifacts in the encoded image.

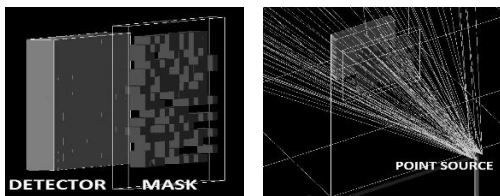


Fig.1 a. Model of detector with the mask
b. Snapshot of GC with point source



Fig.2 16x16 mask pattern designed. The black blocks represent the opaque mask elements

Uniformly Redundant Arrays (URA) satisfy this criterion and they can be generated from a Cyclic Difference Set (CDS). Mask pattern for which all separations between pairs of holes occur a constant number of times, is called URA [5]. A CDS, characterized by parameters n, k and z , is a collection of k integer numbers $\{I_1, I_2, \dots, I_k\}$ with values I_i between 0 and n such that for any positive $J \pmod n$, congruence $I_i - I_j = J \pmod n$ has exactly z solution pairs (I_i, I_j) within the set [4]. If $n = 2^m - 1$, where m is a positive integer then the set is termed as Pseudo Noise Hadamard Cyclic Difference Set (PNHCDS). [4] This was constructed using SRA. Starting from mask pattern length ‘ n ’, Irreducible Primitive Polynomials (IRA) of degree m were used as generating functions to model the URA mask as shown in figure 2. The first ‘ m ’ elements of the binary sequence representing the set is chosen arbitrarily and the subsequent elements are then generated using the following SRA [1]

$$a_{m+i} = \sum_{j=0}^{m-1} p_j a_{i+j} \pmod 2$$

where ‘ P_j ’ represents the coefficient of ‘ x^j ’ in the IRA. Also ‘ a_i ’ can assume value 0 or 1 representing open or opaque element respectively.

II. Detector Design

A pixelated Cadmium Zinc Telluride (CZT)

detector was considered having total of 16x16 sq.mm dimension with a pixel size of 2x2 sq.mm and pitch size of 2.2mm. Simulation was performed by taking the modelled URA lead mask that had one to one correspondence with the detector. The mask thickness was 3mm. Different runs were executed for various distances between the mask and the detector. An isotropic point gamma ray source (140 keV) with 10000 Bq activity was used to illuminate the mask. The acquisition time was fixed to be 10 seconds.

III. Simulation results

A. Energy Resolution

Fig.3 gives the energy resolution curve for the CZT detector. From the plot, the 5% energy resolution for the CZT-based detector at photo peak energy of 140 keV is evident and matches with the result reported in [6]. Also the Compton scattered events are indicated by the lower energy peaks. This validates the modelled gamma camera geometry.

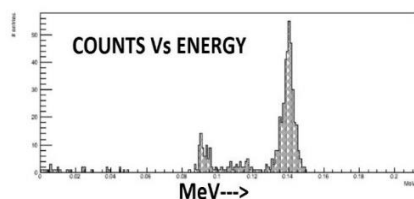


Fig.3 Simulated Energy resolution curve for the CZT detector

B. Mask Projection

One of the primary motivations for using CMA is to perform tomography. Object points at different distances from the aperture cast shadows of the aperture onto the detector with different sizes. One can consider the image of a 2D slice of the object at a certain depth to be formed by an aperture scaled to the size of the shadow. This approach can be used for tomographic image reconstruction.

The source-mask distance was fixed at 10 cm. The shadowgram onto the detector at varying mask-detector distances were then generated. Fig.4 shows one such shadowgram for the mask-detector distance of 30 mm. The shadowgram does not completely resemble the mask pattern. This may be due to the near field nature of the set



Fig. 4 Shadowgram on the detector

up and aberrations. The reconstruction of the image from the encoded projection with aberration corrections can be done using deconvolution or correlation or iterative methods. The physical reconstruction from the shadowgram can also be achieved by using anti-mask. Work in this direction is being pursued in our lab as part of the construction of SOI-GC.

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References

- [1] J.J.M. in't Zand, "A Coded-Mask Imager as monitor of Galactic X-ray Sources", Ph.D. Thesis, Utrecht University (1992)
- [2] E. Caroli, J. B. Stephen, G. Di Cocco, L. Natalucci, and A. Spizzichino, "Coded aperture imaging in X ray and gamma-ray astronomy," Space Sci.Rev., vol. 45, pp. 349–403 (1987)
- [3] G. K. Skinner, "Imaging with coded-aperture masks," Nucl. Instrum. Methods Phys. Res., vol. 221, pp. 33–40 (1984)
- [4] L.D. Baumert, "Lecture Notes in Mathematics No. 182: Cyclic Difference Sets" Berlin: Springer (1971)
- [5] E. E. Fenimore and T. M. Cannon, "Coded aperture imaging with uniformly redundant arrays", Appl. Opt., vol. 17, pp. 337–347 (1978)
- [6] Subam Rai et.al. "Simulation of a CZT - detector for application in SPECT imaging using GATE - a Geant4 plug-in", Proceedings of the DAE Symp. On Nucl. Phys, vol 60 (2015).