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Development of a Gamma Camera Applying Pseudo-Random Patterns for Artifact Reduction

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1. Introduction

Since the Fukushima nuclear accident, the demand for gamma cameras has increased for purposes such as nuclear power plant decommissioning, decontamination, and the classification and management of radioactive waste. Gamma cameras can be broadly classified into two main types: the Compton scattering method and the coded-aperture method. Among these, the coded-aperture method was first proposed in the field of astronomy [1]. A coded-aperture mask with a specific pattern allows radiation passing through it to project a characteristic shadow pattern onto the detector located behind the mask. When the mask and detector are fixed, a field of view is generated. Within this field of view, the projected pattern varies depending on the position of the radiation source, which enables the acquisition of an image of the source. Several types of coded aperture masks have been developed, such as random arrays, Non-Redundant Arrays (NRA), Uniformly Redundant Arrays (URA), and Modified Uniformly Redundant Arrays (MURA).

Through previous studies, Jeju National University developed the Energetic Particle Sensor for the Identification and Localization of Originating Nuclei-Gamma (EPSILON-G) [2]. EPSILON-G is a gamma camera based on a coded-aperture employing a MURA pattern. However, masks with a MURA pattern produce artifacts on the opposite side of the actual radiation source within a certain range of the field of view. In this study, a pseudo-random pattern was applied to mitigate the artifact problem associated with the MURA pattern. The system is identical to the previously developed EPSILON-G, except that the mask pattern was changed to a pseudo-random pattern. In addition, a comparative performance evaluation was conducted against the MURA pattern. The performance evaluation was conducted using a ^{137}Cs gamma-ray source to assess image quality, field of view, angular resolution, and image sensitivity.

2. Material and Method

2.1 Configuration of the gamma camera

The gamma camera used in this study consists of a coded-aperture mask, a GAGG scintillator, a silicon photomultiplier (SiPM) array, and a data processing board, as illustrated in Figure 1.

The scintillator used in the system is a 12 × 12 GAGG(Ce) array (GAGG-HL, Epic Crystal Co., Ltd.). The scintillator has an overall size of 50.2 × 50.2 × 20 mm³, a pixel size of 4 × 4 mm², and a pixel pitch of 4.2 mm. The SiPM array (ArrayC-30035-144p, Onsemi) employs a 12 × 12 array, identical in configuration to the scintillator, with an overall size of 50.2 × 50.2 mm², a pixel size of 3 × 3 mm², and a pixel pitch of 4.2 mm. The data acquisition board employs a row–column readout method and reconstructs gamma-ray source images using the Maximum Likelihood Expectation Maximization (MLEM) algorithm.

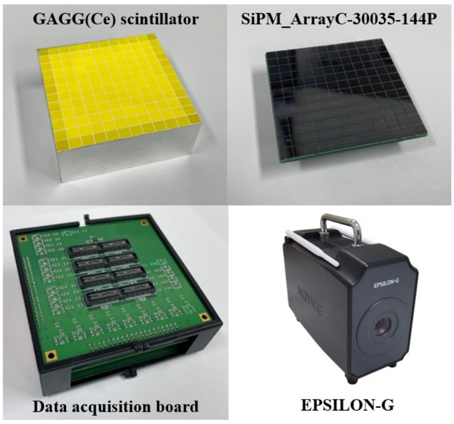

Fig. 1. Detector system configuration applied in EPSILON-G.

2.2 Coded-aperture mask and system matrix

In this study, two types of coded aperture masks were used. The first is a coded-aperture mask with a Rank-11 centered mosaic MURA pattern, which has previously been applied in existing gamma cameras. It corresponds to a 21 × 21 array, and the overall size of the mask is 96.81 × 95.51 × 15 mm³. The aperture size is 4.105 × 4.105 mm², and tungsten (19.3 g/cm³) was used as the material.

The second is a 21 × 21 coded-aperture mask with a pseudo-random pattern, developed in this study. The specifications of the mask are identical to those of the MURA pattern mask. System matrices were generated for each system corresponding to the two applied coded-aperture masks. The system matrices were generated using Monte Carlo N-Particle eXtended (MCNPX)-PoliMi simulations, and the patterns of the coded-aperture masks along with their respective system matrices are shown in Figure 2.

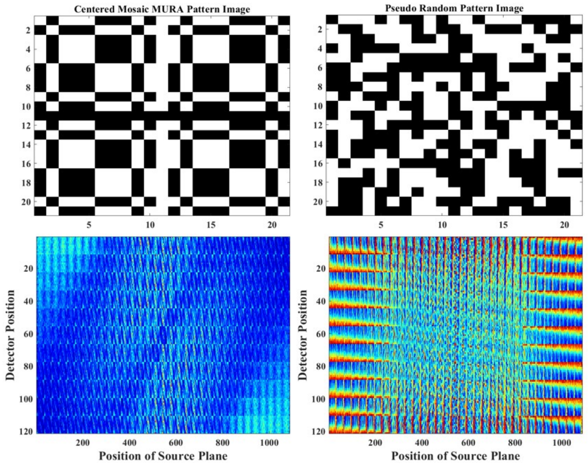

Fig. 2. Upper row: the centered mosaic MURA pattern (left) and the pseudo-random pattern (right). Lower row: the corresponding system matrices.

2.3 MCNPX-PoliMi simulation

Preliminary research was conducted using MCNPX-PoliMi simulations. The masks with the MURA and pseudo-random patterns were modeled as shown in Figure 2, and computational simulations were performed for each system. A point source emitting 662 keV gamma rays was positioned 100 cm in front of the mask, while additional source points were placed to the left and right outside the field of view to determine whether artifacts occur depending on the coded-aperture pattern.

3. Result

3.1 Simulation result for the centered mosaic MURA pattern

The computational simulation results of the centered mosaic MURA pattern are shown in Figure 3. The simulation results showed that when the source was positioned at the center of the mask, the image was correctly reconstructed at the proper location. However, for the left and right positions outside the field of view, artifacts appeared on the opposite side of the correct location.

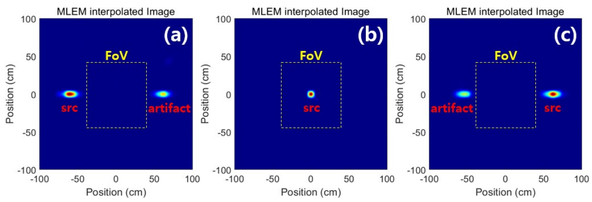

Fig. 3. MCNPX-PoliMi simulation results of the centered mosaic MURA pattern: left (a), center (b), right (c).

3.2 Simulation result for the pseudo-random pattern

The computational simulation results of the pseudo-random pattern are shown in Figure 4. The simulation results confirmed that images were correctly reconstructed at the proper locations for the source positioned at the center of the mask as well as at the left and right positions outside the field of view. No artifacts were observed.

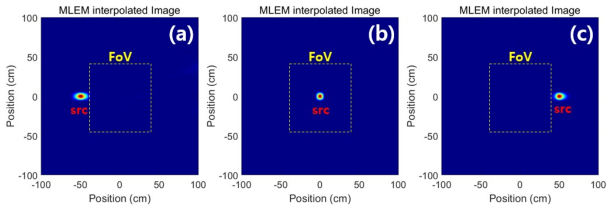

Fig. 4. MCNPX-PoliMi simulation results of the pseudo-random pattern: left (a), center (b), right (c).

4. Conclusions

Preliminary MCNPX-PoliMi simulations confirmed that artifacts occur when the radiation source is located outside the field of view with the MURA pattern, whereas no artifacts were observed with the pseudo-random pattern. The pseudo-random pattern will be applied to the actual device to evaluate image quality, field of view, angular resolution, and image sensitivity. The comparative performance results will be presented at a conference.

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