Characteristics of Coded-aperture gamma-ray imager with high-rank MURA mask

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1. Introduction

In the preceding study, we developed *Energetic Particle Sensor for the Identification and Localization of Originating Nuclei-Gamma (Epsilon-G)* which is a gamma-ray imager based on coded-aperture [1]. It acquires source image using the system matrix which is derived through Monte Carlo N-Particle eXtended (MCNPX)-Polimi. Epsilon-G has 45° of field of view (FOV), energy resolution (R) of 8.3% at 662 keV, and image sensitivity of less than 2 seconds to 0.3 μCi ^{137}Cs gamma-ray point source. In addition, it provides ambient gamma-ray dose rate and enables nuclide analysis [2]. However, its angular resolution was measured to be 6.8° in previous study, which was poorer than expected [3]. In coded aperture-based gamma-ray imaging system, the FOV and angular resolution are affected by the choice of a mask pattern type, by the mask-to-detector distance, by the spatial resolution of the detector, and by the size of the mask pixel. According to Ref. 4, the benefit to the higher mask rank is that it is more precise with the angular resolution, albeit with a decrease in efficiency (due to less open area) [4]. In our system, the system matrix contains the number of source plane pixels and FOV. Therefore, the number of source plane pixels in the system matrix is also expected to affect the angular resolution.

In this study, we will derive the number of pixels in the source plane that can reach the theoretical angular resolution of the gamma imaging system constructed using the coded aperture with 23 rank.

2. Methods and Results

The detector module is composed of silicon photomultiplier (SiPM, On Semiconductor) coupled with $Gd_2A_{l2}Ga_3O_{12}$ (GAGG(Ce), Epic-Crystal Co. Ltd., China) scintillator array. As shown in Fig. 1, GAGG(Ce) scintillator array is pixelated with 24 × 24, and each pixel volume size is 2 mm × 2 mm × 20 mm. And the SiPM array is consists of 144 pixels, in which each pixel has an active area of 4 × 4 mm^2. Since the rank number of the scintillator array is 24, the rank of the coded aperture mask is 23, which is the closest prime number to 24. For a centered mosaic Modified Uniformly Redundant Array (MURA), the mask having a MURA pattern of an array type having 45 × 45 (2p-1) pixels was used [3]. The encoding aperture mask was used by inserting tungsten pieces into the mask holder which is manufactured with 3-D printer.

There are two system matrices used for system evaluation and were calculated as shown in Fig. 2 under the following conditions: the FOV was 45 degrees, the distance between the detector and the source was 1 m, and the pixels of the source plane were 23 × 23 and 33 × 33, respectively.

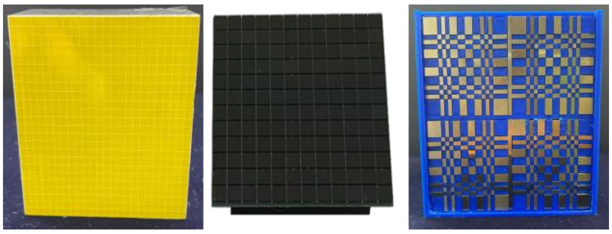

Fig. 1. Pixelated GAGG(Ce) scintillator array (left), 12 × 12 SiPM array (middle), and coded-aperture (right). The coded-aperture pixel size is 2.05mm and weight is 3.083kg.

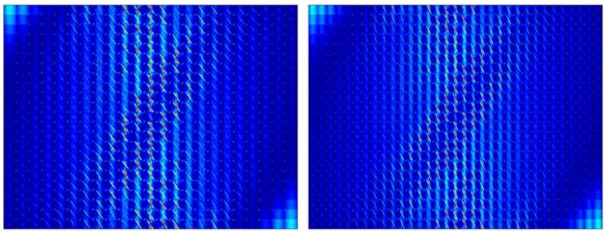

Fig. 2. A system matrix with a source plane of 23 × 23 (left) and a system matrix with a source plane of 33 × 33 (right)

To measure the angular resolution, two ^{137}Cs sources with activity of 8.1245 μCi and 8.22 μCi, respectively, were placed at 1 m from the gamma-ray imaging system. As shown in Fig. 3, two sources were placed at the same angle apart from the center of the FOV of the gamma imaging system, and 50,000 data were acquired at each degree.

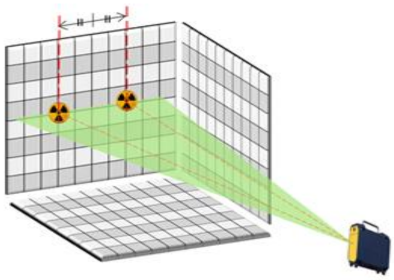

Fig. 3. Configuration schematic diagram for angular resolution measurement experiment

According to Ref. 5, the theoretical angular resolution of the coded-aperture imaging system can be calculated through Eq. 1, where m is the horizontal spacing between the mask pixels, d is the position resolution of the detector elements, and L is the distance from the mask to the detection plane.

$$\Delta\theta^2 = (m/L)^2 + (d/L)^2 \quad (1)$$

If the pixel spacing is much larger than the detector spatial resolution, i.e., $d << m$, thus the angular resolution can be approximated by Eq. 2 [5].

$$\Theta = arctan(m/L) \quad (2)$$

The angular resolution through the above equation is calculated to be about 2.7°.

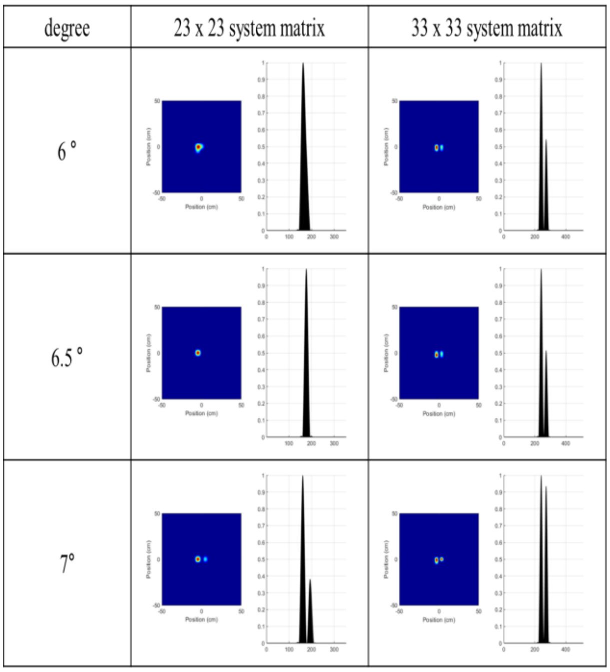

Fig. 4. MLEM images obtained by applying each system matrix and 1-D sum profile from each image.

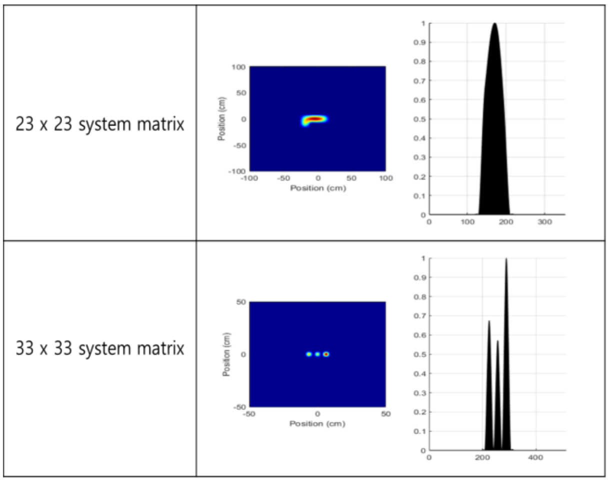

Fig. 5. Images reconstructed using 23 × 23 system matrix and 1-D sum profile (top) and images reconstructed using 33 × 33 system matrix and 1-D sum profile (bottom) for three gamma ray sources.

The angles between the two sources were set as 6°, 6.5°, and 7°. The reconstructed image of sources through MLEM at each angle and the 1-D sum profile result are shown in Fig. 4.

As a result of the experiment, at 6° and 6.5°, it was confirmed that the two sources were clearly separated in the 33 × 33 system matrix, whereas in the 23 × 23 system matrix, the two sources seemed to be merged into one. Similarly, as shown in Fig. 5, when images were acquired with three sources separated by 7° from each other, in the MLEM image reconstructed using the 23 × 23 system matrix, the three sources were combined into one, but the image which is reconstructed through 33 × 33 system matrix, the three sources were clearly distinguished.

In this conference, we will present whether it is possible to acquire the reconstructed image indicating the two sources separated at 2.7° ~ 7°. Also, we will gradually increase the number of pixels in the source planes, such as 55 × 55, 77 × 77, and derive the optimal pixel number to reach theoretical angular resolution. In addition, the performance (FOV, angular resolution, and image quality) between the 12 × 12 MURA system and the 24 × 24 MURA system will be compared and presented.

3. Conclusions

In this study, it was confirmed how the FOV affects each resolution as the number of source plane pixels varies in the same system matrix. As a result of the experiment, as the number of source plane pixels increased, it was confirmed that the angular resolution became closer to the theoretical angular resolution.

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