

Real-time Gamma Ray Imager Based on Coded-aperture Imaging System

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1. Introduction

Real-time radioactive field measurement, which is an unconfirmed technology for nuclear decommissioning, is an indispensable for estimating cost for the successful dismantling, optimizing the management system for various types of disposal waste, and checking the radioactive contamination of the surface. In addition, based on the proven technology, efforts should be made to improve the technology to reduce the radiation exposure of the workers and the amount of waste disposal, and to do so with the strategic development of the indigenous technology essential for decommissioning the nuclear power plant. For this reason, in South Korea, it is necessary to develop a portable system that can accurately map the position of radioactive materials in real-time, because nuclear waste containers are often uncertain and are ambiguous to increase the health risks of personnel close to these materials. [1,2]. In this paper, we will present developed gamma ray imaging system based on silicon-photomultiplier (SiPM) with coded-aperture mask aimed at real-time gamma ray localization, which is one of the core-techniques for the nuclear decommissioning mentioned above.

2. Methods and Results

This section describes the configuration of the real-time gamma ray imager based on SiPM with coded-aperture imaging system, how to process the signal, and the information that can be obtained using this device.

2.1 3D MURA Mask Design for SiPM Array

The use of a mask and its anti-mask for the coded-aperture imaging system has been reported previously for reducing non-uniform background noise and compensating for systematic irregularities [3], and an anti-mask could be utilized by simply rotating the mask 90 degrees for the anti-symmetric MURA (modified uniformly redundant array) mask. However, mechanical rotation of the mask is time-restricting for a real-time imaging system. Thus, only one mask is chosen for the simulation and experiment and is based on a cyclic replication of a MURA pattern of rank 11, expanded to 21×21 pixels, and it is comprised of 2 cm thick of tungsten. Furthermore, a remedy for the artifacts the are due to the signal distorting via the finite mask thickness is needed. Because of this, centered, anti-symmetric,

and mosaicked MURA patterns of the mask are used as shown in Fig. 1.

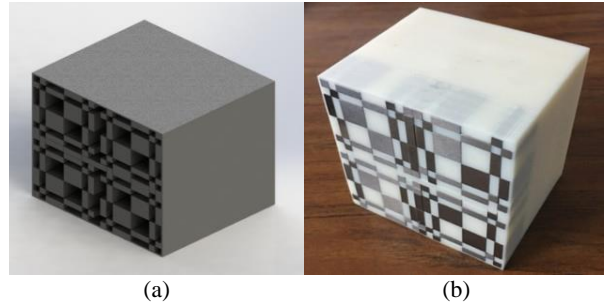


Fig. 1. (a) 3D model of centered, anti-symmetric, and mosaicked MURA mask and (b) 3D printed mask fitted with 2 cm thick of tungsten elements.

2.2 Signal Read-out Circuits for SiPM array

Used SiPM sensor (Sensl Technologies, ArrayC-30035-144-PCB) has a 144-pixel array, within which each pixel has an active area of $3 \times 3 \text{ mm}^2$. The square array has a 4.2 mm pixel pitch. The total outside dimension of the SiPM is $50.2 \times 50.2 \text{ mm}^2$. For the signal readout for this sensor, the readout scheme makes use of a charge division resistor network providing positional and spectroscopic information for each SiPM row and column output, in which two resistors are connected at the end of each pixel to facilitate the voltage division along the line as shown in Fig. 2. Each row and each column transmits the current signal to one of twenty-four fast operational amplifiers, from which the lateral position and energy is determined. This readout method processes the analog signals directly after the linear amplifier front-end, which provides better charge collection while minimizing the noise contribution of the resistive readout chain.

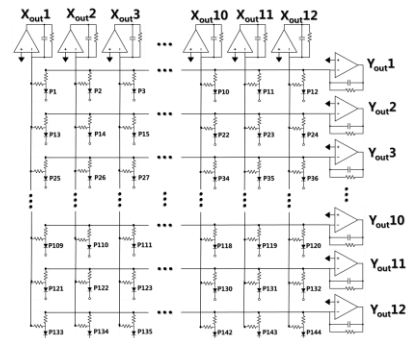


Fig. 2. A resistor matrix readout network for the charge division circuit of each anode output.

2.3 Image Reconstruction

The coded-aperture was designed using a mosaic MURA mask-based system which involves construction of both an encoding (mask pattern) and a decoding array. The detailed explanation for the image reconstruction with cross-correlation is described in Ref [4]. For the real-time imaging, cross-correlation method is not proper because it needs full data acquisition time to reconstruct image from sensor data. If acquired data is sparse, the probability of indicating an incorrect position is increased when the system uses cross-correlation method. However, iteration methods which use the system matrix are considered to be robust to high-noise and low-count problems, while producing results in a relatively short computing time. For this reason, developed coded-aperture imaging system adopted the maximum-likelihood expectation maximization (MLEM) algorithm for the real-time image reconstruction [5].

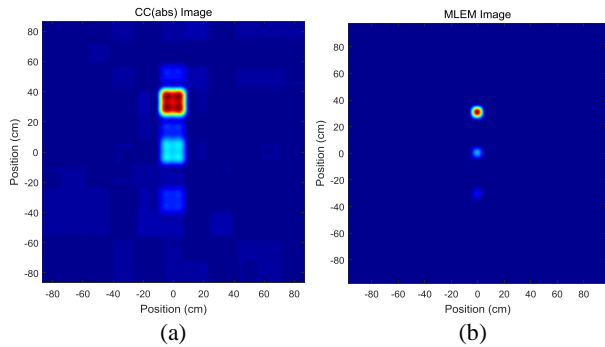


Fig. 3. Example images for three gamma sources which have different strength at different position reconstructed by (a) cross-correlation and (b) MLEM technique.

2.4 Graphic User Interface

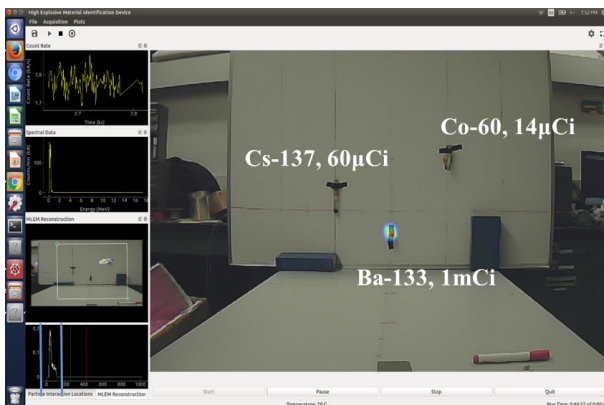


Fig. 4. Example of graphic user interface written by Python in Linux operating system for the real-time gamma ray imager, which shows count rate, spectrum, and localization.

We developed a graphic user interface based on python in Linux to show the count rate, spectrum, and position information of the radiation source from the

acquired sensor data through the external screen of laptop. Figure 4 shows an example of image information acquired from the developed system, showing the location discrimination, count rate, and total spectrum for multiple gamma rays. By the way, the disadvantage of using MLEM is that only the location of the strongest intensity of the gamma ray can be found, as shown in Fig. 4. In order to overcome this disadvantage, we set the energy interval in the obtained spectrum and classify the position of the source to the energy. For example, with proper energy binning for the specific energy region, such as 662 keV for Cs-137 and 1.173 keV for Co-60 with gated energy range of full width of half maximum (FWHM) energy resolution of detector, the localization and source identification could be realized as shown in Fig. 4. In addition, the image acquisition mode of the GUI has a real-time mode and a cumulative mode. When the intensity of the gamma ray is strong (> 100 counts per second at certain distance), the image can be reconstructed in the real-time mode and in the opposite case, the accumulation mode can be used.

3. Conclusions

A real-time gamma imaging system based on a coded-aperture technique using a large-area SiPM array combined with an inorganic scintillator have been successfully developed. In order to simplify the readout for the 144-pixel array, a resistor network with charge division circuitry is applied, which successfully provides a significant reduction in the multiplicity of analog outputs and reduced the size of accumulated data, which makes real-time source localization possible. In addition, the coded-aperture gamma ray camera using iterative image reconstruction methods based on system matrix can be usefully exploited for the real-time localization of the radioactive sources, and thus can be utilized for various applications including radiation safety, nuclear security and safeguards.

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