Transactions of the Korean Nuclear Society Virtual Spring Meeting
July 9-10, 2020

A new readout method to minimize blurring by Compton scattering effects in the coded-aperture imaging system

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1. Introduction

Gamma imagers using coded-aperture mask or Compton camera are widely used in the medical, industrial and homeland security fields for the purpose of localization and determining of unknown radionuclide [1-4]. In the case of Compton camera, the location of the radiation source is determined by using the scattering events inside the detector [5-6]. On the other hand, in the case of coded-aperture, the location information generated by the photoelectron absorption effect inside the detector through the mask is used [7]. In other words, what is needed to determine the location of the radiation source in Compton camera is a scattering phenomenon that occurs primarily at gamma ray in the energy range over 300 keV, so there is a disadvantage that it is difficult to determine the location of the low-energy gamma ray. However, for gamma cameras using coded-aperture masks, the interaction of position for photons that have been completely passed or attenuated through the mask are determined by the photoelectrical effect inside the pixel-type image sensor, so the scattering effect can be a factor that causes blurred image or determines the wrong position during image reconstruction. Therefore, it is necessary to properly select and remove scattering events in order to reduce blurring phenomena and errors in mislocation of images in a coded-application-based gamma camera.

This paper introduces the method of removing scattering events effectively via both traditional Anger logic-based readout circuits and new readout method used to determine the response location and energy of silicon photomultiplier (SiPM) array, which can evaluate image quality and location accuracy through peak signal-to-noise ratio (PSNR), normalized mean-square error (NMSE), and structural similarity (SSIM).

2. Methods and Results

The physical causes of Compton scattering events in the coded-aperture imaging system and how much noise influenced on reconstructed images for each cause were examined through Monte Carlo simulation such as Monte Carlo N-Particle eXtended (MCNPX)-Polimi software [8].

2.1 MCNPX-Polimi Simulation for Configuration of Scattering Events

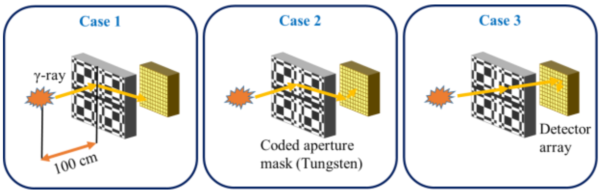

Fig. 1. The cases of Compton scattering events in the coded-aperture imaging system, which increase the probability of blurred reconstructed image and wrong location determination of gamma ray.

The Coded-aperture imaging system consists of an instrumental mask, pixel-type scintillator, and array-type SiPM. At this time, there are three possible cases where Compton events can occur: (a) total interaction events after scattering via mask, (b) Compton scattering event positions in a detector array without scattering via mask, and (c) Compton scattering event positions in a detector array after scattering via mask as shown in Fig. 1.

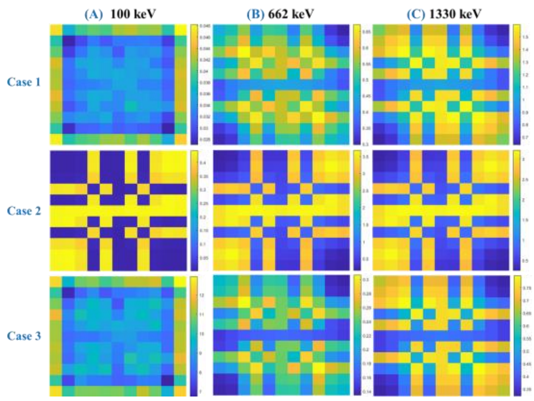

Fig. 2. Detector response maps for each case and radiation energy.

In each case, Figure 2 shows the extent to which Compton scattering events affect the determination of the response position in the detector array. For the case 1 and 3, scattered gamma ray via the mask contributes to the blurring pattern on the detector and the higher energy of gamma ray show more obvious blurring pattern. In the case 2, the blurring effect occurred due to pixel jumping when an incident gamma ray has a higher energy.

The low energy, i.e. the main response for 100 keV, is photoelectrical absorption, so the case 1 and case 3 have an even effect on the detector array, but the relatively high energy, for 662 keV and 1,330 keV, is

Compton scattering, so it can be seen that the main response is used as important information to determine the location of radiation as shown in the case 2 of Fig.2. Note that the ratio of scattered responses to total interaction events to the detector after scattering from the mask were 2.66%, 43.2%, and 48.7% for 100 keV, 662 keV and 1,330 keV, respectively.

2.2 Scattering Events Range Determination

For the scattering of the photon that entered the detector array, the stopping and range of ions in matter (SRIM) [9] and MCNPX-Polimi software were used to predict the range of movement between pixels. The raw data for use of SRIM software is acquired by MCNPX-Polimi.

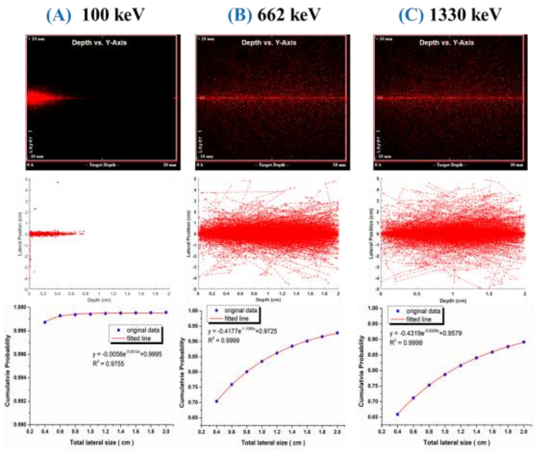

Fig. 3. The stopping and range of ions in matter (SRIM) simulation results for the inspection of scattered photon inside of detector array for different energy of gamma rays (100 keV, 662 keV, and 1,330 keV).

For each energy of 100keV, 662keV, and 1330 keV, the track path of the photon due to Compton scattering shows that 0.15%, 29%, and 33% of the total event deviate from the center of pixel which has 4 mm x 4 mm area, respectively, as shown in Figure 3.

2.3 New Readout Method for Rejecting the Compton Scattering Events

Traditionally, the Anger logic-based readout method is used to utilize the response position information and energy using signals obtained by pixel-type detectors. However, this method cannot remove Compton scatting events inside of the detector. Therefore, instead of using traditional methods, the signal of each pixel is directly digitized, and it can be seen that multiple events occur on the x-axis or y-axis at the same time as shown in Fig. 4 and 5, so that the Compton scattering event can be identified as occurring. In this case, the relative difference between the locations using the traditional method and using the new readout is determined, which effectively removes the events caused by Compton scattering. Therefore, reconstructed images using maximum likelihood expectation maximization (MLEM) for the detector response from new readout method shows better noise and localization performance than that of conventional one as shown in Fig. 6.

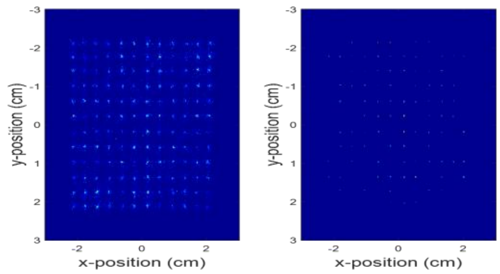

Fig. 4. 2D flood histograms for the 12 x 12 pixels detector array for the Cs-137 located at the center with 1 meter source to detector distance using conventional Anger logic readout (left) and applying new readout method (right).

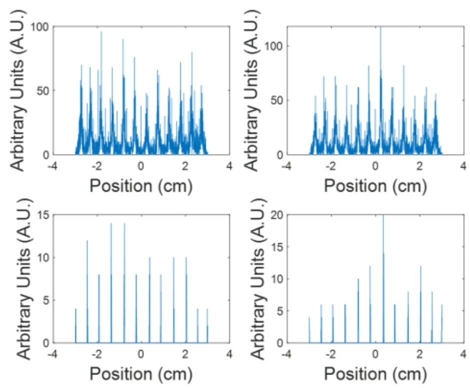

Fig. 5. 1D flood histogram for the x-axis (left) and y-axis (right) from conventional method (top) and new readout method (bottom).

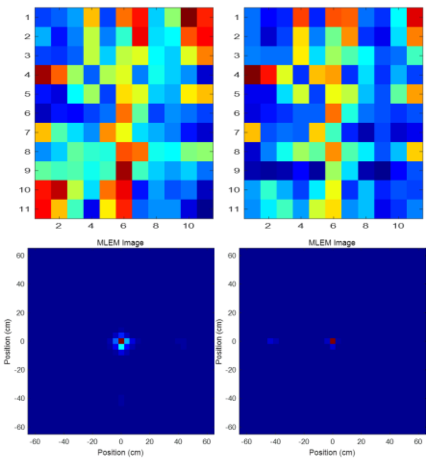

Fig. 6. Detector response map acquired by conventional method (top left) and by new method (top right) testing with Cs-137 located at center and 1 meter source-to-detector distance. And reconstructed images using MLEM for each cases (bottom)

The results of the image quality assessment and localization accuracy on the application of new readout methods to various energies through PSNR, NMSE, and SSIM will be discussed in detail in this meeting.

3. Conclusions

In the coded-aperture imaging system, we will suggest a new readout method for removing Compton scatting events that can cause blurring and mislocation in reconstructed images. The new readout method effectively identified the Compton scatting event, which resulted in improved quality and good positioning. This method will be used to detect the accurate location of radiation sources in real-time and to develop equipment for nuclide analysis in the field of medical, nuclear industrial, and homeland security.

Acknowledgements

This work was partly supported by Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government (MOTIE) (20181520302230) and by the Nuclear Safety Research Program through the Korea Foundation of Nuclear Safety (KoFONS) using the financial resource granted by the Nuclear Safety and Security Commission (NSSC) of the Republic of Korea (No. 1903011-0119-CG100).

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