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P1.57: Regression-based detector gain optimization method to improve position estimation performance of high-speed gamma imaging system

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To combat illicit trafficking at airports and harbours, the presence of nuclear and radioactive material in imported goods must be carefully inspected. For fast and precise inspection, we are developing a high-speed gamma imaging system, which rapidly localizes and specifies nuclear and radioactive material in a wide outdoor environment, as shown in Figure 1. This system offers a number of advanced features, including (1) high imaging sensitivity achieved by utilizing two quad-type detectors, each of which includes four large-area NaI(Tl) crystals (146 x 146 mm^2) coupled with 36 photomultiplier tubes (PMTs), and (2) a broad energy range of imaging by utilizing a hybrid gamma imaging technique that combines Compton imaging and coded aperture imaging. In both imaging techniques, high-precision position estimation for gamma-ray interaction in the crystal is required to obtain high resolution image and, in the present study, the estimation of gamma-ray interaction location is done via the maximum likelihood position estimation (MLPE) method [1], which compares ratio of the nine PMT signals to pre-measured data, making PMT gain maintenance critically important. The outdoor operation of the system, however, can cause variation in system temperature, which will affect the uniformity of PMT gains as the gain of PMTs is highly dependent on temperature [2]. To address this issue, we have proposed a regression-based gain optimization method to maintain the uniformity of PMT gains and have evaluated its performance through several experiments. This method involves four main steps: first, acquiring training data (i.e., PMT signals) using sources of known energies; second, calculating the gain optimization matrix, which compensates for inter-channel deviation, by applying linear regression on training data and true interaction energy; third, repeating the calculation of the matrix to acquire optimal gain by refining the training data (i.e., applying the gain optimization matrix to the training data and updating the matrix until the ratio of the newly and previously acquired matrix is under 3%); and finally, applying the gain optimization matrix to the new measured PMT signals by matrix multiplication to optimize the performance of position estimation. To evaluate the performance of the proposed method, experiments were conducted under two conditions; when all the original PMT gains were maintained, and when the gains of five PMTs were randomly changed within the range of 0.75-1.6 times. For both conditions, the position estimation performance was evaluated at 20 mm intervals using a 137Cs pencil-beam source to compare the position estimation performance without and with the method. As a measure of the accuracy in position estimation and spatial resolution, the mean displacement (MD), which is calculated by the estimation error of each event, was evaluated for 49 positions in each experiment condition. The estimated interaction position of the 49 positions with and without gain optimization when PMT gains were maintained and changed are shown in Figure 1. When the PMT gains were maintained, the developed method marginally reduced the MD, i.e., from 4.5±0.7 mm (average ± standard deviation) to 4.3±0.5 mm. On the other hand, when the PMT gains were changed, the MD was significantly reduced, i.e., from 12.7±7.1 mm to 4.6±0.6 mm; that is, the original MD was successfully recovered. These results indicates that the developed gain optimization method maintains the position estimation performance of the gamma imaging system even when the PMT gains are changed by temperature during outdoor operation. Future works will include using background radiations on the developed method.

[1] L. R. Furenlid, et al., Penetrating Radiation Systems and Applications VIII (2007), 6707, 67070N.

[2] M. Moszyński, et al., Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 568(2) (2006), 739–751

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