Development of a simplified readout for a compact gamma camera based on 2×2 H8500 multi-anode PSPMT array

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Development of a simplified readout for a compact gamma camera based on 2×2 H8500 multi-anode PSPMT array

Abstract
The aim of this study was to develop a high-performance simplified readout electronic for a compact gamma camera to achieve a maximized performance in its intrinsic spatial resolution. This compact camera is based on a pixellated NaI(Tl) crystal with 1.2 mm×1.2 mm×5 mm pixel element and 1.4 mm pixel pitch coupled to a 2×2 Hamamatsu H8500 multi-anode position sensitive photomultiplier tube (PSPMT) array. The design of the simplified readout is based on novel two-stage charge divisions with Truncated Center-of-Gravity (TCOG) positioning method to maximize the detector performance. The performance of the compact camera with the novel simplified readout was evaluated by flood imaging of a 57Co source. The experimental results show that the readout circuits we developed can effectively reduce the readout channels from 256 to 4 and well resolve the 1.2 mm crystal elements of the NaI(Tl) crystal array while maximizing the effective field-of-view (FOV) of the detector to cover the whole active area of the detector. In addition, the optical coupling measures in the gap regions among the PSPMT array are necessary in order to improve the image distortion in the gap regions. The results indicate that our design is effective approach which can be adopted for other high-resolution gamma camera based on multi-anode PSPMT array with a larger FOV.

Keywords
camera, 2, development, h8500, simplified, multi, pspmt, array, anode, readout, compact, gamma

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Abstract—The aim of this study was to develop a high-performance simplified readout electronic for a compact gamma camera to achieve a maximized performance in its intrinsic spatial resolution. This compact camera is based on a pixellated NaI(Tl) crystal with 1.2mmx1.2mmx5 mm pixel element and 1.4 mm pixel pitch coupled to a 2x2 Hamamatsu H8500 multi-anode position sensitive photomultiplier tube (PSPMT) array. The design of the simplified readout is based on novel two-stage charge divisions with Truncated Center-of-Gravity (TCOG) positioning method to maximize the detector performance. The performance of the compact camera with the novel simplified readout was evaluated by flood imaging of a $^{57}$Co source. The experimental results show that the readout circuits we developed can effectively reduce the readout channels from 256 to 4 and well resolve the 1.2mm crystal elements of the NaI(Tl) crystal array while maximizing the effective field-of-view (FOV) of the detector to cover the whole active area of the detector. In addition, the optical coupling measures in the gap regions among the PSPMT array are necessary in order to improve the image distortion in the gap regions. The results indicate that our design is effective approach which can be adopted for other high-resolution gamma camera based on multi-anode PSPMT array with a larger FOV.

I. INTRODUCTION

In recent years there have been many efforts to develop high-resolution modular gamma cameras for small animal molecular imaging. In terms of size, cost effectiveness and performance, the use of pixellated scintillation crystal array combining with position sensitive photomultiplier tube (PSPMT) still remains the best choice for high-resolution modular gamma cameras.

Because of its relatively higher performance-to-price ratio, the Hamamatsu H8500 multi-anode PSPMT has been widely used for the development of modular gamma camera. The H8500 is a multi-anode PSPMT which has a matrix of 8x8 anode pads and an active photocathode size of 49mm in square. However, the small field-of-view (FOV) of 5cm with single H8500 unit is limited its applications for small animal imaging. The development of the compact gamma camera with larger FOV using an array of H8500 tubes has been studying by several research groups [1-3]. However, the large number readout channels of an array of H8500 tubes results in a significant increase of the complexity of the readout electronics. The development of a simplified readout to reduce the complexity of the readout electronics of the H8500 array’s while maintaining the high performance of the detector is still a challenge issue [3-4]. We have successfully developed a simplified compact readout for the single H8500 tube and would like to extend the same design scheme to an array of H8500 tubes.

In this work we aimed to develop a high-performance compact gamma camera using a NaI(TI) crystal array with a 2x2 array of H8500 PSPMTs. Since the 2x2 H8500 array has a total of 256 individual signal readouts, the design and development of a simplified readout to reduce the readout channels are very essential for the compact camera. A two-stage charge division readout scheme with truncated center-of-gravity (TCOG) positioning method is designed to maximize the detector performance. The performance of the compact camera with the novel simplified readout will be evaluated by a flood image of $^{57}$Co source.

II. MATERIALS AND METHODS

A. Compact gamma camera

This compact gamma camera composed of a pixellated NaI(TI) crystal array and a 2x2 Hamamatsu H8500 PSPMT array, shown in Fig.1. The crystal array from Saint-Gobain crystals and detectors Inc. has a active area of 102mm square with a 1.2x1.2 mm² pixel element, 1.4 mm pixel pitch and 5 mm crystal thickness. The crystal array has a total of 72x72 pixels and is encapsulated in a compact housing with a 2mm thick quartz window. The scintillation light output from the crystal array is detected by the directly coupled PSPMT. The H8500 is a multi-anode PSPMT which has 8x8 matrix-anode

![Fig.1](image-url)
pads and an active photocathode size of 49mm in square. The 4 H8500 tubes were combined according to a 2x2 matrix, which results in a total of 16x16 readout channels. The inter-tube dead gap is about 4mm.

B. Design of the simplified readout

The simplified readout is based on a novel two-stage charge division scheme with truncated center-of-gravity (TCOG) positioning method, shown in Fig.2. First, the incoming 256 anode charge signals from the 2x2 H8500 array are equally split into X and Y directions using a symmetric 2D decoupling resistive matrix [5], which results in 256 readout channels reducing to 32 channels (16 rows and 16 columns).

Secondly, the 32 readout channels are individually amplified and shaped. Then a fractional subtraction circuit is designed to cut off the long tail of charge distribution and remove the noise contributions far from the incident site of gamma-ray, which results in an implementation of the truncated center-of-gravity (TCOG) algorithm [6] to determine the incident position of the detected gamma-rays.

Thirdly, a conventional resistive bridge circuit [7] was used to further reduce the readout channels from 32 to 4 outputs (X, X', Y, Y'). Then the incident position and energy of the detected gamma-rays in the detector is determined by the following equations:

\[
X = \frac{X^+ - X^-}{X^+ + X^-} \quad Y = \frac{Y^+ - Y^-}{Y^+ + Y^-} \quad E = X^+ + X^- + Y^+ + Y^-
\]

C. Implementation of the simplified readout

According to the above design scheme, we have implemented the simplified readout using SMD components into 3 compact circuit boards, shown in Fig. 3. The first circuit board was implemented with a symmetric 2D decoupling resistive matrix network, which reduces the 16x16 matrix readout into a16-row plus 16-column readout. The second circuit board is to amplify and shape the 32 charge signals from the first circuit board while embedding a fractional subtraction circuit based on the truncated center-of-gravity algorithm. The third circuit board was implemented with a conventional resistive bridge circuit to further reduce 32 charge signals from the first circuit board to 4 readout signals.

We used a 12-bit PCI-6110E ADC card from the National Instrument for the DAQ. The performance of the compact gamma camera with the novel simplified readout was tested in the flood images using a 57Co source. We have tested two coupling modes between the scintillation crystal and the PSPMTs. One is to use directly coupling between the crystal and tubes. Another is to use optical grease coupling between the crystal and tubes.

III. RESULTS

The measured flood image of the compact detector with directly coupling between the scintillation crystal array and the PSPMTs is shown in Fig.4. The projection histogram in the X direction of a middle pixel row of the raw flood images is shown in Fig. 5. We can see that the individual crystal elements are well resolved in the central region of each H8500 PSPMT. However, the image distortion of the detector in the edges of each H8500 and in the gap regions between H8500s is significant. There exists a significant cross-type dead gap in
the central region of the detector due to the loss of the scintillation photons in the joint gap regions between the H8500 tubes. So the optical coupling measures in the gap regions between the PSPMTs are necessary in order to improve the image distortion in the gap regions.

Then we added a thin light guide layer and optical grease in the gap regions between H8500s to make the scintillation light in the gap regions to be shared between the H8500 tubes. The measured flood image of the detector with the improved coupling measure between the scintillation crystal and the PSPMTs is shown in Fig. 6. The projection histogram in the X direction of a middle pixel row of the raw flood images is shown in Fig. 7. We can see that the detector performance is significantly improved in the joint gap regions between H8500 tubes. More crystal elements in the gap regions are resolved.

![Fig. 6 A measured flood image of the detector with a improved optical coupling between the scintillation crystal and the PSPMTs: (a) the raw flood image; (b) enlarged view of a selected region.](image)

![Fig. 7 X-projection histogram of the central region of the raw flood image with improved coupling measure between the crystal and H8500 tubes.](image)

The preliminary results show that the novel two-stage charge division readout with truncated center-of-gravity method could significantly reduce the non-linearity and the compress effect of positioning to maximize the crystal element identification and the useful field-of-view (FOV). The compact gamma based on our simplified readout can achieve a high spatial resolution with relative large FOV. This compact detector was further calibrated using a $^{99m}$Tc source. The solved crystal elements of the detector can reach up to 70x70, very close to the detector’s physical size. The measured energy spectrum obtained from this compact detector with the novel simplified readout is shown in Fig. 8. The overall energy resolution of the detector is ~20% for the gamma-rays at the energy of 140 KeV.

![Fig. 8 The measured energy spectrum obtained from the compact gamma camera with the novel simplified readout using $^{99m}$Tc source.](image)

IV. CONCLUSION AND DISCUSSION

We have successfully designed and developed a simplified readout based on two-stage charge division with truncated center gravity positioning method for a compact gamma based on a 2x2 of H8500 multi-anode PSPMTs. This simplified readout can effectively reduce the large number of readout channels from 256 to 4 and well resolve the 1.2mm crystal elements of the NaI(Tl) crystal array while maximizing the effective field-of-view (FOV) of the detector to cover the whole active area of the detector. The optical coupling measures in the gap regions among the PSPMT array are necessary in order to improve the image distortion in the gap regions. These results indicate that the simplified readout design that we developed is effective approach which can be adopted for other high-resolution gamma camera based on multi-anode PSPMT array with even larger FOV. Further evaluate the performance of the compact gamma with the simplified readout is under the studies.

REFERENCES


