CPC(HEP & NP), 2010, 34(8): 1148–1152 Chinese Physics C Vol. 34, No. 8, Aug., 2010

Investigation of high resolution compact gamma camera module based on a continuous scintillation crystal using a novel charge division readout method*

DAI Qiu-Sheng(代秋声)[1;1)] ZHAO Cui-Lan(赵翠兰)[1] ZHANG Hua-Lin(张华林)[2] QI Yu-Jin(漆玉金)[1]

[1] Shanghai Institute of Applied Physics, Chinese Academy of Sciences, Shanghai 201800, China
[2] Department of Radiation Medicine, Ohio State University, Columbus, OH 43210, USA

Abstract The objective of this study is to investigate a high performance and lower cost compact gamma camera module for a multi-head small animal SPECT system. A compact camera module was developed using a thin Lutetium Oxyorthosilicate (LSO) scintillation crystal slice coupled to a Hamamatsu H8500 position sensitive photomultiplier tube (PSPMT). A two-stage charge division readout board based on a novel subtractive resistive readout with a truncated center-of-gravity (TCOG) positioning method was developed for the camera. The performance of the camera was evaluated using a flood ^{99m}Tc source with a four-quadrant bar-mask phantom. The preliminary experimental results show that the image shrinkage problem associated with the conventional resistive readout can be effectively overcome by the novel subtractive resistive readout with an appropriate fraction subtraction factor. The response output area (ROA) of the camera shown in the flood image was improved up to 34%, and an intrinsic spatial resolution better than 2 mm of detector was achieved. In conclusion, the utilization of a continuous scintillation crystal and a flat-panel PSPMT equipped with a novel subtractive resistive readout is a feasible approach for developing a high performance and lower cost compact gamma camera.

Key words compact gamma camera module, truncated center-of-gravity method, image shrinkage effect

PACS 87.57.cf, 87.57.ue, 85.60.Ha

1 Introduction

Single photon emission computed tomography (SPECT) imaging plays an important role in the rapidly growing field of molecular imaging [1, 2]. A recent advance of SPECT has been focused on the development of a multi-camera SPECT system for small animal imaging with a large detection efficiency, while maintaining high spatial resolution [3–5]. The multi-camera SPECT system usually requires a high-resolution compact gamma camera module.

The main approach with the high-resolution compact gamma camera module is based on the discrete scintillation crystal array with a position sensitive photomultiplier tube (PSPMT). This has been well proven in obtaining high spatial resolution, good performance and reliability in breast and small-animal imagers [6–12]. However, the high price of the discrete crystal array as compared with the continuous crystal usually leads to expensive costs for multi-camera SPECT system. So a lower cost alternative to the high resolution discrete crystal design using a continuous crystal slab with PSPMT for compact modular camera has aroused increasing interest [13–15].

The continuous scintillation crystal slab with a cross-anode PSPMT for the development of a miniature gamma camera has been studied by several groups [14, 15]. Their results show that the performance of these miniature gamma cameras is limited by the conventional resistive readout with the Anger positioning method [16], which resulted in significant shrinkage of the effective field-of-view (FOV) of the camera [15]. Therefore, improvement of the readout and positioning method is essential for the development of a high performance and lower cost modular

Received 20 October 2009, Revised 12 January 2010
* Supported by National Natural Science Foundation of China (30570520, 10875162)
1) E-mail: qiyujin@sinap.ac.cn

gamma camera.

The aim of our study is to develop a high performance and lower cost compact gamma camera module for the multi-camera small animal SPECT system. In this study, we investigated a compact gamma camera module using a continuous lutetium oxyorthosilicate (LSO) scintillation crystal slab coupled to a compact multi-anode flat panel PSPMT (Hamamatsu H8500). A novel subtractive resistive readout based on the truncated center-of-gravity (TCOG) positioning method was developed for the camera [7, 17]. The performance of the detector module was evaluated by experiment.

2 Readout methods

2.1 Conventional readout

Two main readout schemes have been adopted for the compact gamma camera based on PSPMT. One is based on the channel-by-channel readout method, which requires complex readout processing circuits and the data acquisition system, because the individual anode signals need to be processed to decode the position information. The other is based on the charge division method using a resistive matrix network, which needs simple readout circuits and data processing. The resistive charge division method has therefore been widely used in the development of a compact gamma camera.

In the charge division method, the anodes are directly connected to a simple resistive network, which provides a proportional charge division as a function of position defined by the anode location, generally with four output channels. The coordinate of charge distribution centroid is determined by the following equation [18]:

$$x=\frac{\sum w_i^X q_i^X}{\sum q_i^X},\quad y=\frac{\sum w_i^Y q_i^Y}{\sum q_i^Y},\tag{1}$$

where x and y are the event coordinates, w_i is the weighting factor for the ith strip anode, q_i is the charge collected on it and the superscripts X and Y denote the anode direction.

The conventional resistive charge division method can usually reduce the readout channels down to four outputs. So subsequent signal processing and data acquisition become much simpler and cost less. However, this has a major disadvantage in the position determination with serious non-linearity because of the significant contributions of noise and cross-talk far away from the incident area in the position calculations with Eq. (1), which results in significant shrinkage of the effective field-of-view (FOV) of the camera image [15].

2.2 A novel subtractive resistive readout with TCOG positioning method

In order to overcome the problems of the conventional resistive readout, a novel subtractive resistive readout method was proposed [17], as shown in Fig. 1. This can be regarded as the combination of the individual readout with the conventional resistive readout. The basic idea of the subtractive resistive readout is to implement a fractional subtraction technique in the readout circuit to subtract the long tail of the charge distributions on the anode plane of the PSPMT and remove the noise contributions far from the gamma-ray incident area. Then a truncated center-of-gravity (TCOG) algorithm is applied to improve the accuracy of the position determination and to reduce the image shrinkage effect.

The fractional subtraction factor (referred to as the f-factor) is critical in the subtractive resistive readout since it determines the selection size of the local region, which is involved in the position calculations. Therefore, it is important to select an appropriate f-factor in the subtractive resistive readout. If the f-factor is set too high, the uniformity of the flood image becomes worse, whereas if the f-factor is set

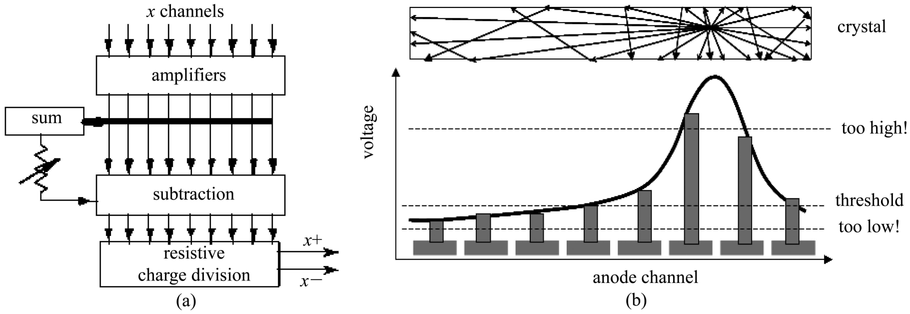

Fig. 1. (a) Diagram of the subtractive resistive readout [17] and (b) a simple illustration of the truncated center-of-gravity positioning principle.

too low, the nonlinearity and image shrinkage cannot be suppressed. We usually determine the appropriate f-factor by experiment.

3 Compact gamma camera module

The compact gamma camera module that we have developed is based on a continuous LSO crystal slab with a Hamamatsu H8500 PSPMT, as shown in Fig. 2. The LSO slab from the Shanghai SICCAS High Technology Corp. is 50 mm square with a thickness of 2 mm, and it has a stopping power of about 80% for gamma rays at an energy of 140 keV. The LSO crystal slab is directly coupled onto an H8500 PSPMT. The H8500 is a square, compact, flat-panel PSPMT with external dimensions of 52 mm×52 mm×28 mm, a sensitive photocathode area of 49 mm×49 mm, and a glass window of 1.5 mm in thickness. It has 12 metal channel dynodes with a gain of about 10^6 and an 8×8 array of anode pads to collect the multiplied charges.

The readout circuit board, shown in Fig. 2(c), was developed using a novel two-stage charge division method. First, the incoming charge from 64 anodes is equally split into X and Y directions using a 2D symmetric decoupling resistive matrix [19], which results in 8-X and 8-Y outputs. Then the 16 readout channels are further reduced to 4 outputs by using a subtractive resistive charge division [17], where a fractional subtraction circuit is used to remove the long tail of charge distribution and the noise contributions far from the gamma-ray incident region. Then a truncated center-of-gravity (TCOG) algorithm is applied to determine the incident position of the detected gamma-rays.

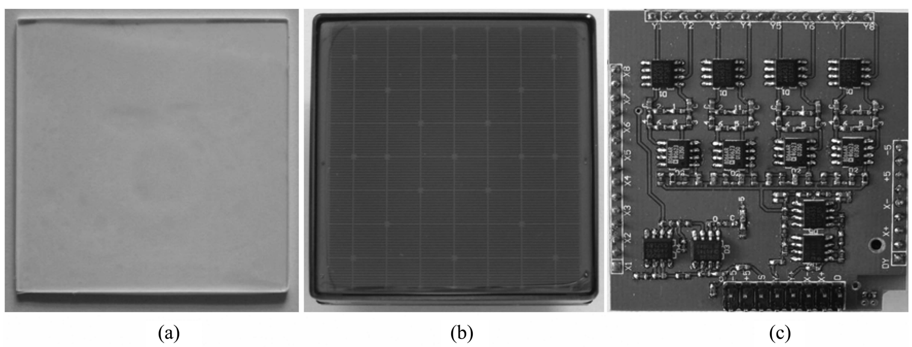

Fig. 2. Photographs of the components of our assembled detector module: (a) LSO crystal plate; (b) H8500 PSPMT; (c) readout circuit board.

4 Experimental test methods

The general performance of the assembled compact gamma camera module was evaluated using a flood ^{99m}Tc source, and the spatial resolution of the detector module was assessed with a preliminary imaging experiment using a four-quadrant bar mask phantom, as shown in Fig. 3. In the flood imaging experiment, the detector performance was evaluated with different subtractive fraction factors of 0.1%, 3% and 6%, in which the subtractive resistive readout with the f-factor of 0.1% is equivalent to the conventional resistive readout. The four-quadrant bar mask phantom, which is 180 mm in diameter and 5 mm in thickness, was made of lead strips with widths equal to the spaces between them. The four bar patterns are 2 mm, 3 mm, 4 mm and 5 mm. We only used the 2 mm bar-mask pattern in the imaging experiment. The flood images with different f-factors were used for the uniformity correction of the bar-mask phantom imaging.

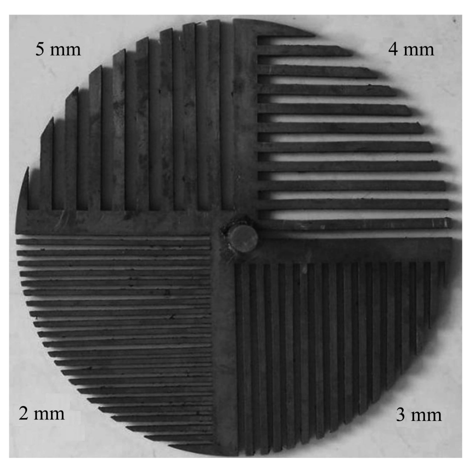

Fig. 3. Photograph of a four-quadrant bar mask phantom.

5 Results and discussion

The raw flood images acquired with different f-factors of 0.1%, 3% and 6% using a ^{99m}Tc source are shown in Fig. 4. The results show that the image shrinkage effect of a detector is very serious when the f-factor is set too low at 0.1%, where the subtractive resistive readout is equivalent to the conventional resistive readout. When the f-factor is increased to an appropriate level around 6%, the shrinkage of the flood image is significant reduced.

The raw flood images acquired with the bar-mask are shown in Fig. 5(a), (b) and (c) and the profiles of the flood images in the middle region are shown in Fig. 5(d). We calculate the response output area (ROA) of the camera to qualitatively compare the image shrinkage effect with different f-factor settings. The results show that the ROA of the camera with a f-factor of 6% almost reaches the active area of the PSPMT, and it is increased by about 34% as compared with the ROA with an f-factor of 0.1%, which is equivalent to the conventional resistive charge division method. Therefore, the image shrinkage effect with the conventional resistive charge division is effectively suppressed by using the subtractive resistive charge division method.

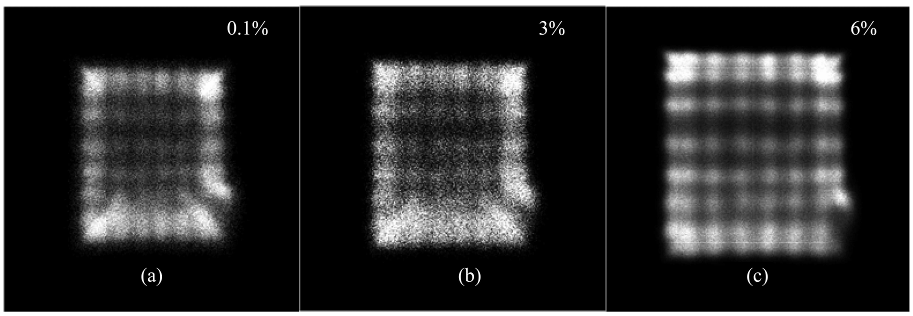

Fig. 4. Comparison of the raw flood images obtained with different f-factors using a flood ^{99m}Tc source. All images are at the same scale.

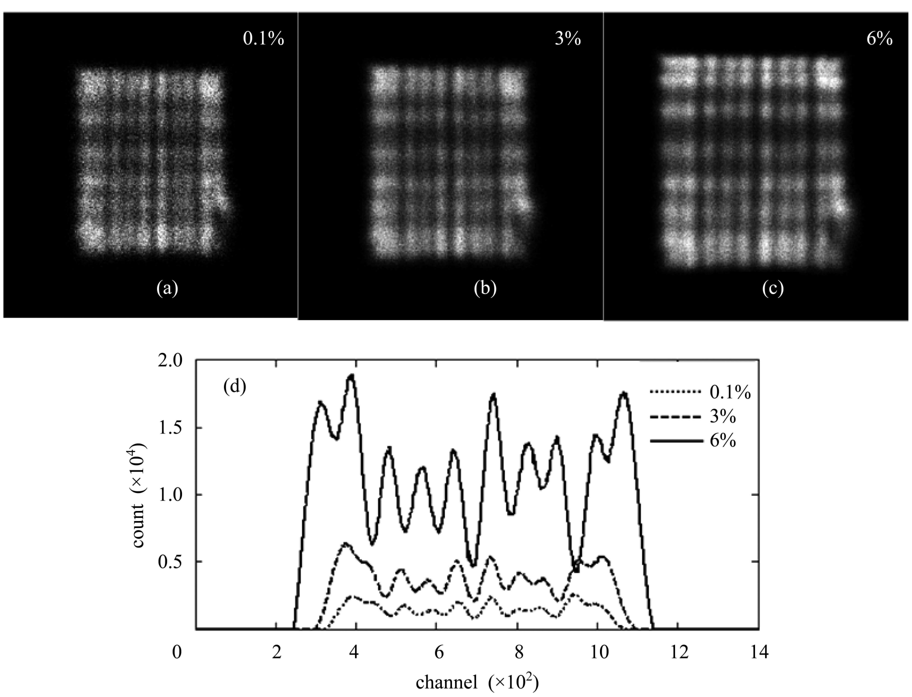

Fig. 5. Raw images obtained with a bar mask. All images are at the same scale. The profiles of the flood images in the middle region are shown in (d).

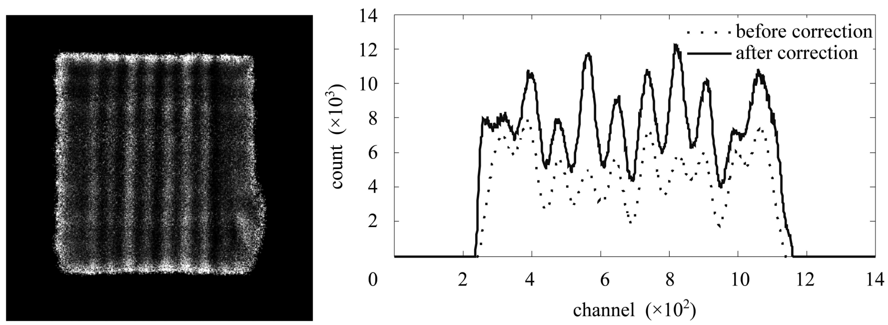

Fig. 6. Uniformity corrected image of the bar mask and the profile.

The bar image with an f-factor of 6% using a coarse uniformity correction is shown in Fig. 6. The coarse uniformity correction simply divided the raw bar image in Fig. 5(c) by the raw flood image in Fig. 4(c). We can see from Fig. 6 that the image quality is improved and the bar pattern with 2 mm separation is clearly resolved. This indicates that the compact gamma camera module that we designed could achieve an intrinsic spatial resolution of less than 2 mm.

6 Conclusions

We have developed a lower cost compact gamma camera module using a continuous LSO scintillation crystal slab and a Hamamatsu H8500 flat-panel PSPMT. A compact readout board based on a novel two-stage charge division method was developed for the camera. With the novel subtractive resistive readout and TCOG positioning algorithm, the image shrinkage effect associated with the conventional resistive readout can be effectively overcome to achieve high performance of the camera. In conclusion, the utilization of a continuous scintillation crystal and a flat-panel PSPMT equipped with the novel subtractive resistive readout is a feasible approach for developing a high performance and lower cost compact gamma camera.

References

1 Meikle S R, Kench P, Kassiou M et al. Phys. Med. Biol., 2005, **50**: R45–R61.
2 Madsen M T. J Nucl. Med., 2007, **48**: 661–673
3 Meikle S R, Kench P, Wojcik R et al. Nuclear Science Symposium Conference Record, 2003, **3**: 1988–1992
4 Furenlid L R, Wilson D W, CHEN Y C et al. IEEE Trans. Nucl. Sci., 2004, **51**: 631–635
5 Figueroa S D, Winkelmann C T, Volkert W A et al. Nuclear Science Symposium Conference Record, 2005, **3**: 1752–1756
6 Weisenberger A G, Kross B, Majewski S et al. IEEE Trans. Nucl. Sci., 1998, **45**: 3053–3058
7 Wojcik R, Majewski S, Steinbach D et al. IEEE Trans. Nucl. Sci., 1998, **45**: 487–491
8 Pani R, Soluri A, Scafe R et al. IEEE Trans. Nucl. Sci., 1999, **46**: 702–708
9 McElroy D P, MacDonald L R, Beekman F J et al. IEEE Trans. Nucl. Sci. 2002, **49**: 2139–2147
10 QI Y J, Tsui B M W, WANG Y. IEEE NSS-MIC Conference Record, 2003, **4**: 2325–2329
11 Giokaris N D, Loudos G K, Maintas D et al. Nuclear Instruments and Methods in Physics Research A, 2003, **497**: 141–149
12 Bradley E L, Cella J, Majewski S et al. IEEE Trans. Nucl. Sci., 2006, **53**: 59–65
13 Seo H K, Choi Y, Kim J H et al. Nuclear Science Symposium Conference Record, 2000, **3**: 94–97
14 Schramm N, Wirrwar A, Sonnenberg F et al. IEEE Trans. Nucl. Sci., 2000, **47**: 1163–1167
15 ZENG Hai-Ning, XU Zi-Zong, WANG Zhao-Min et al. HEP & NP, 2000, **24**: 166–171 (in Chinese)
16 Anger H O. Rev. Sci. & Instr., 1958, **29**(1): 27–33
17 Wojcik R, Majewski S, Kross B et al. IEEE NSS-MIC Conference Record, 2001, **3**: 1821–1825
18 Soluri A, Massari R, Trotta C et al. Nuclear Instruments and Methods in Physics Research A, 2005, **554**: 331–339
19 Popov V, Majewski S, Weisenberger A G. IEEE Nucl. Sci. Symp. Conf. Rec., 2003, **3**: 2156–2159