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Design and development of a position-sensitive γ-camera for SPECT imaging based on PCI electronics

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Abstract

A position-sensitive γ-camera is being currently designed at IASA. This camera will be used experimentally (development mode) in order to obtain an integrated knowledge of its function and perhaps to improve its performance in parallel with an existing one, which has shown a very good performance in phantom, small animal, SPECT technique and is currently being tested for clinical applications. The new system is a combination of a PSPMT (Hamamatsu, R2486-05) and a PMT for simultaneous or independent acquisition of energy and position information, respectively. The resistive chain technique resulting in two signals at each (X, Y) direction will perform the readout of the PSPMT's anode signals; the system is based on PCI electronics. Status of the system's development and the ongoing progress is presented.

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Keywords: SPECT; PSPMT; γ-camera; Position resolution; Position imaging

1. Introduction

The design and construction of a γ-camera imaging system requires good understanding of the function of the system's basic hardware constituent, the Position Sensitive Photomultiplier (PSPMT), as well as an adequate data acquisition system using the appropriate electronics.

In order to obtain an integrated imaging device, a test of the PSPMT's position resolution must be performed without any scintillating crystal prior to the construction of the camera [1,2]. In addition, appropriate timing conditions should be ensured in order to exclude noisy signals from the position and energy determination. Special attention must be paid to the form of the output pulse of the PSPMT, so as to further manipulate it and appropriately digitize it.

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In the following sections a brief description of the experimental setup will be given; the basic electronic modules as well as the mechanical layout of the experimental apparatus are presented. In addition, the experimental results concerning the position imaging and the determination of the position resolution are discussed and future prospects are mentioned.

2. Description of the experimental setup

The main goal to be served by the construction of this γ-camera imaging device is to provide the user with the ability of collecting position information and at the same time assuring the best possible position resolution in a very compact system. This system is being developed parallel with an existing one, which has shown a very good performance in phantom, small animal, SPECT technique and is currently being tested for clinical applications [3–5].

An easy way to test the correct functionality of the imaging device is to collect, independently or simultaneously with the position information, the corresponding energy information as well, in order to compare it with the energy information collected by a conventional PMT. Any differences in the same energy spectrum arising from the PSPMT and the conventional PMT will help to improve the position reconstruction algorithms and, consequently, to improve the final reconstructed image. One of the existing problems in the position reconstruction is the inhomogenity of the charge in the X and Y anode wires [6].

2.1. Description of the electronic setup

A schematic block diagram of the electronic constituents of the imaging system is shown in Fig. 1. It should be pointed out that this diagram corresponds to the final construction, part of which has already been realized, and it illustrates the basic connections among the various electronic modules. Some of the modules shown in the figure, such as the discriminator or the delay module, have been combined to more sophisticated modules which were available in the laboratory.

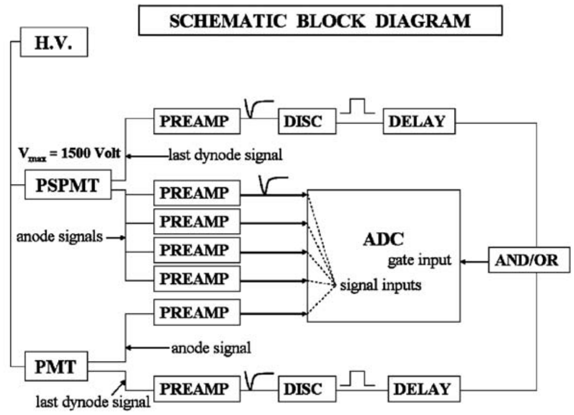

Fig. 1. Schematic block diagram of the electronic setup of the imaging device.

The PSPMT model used in the specific imaging device (Hamamatsu R2486-05 [7]) consists of 32 anode wires (16 anode wires at x direction and 16 anode wires at y direction), but for reasons of simplicity, in our first approach, a resistive chain technique at each direction resulting in only four signals (two at x and two at y direction) has been applied. The four signals, after having been preamplified, are fed to four analog inputs of a PCI card, which is incorporated to a PC. In our case, the model PCI-MIO-16E-4 that multiplexes the 16 input channels to an Analog to Digital Converter of 500 Ksamples/sec sampling speed and 12-bit resolution, has been used.

So far, the four anode signals called X_A, X_B, Y_C, Y_D of the PSPMT have been guided to the data acquisition system (PCI-MIO-16E-4), whereas for the production of a NIM gate signal the X_A signal has been used.

In order to achieve correct timing conditions during digitization, the last dynode signal should be used to trigger the acquisition. Since this signal is not separately provided in the model R2486-05, one of the four wire-signals can be used instead. A gate generator (model GD150/N, replacing the discriminator shown in the block diagram) is performing the generation and the delay of the trigger. Since the signal, which is used for the production of the trigger, is being attenuated, probably due to impedance difference between the cable and the gate generator, attention must be paid to correct it. By multiplying the corresponding signal with the appropriate correction factor, which is indicative of the attenuation, in the position calculation algorithm, the problem is resolved.

Another aspect that needs special attention is the appropriate adjustment of the trigger's width and delay with respect to the simultaneous analog signals in order to synchronize the peak of each signal with the NIM gate.

According to the block diagram there is also possibility of simultaneous or independent collection of energy information by feeding the anode signal of the conventional PMT to an additional analog input of the PCI card. Nevertheless, special attention must be paid to the appropriate positioning of the PMT with respect to the PSPMT if one wants to obtain energy spectrum at the same time from both photomultipliers.

As can be seen from the block diagram, there are two alternative modes for the simultaneous functioning of the PSPMT and the PMT; the one uses the AND logic, that requires a radioactive source emitting two coincident photons at opposite directions (positron emitter), and the other uses the OR logic that requires either a positron emitter or a radioactive source emitting photons at a solid angle 4π. Since, in our case the usual source used in experiments is ^{99}Tc, only the OR logic is possible.

2.2. Description of the mechanical setup

The mechanical setup used to test the position resolution of the system's PSPMT is shown in Fig. 2, where the basic components of the measurement apparatus and the data acquisition system are illustrated.

For the test of the position resolution of the PSPMT, light has been directly applied to the PSPMT window instead of using scintillating crystals and radioactive sources. The light pulses are being produced by a common, green LED and are guided to the PSPMT window via an optical fiber. One can adjust the duration and the repetition rate of the light pulses by connecting the LED to the output of a CAMAC programmable pulse generator (model BiRa 5500).

In order to guide the light at different positions with respect to the PSPMT window—and, consequently to the cross-wired anode—a matrix plate consisting of 21 holes has been constructed and applied to the PSPMT window. The optical fiber is then adjusted at each hole and measurements of the position of the fiber are performed. During the measurement the data (consisting of four voltage values corresponding to the X_A, X_B, Y_C, Y_D signals) are being digitized in the PCI card and proceeded in order to be further analyzed. The software used for the position determination is

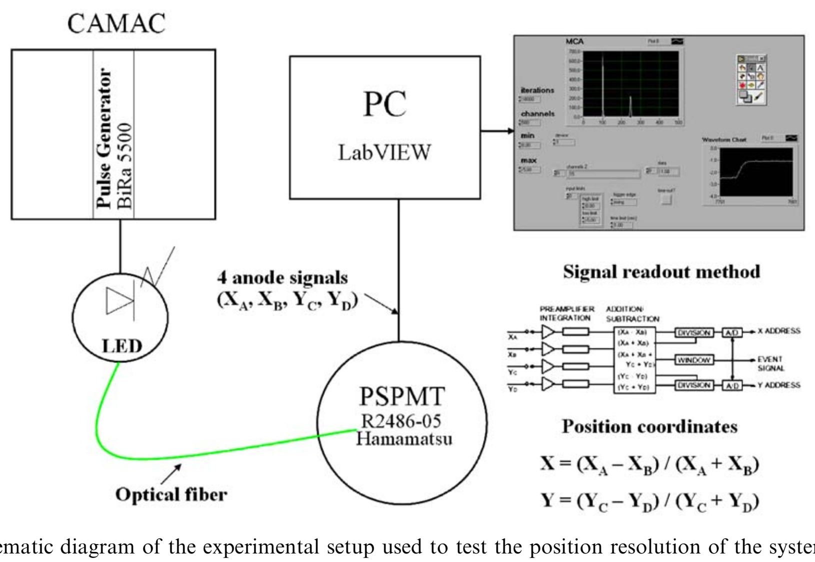

Fig. 2. Schematic diagram of the experimental setup used to test the position resolution of the system's PSPMT.

LabVIEW and the position reconstruction is based on the following algorithm that defines the X and Y coordinates of the optical fiber with respect to the PSPMT window.

$$X = (X_A - X_B)/(X_A + X_B)$$

$$Y = (Y_C - Y_D)/(Y_C + Y_D).$$

It should be added that in the above equations the signal that is also used for the production of the trigger must be multiplied by a correction factor determined from the central position of the optical fiber, where the equation of the left and right signals at each direction is supposed.

3. Experimental results

From the measurements described above, one needs to know how the various positions of the optical fiber can be determined by the constructed imaging system. More specific, the correspondence between the holes of the constructed matrix and the positions of the optical fiber, determined experimentally and depicted in a two-dimensional x–y histogram, must be examined.

In addition, knowing the exact geometric characteristics of the constructed matrix one can estimate the position resolution of the PSPMT device from the FWHM of the distribution of the measured spots projected at the x and y axis. A small arithmetic value of the FWHM indicates a good position resolution of the imaging device.

3.1. Position imaging

In Fig. 3 the measured position diagram is shown and compared to the corresponding matrix of holes, which are at a distance of 10 mm of each other.

As can be seen from the figure, the experimentally determined positions are very well distinguishable and their X–Y coordinates are comparable with the ones of the matrix holes, although no care has been taken in a possible rotation of the PSPMT. Nevertheless, the distance between two neighboring positions in the measured position diagram is not constant, a fact that reveals a non-uniformity among the anode wires at each direction.

Although the primary reasons for these fluctuations can be found in differences of the preamplifications of the four anode signals, mechanical inconsistencies, such as variations in the matrix hole diameters or variations in the distance between the head of the optical fiber and the PSPMT window, can be considered as an additional, but less important, reason for non-uniformities in position imaging.

A possible explanation for these fluctuations may be given by the mechanical construction of the 21-hole matrix. If the diameter of the holes is even slightly bigger in comparison to the diameter

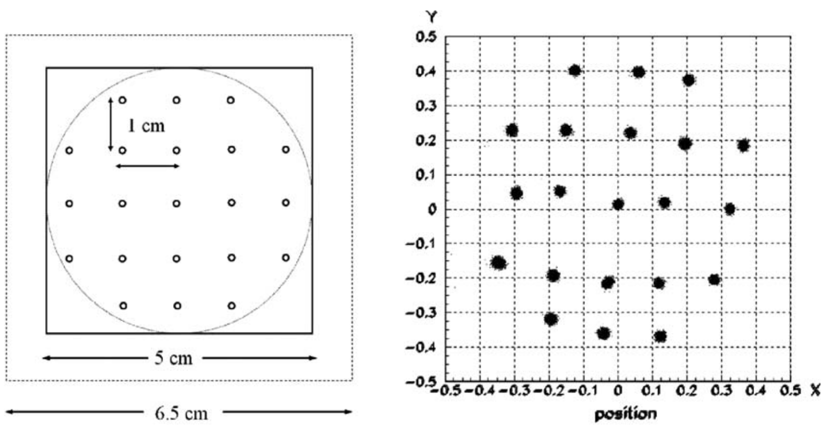

Fig. 3. Measured position diagram (right) in comparison to the layout of the constructed matrix (left).

of the optical fiber, then it is highly possible that the fiber points out to a different spot in the PSPMT window than the one indicated by the corresponding hole. One must also take into account a possible rotation of the PSPMT's cross-wired anode, a fact that explains the lack of coincidence between a perpendicular series of spots and the y axis in the right diagram of Fig. 3.

3.2. Determination of position resolution

In order to determine the position resolution of the system, the projections of the measured spots at each direction (in the two-dimensional X–Y histogram) are needed (see Fig. 4).

In order to have a quantitative estimation of the position resolution of the system one must apply a Gaussian fit to two neighboring projections of each direction and calculate the FWHM of the Gaussians in mm as shown in Fig. 5.

Taking into account the fact that the real distance between two neighboring locations in the constructed matrix is 10 mm, Table 1 shows the mean position resolution calculated for each of the

Table 1
Measured FWHM for the two Gaussians of each direction of Fig. 5

	X direction		Y direction	
Distance between Gaussians	0.130 (a.u.)		0.207 (a.u.)	
FWHM	0.92 mm	0.92 mm	0.73 mm	0.76 mm

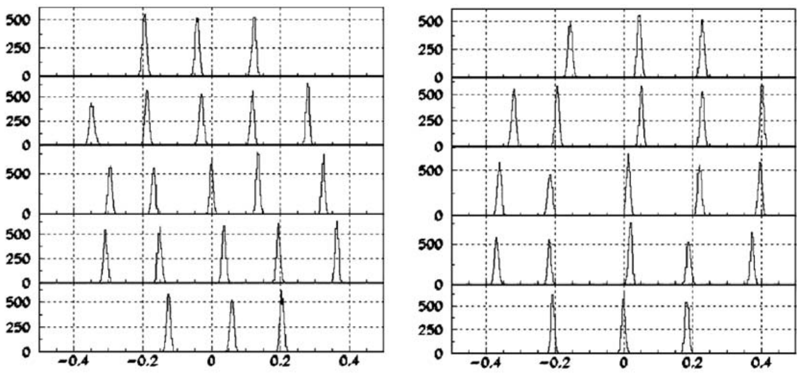

Fig. 4. Projections of the measured spots at the X (left) and at the Y (right) direction.

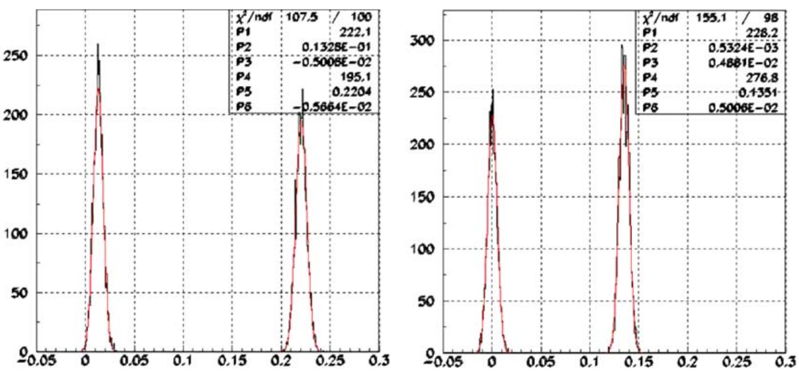

Fig. 5. Gaussian fit (red lines) on two neighboring projections at the X (left) and Y (right) direction.

two Gaussians at each direction, mainly affected by the natural size of the light source.

As it can be seen by the arithmetic results of Table 1, there is a small difference in the position resolution at each direction. Non-uniformities in the preamplification of the anode signals and systematic errors of the mechanical system for guiding the light source could be possible reasons for this difference.

4. Future plans

After having examined a first performance of the PSPMT device in position imaging, some of the next steps that are to be accomplished should be mentioned.

In order to test the position resolution of the integrated imaging device, direct application of a scintillating crystal (pixilated and planar) to the PSPMT window is necessary. A test of the energy resolution of the system can be performed by the collection of energy spectrum with the PSPMT and comparison with the energy spectrum collected by a conventional PMT.

Finally, an alternative method of data readout using CAMAC electronics should be realized in order to improve the performance of the γ-camera concerning the data acquisition speed.

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