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A Study on the Optimization of Optical Guide of Gamma Camera Detector

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Abstract

An optical guide, which is a light guide located between NaI(Tl) scintillation-crystal and array of photo-multiplier tubes (PMTs) in the gamma camera detector system, is an essential component to deliver the spatial information recorded in scintillator to the PMTs. Without the optical guide, the spatial information within the range of a single PMT could not be obtained. For the design of the optimal optical guide, it is necessary to characterize its properties, especially sensitivity and spatial resolution of detector. In this study, the thickness and the refractive index of optical guide, which affect not only on the sensitivity but also on the spatial resolution of gamma-camera detector, were investigated by using Monte Carlo simulation. A 12”×12”×3/8” NaI(Tl) and 23 PMTs with each 5” diameter were considered as a gamma-camera detector components. Interactions of optical photons in the scintillator and the optical guide were simulated using a commercial code DETECT97, and the spatial resolution, mainly interfered by the intrinsic inward distortion within the PMT, was investigated using our own ANGER program, which was developed to calculate positions of incident photons in the gamma camera. From the simulation results, it was found that an optical guide with 1.6 of refractive index and 10 mm of thickness give maximum sensitivity and minimum spatial distortion, respectively.

Introduction

Due to the ability of functional imaging and relatively easy production of radioisotopes, the gamma camera is the most widely used in nuclear medicine. The detector of gamma camera system typically consists of a thin-, large-, single crystal of NaI(Tl) and an array of photo-multiplier tubes (PMTs). In order to get the best spatial resolution, optical photons sharing among PMTs require an introduction of gap between the scintillator and PMTs, so that an optical guide is usually employed to couple the scintillation-crystal and PMTs.

The outputs of the PMTs are fed into an electronic position logic circuit, called Anger logic, which determines the location of incident gamma ray. The coordinates of the interaction point are provided to a cathode-ray tube (CRT) display and the image is formed as a result of the summation of thousands of these coordinates. (**Fig.1**) [1-2]

The Anger logic does not give a true mapping of source position because PMTs are not ideal point detectors. Because of the spatial non-uniformity of the light collection efficiency and gaps between PMTs due to their geometric shapes, the image of a line source crossing in front of a PMT should be bowed toward its center (we call it a PMT inward distortion). This result is a characteristic pin-cushion distortion in areas of a gamma camera image lying directly in front of PMTs. [3] In order to decrease the PMT inward distortion, the light photons emitted by the crystal must somewhat diffuse before they fall on the PMT array. So the relatively thick optical guide is necessary, and this allows better localization of the event that is achieved by comparing the relative outputs of several PMTs.

To reduce the spatial distortion and to find parameters affecting to it, imaging characteristics of gamma camera have been intensively investigated and evaluated by many research groups. [4-6] However, since these studies were done for gamma camera using the light output distribution at the surface of PMT photo-cathode or for small gamma camera using the position-sensitive PMT, they could not evaluate the spatial distortion of position-determination but only the intrinsic resolution.

In this study, accounting for the sensitivity and the PMT inward distortion, the effects of various combinations in thickness and refractive index of optical guide have been investigated by Monte Carlo simulation and numerical position-determination algorithm. This study will be useful to determine the optimal condition of the optical guide to increase the sensitivity and the spatial resolution when designing the gamma camera.

Materials and methods

In order to simulate interactions of light photon, the commercial light transport code, named by DETECT97, used. [7] The DETECT97 code is a Monte Carlo model describing the optical behavior of scintillation detectors. It generates individual scintillation photons isotropically in specified positions of the scintillator, follows each optical photon in its passage through the various components and interactions, and records its fate such as absorption, escape, or detection.

In this study, the detector of gamma camera was modeled simply and the schematic view is shown in **Fig.2**. The simulation geometry, considered for the prototype gamma camera for brain study, includes an aluminum housing (2 mm-thick) in contact with a 12”×12”×3/8” NaI(Tl) scintillator, glass window (2 mm-thick), optical grease (1 mm-thick), optical guide and 23 PMTs with 5’-diameter each arranged in hexagonal array. The incident surface of NaI(Tl) scintillator was assumed to be coated with a diffusive reflecting material of 0.98 reflection coefficient (RC) and the side surface to be coated with a absorbing material of 0.02 RC. The refractive indices of the NaI(Tl) and optical grease were assumed to be 1.85 and 1.58, respectively.

The geometrical shape, size and surface condition of the NaI(Tl), and optical properties of all materials were considered as input parameters of the DETECT97. Accounting for the sufficient statistical error-reduction the number of emerging light photons from 100,000 histories was collected by PMT photo-cathode surface.

In this study, sensitivity of the gamma camera is defined as a fraction of the total counted optical photons in PMTs. In order to estimate the optimal refractive index of optical guide, sensitivity as a function of refractive index of optical guide from 0.9 to 2.0 was simulated for the 10 mm-thick optical guide.

Based on the results from the sensitivity simulation as a function of thickness of optical guide with DETECT97, the optimal thickness of optical guide was estimated by using our own ANGER program, which determines the spatial localization of the source position by Anger algorithm. As shown in **Fig.3**, PMT signals in each interaction are weighted according to the position of the PMT and then combined to form +X, -X, +Y, and –Y signals. These four signals are subsequently combined to form a single X and Y coordination. The result created by DETECT97 is then used as the input for the ANGER program. Accuracy of position determination and the measure of PMT inward distortion were simulated by changing thickness of optical guide from 0 to 30 mm with refractive index of 1.6. Accuracy of position determination is defined by comparing the deviation between the true source position and the simulated source position with unit of mm. The measure that describes the PMT inward distortion is defined as the ratio of the true source position and the simulated source position from the origin of PMT center, and the PMT inward distortion decreases as it goes to 1.

Results

For 10 mm-thick optical guide, the percentage of total counted photons as a function of refractive index of optical guide is shown in **Fig.4**. The result shows that sensitivity slowly approaches to the maximum value at 1.6 of refractive index, and then saturates with maximum value.

For the optical guide with 1.6 of refractive index, the deviation between true source position and simulated source position as a function of thickness of optical guide is shown in **Fig.5**. The deviation rapidly approaches to the minimum value at 8~10 mm-thick, and then increases relatively slowly as the optical guide thickness increases. This characteristic can be understood by using the distribution of optical lights over the PMT photo-cathode surface. As the optical guide thickness increases, the optical lights spread and are detected by several PMTs. This allows better localization of the event that is achieved by comparing the relative outputs of several PMTs. Since the relative outputs of several PMTs should be similar to each other if optical lights spread too much, the positioning algorithm can not calculate the position of event accurately. So there is a trade-off between the spread function and the accuracy as a function of the optical guide thickness, and the cross-over point is about the 10 mm as shown in **Fig.5**.

For the 1.6 of refractive index and 10 mm-thick optical guide, the appearance of the PMT inward distortion was simulated and compared with the case when no optical guide was introduced. Over the half of diameter of a PMT, the difference between the true and the simulated X position with a variable of true X position is plotted in **Fig.6.** As shown in **Fig.6**, the measures of the PMT inward distortion, defined by the slope of differences, are approximately 1, 0.85, and 0.5 for ideal detector, with 10mm-thick optical guide and no optical guide, respectively. It was found that the PMT inward distortion was almost diminished by use of a 10mm-thick optical guide and the accuracy of position determination was improved approximately from 50 % to 85 % compared to the case of no optical guide.

Conclusion

Compromising the sensitivity and spatial resolution of the detector in gamma camera system, the optimal refractive index as well as the thickness of the optical guide was estimated by using Monte Carlo simulation. For the prototype gamma camera, it was found that the sensitivity was maximized with the 1.6 of refractive index of optical guide and the PMT inward distortion was minimized at the thickness of 8~10 mm. This result will be useful when designing the gamma camera detector with high performances and the ANGER program, developed to simulate the position determination, can also be useful when estimating spatial resolution of the gamma camera.

References

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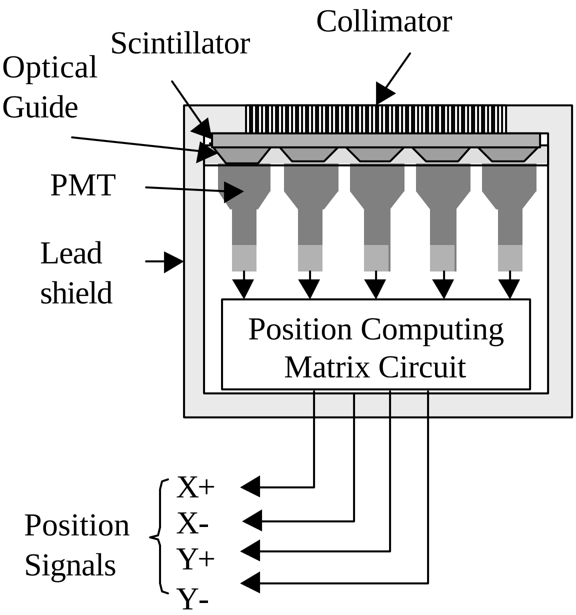

Fig.1. Schematic diagram of gamma camera detector which consists of collimator, scintillator, optical guide, position computing circuit and lead shied.

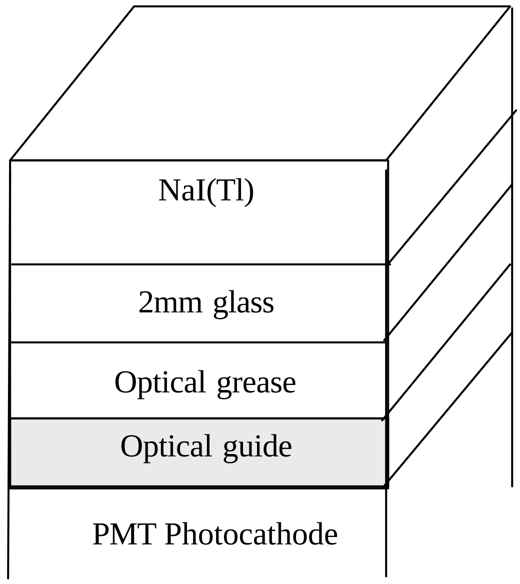

Fig.2. DETECT97 simulation geometry

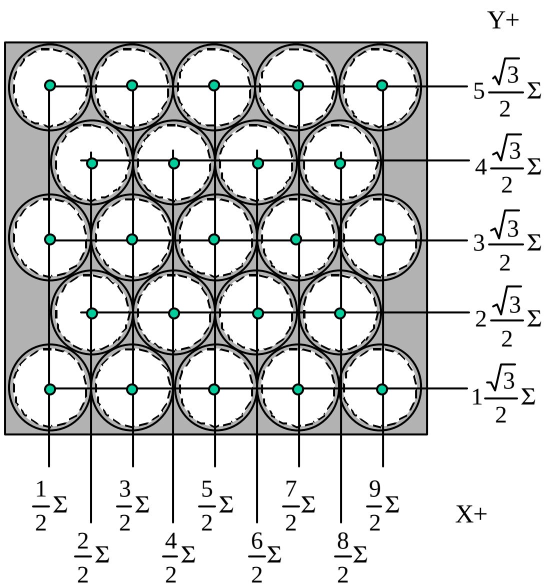

Fig.3. Schematic diagram of gamma camera position determination logic (Anger logic)

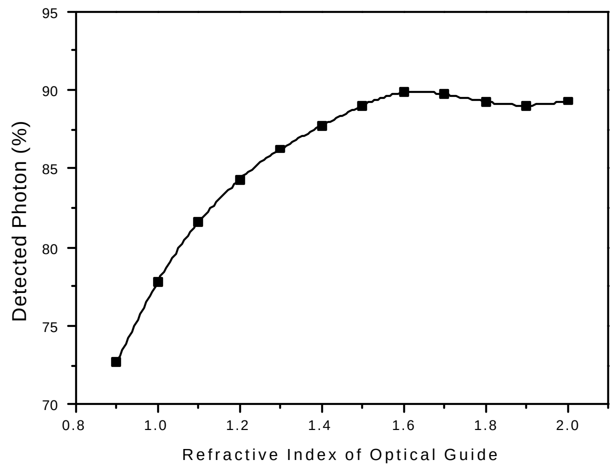

Fig.4. Sensitivity of a PMT as a function of refractive index of optical guide. At 1.6, the sensitivity is maximized.

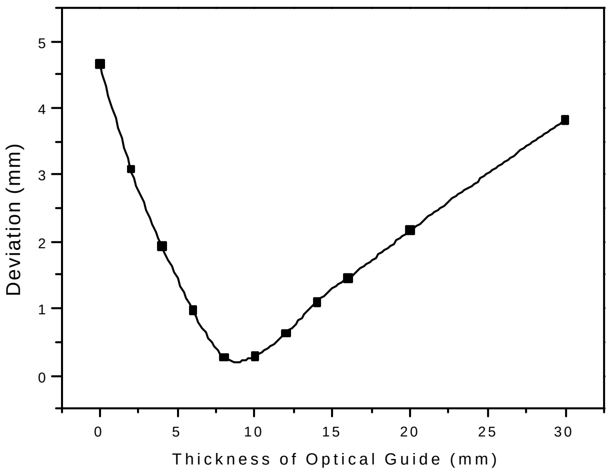

Fig.5. Deviation between true source position and simulated source position as a function of thickness of optical guide. At 8 ~ 10 mm, the deviation is minimized.

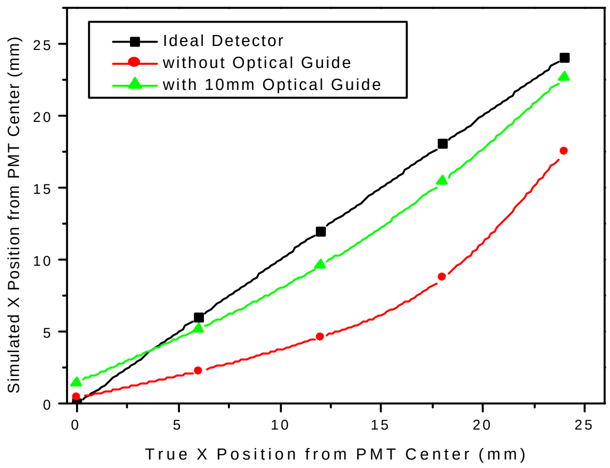

Fig.6. Ratio of true X position and simulated X position from PMT center for ideal detector (1), without optical guide (2), and with 10 mm optical guide (3). Slope of 1, 0.5 and 0.85 for (1), (2), and (3), respectively.