▸원 저◂

ISSN 1226-2854

Position Uncertainty due to Multi−scattering in the Scintillator Array of Dual Collimation Camera

—복합 집속 카메라의 섬광체배열에서 다중산란에 의한 위치 불확실성—

Department of Radiologic Science, Korea University

Wonho Lee

• Abstract

Position information of radiation interactions in detection material is essential to reconstruct a radiation source image. With most position sensing techniques, the position information of a single interaction inside the detectors can be precisely obtained. Each interaction position of multi−scattering inside scintillators, however, can not be individually measured and only the average of the scattering positions can be obtained, which causes the uncertainty in the measured interaction position. In this paper, the position uncertainties due to the multi−scattering were calculated by Monte Carlo simulation. The simulation model was a 50 by 50 by 5 mm $LaCl_3$(Ce) scintillator(pixel size is 2 by 2 by 5 mm) which was utilized for the dual collimation camera. The dual collimation camera uses the information from both photoelectric effect and Compton scattering, and therefore, position uncertainties for both partial and full energy deposition of radiation interactions are calculated. In the case of partial energy deposition(PED), the standard deviations of positions are less than 1~2 mm, which means the uncertainty caused by multi−scattering is not significant. Because the effect of the multi−scattering with PED is insignificant, the multi−scattering has little effect on the performance of Compton imaging of dual collimation camera. In the case of full energy deposition(FED), however, the standard deviation of the positions is about twice that of the pixel size of the 1^{st}detector, except for 122 keV incident radiations. Therefore, the standard deviations caused by multi−scatterings should be considered in the design of the coded mask of the dual collimation camera to avoid artifact on the reconstructed image. The position uncertainties of the FEDs are much larger than those of the PEDs for all radiation energies and the ratio of PEDs to FEDs increases when the incident radiation energy increases. The position uncertainties of both PEDs and FEDs are dependent on the incident radiation energy.

Key Words : Multi−scattering, Position Uncertainty, Monte Carlo Simulation, Dual Collimation Camera

Ⅰ. Introduction

When radiation undergoes multi−scattering, its deposits energy at each position of interaction. In the case of the semiconductor, each position and deposited energy of the multi−scattering can be directly obtained by measuring induced charges with pixelized or strip electrodes[1−4]. In the case of the scintillator coupled PSPMT[5−8], however, the deposited energy converts to light, which spreads inside the pixelated scintillator and reaches the photo-

*접수일(2008년 6월 2일), 심사일(2008년 8월 28일), 채택일(2008년 9월 1일)

책임저자 : 이원호, (136−703)서울시 성북구 정릉3동 산1번지
고려대학교 보건과학대학 방사선학과
Tel : 02−940−2826, Fax : 02−917−9074
E−mail:wonhol@korea.ac.kr

cathode of a PSPMT. On the backside of the photocathode, the light again converts to electrons drifting to the dynode stages in which the electrons are multiplied and driven toward the anode of the PSPMT. During the multiplication process, the cloud of electrons stretches parallel to each dynode and each dynode is oriented perpendicular to the electron drift direction to the anode. The manufacturer designed the PSPMT to create this parallel stretch of the electron cloud because spreading actually yields finer position information in the final image. While this improved information is beneficial, the stretching process combines all electron clouds, even those caused by multi−scattering, into a summed cloud which then causes the loss of the position information for each interaction. As a result, in the case of multi−scattering, the measured position differs from the exact position information. This deviation of the measured data from the exact information is comparable with other uncertainties, such as geometrical and energy uncertainties, and therefore the deviation needs to be quantified for the optimization of the gamma ray imaging system using scintillators. To quantify the deviation, radiation interactions inside a scintillator were simulated using the Monte Carlo method(MCNP5). The electron combination due to the spreading inside the PSPMT was calculated on the basis of the energy weighting on each interaction position.

Ⅱ. Material and Methods

As shown in Fig. 1, the dual collimation camera is consisted of a coded aperture, the first detector and the second detectors. The low energy radiations are assumed to be collimated and deposit all energy in the first detector. With the position and energy information of the radiation interacted in the first detector, a coded aperture image can be reconstructed. The high energy radiations are assumed to penetrate the collimator and be scattered in the first detector, and therefore, the energy is partially deposited in the first detector(Compton scattering). If the scattered radiation is detected in the second detector, a Compton image can be reconstructed with the position and energy information of the radiation interacted in the first and the second detector. As illustrated in Fig. 2, the radiation interactions were categorized according to the amount of the deposited energy. Radiation that led to multiple interactions and escaped from the scintillator was considered a partial energy deposition(PED), an event that is a prerequisite to reconstruct a Com-

Fig. 1. Schematic diagram of dual modality gamma camera.

Fig. 2. Illustration of position uncertainties caused by multi−scatterings.

pton image. If the radiation deposited all of its energy and stopped inside the scintillator, it was considered a full energy deposition (FED) which is the desired case for a coded aperture image.

A $LaCl_3(Ce)$ scintillator is chosen for our application since its energy resolution and timing resolution, on which the performance of coded aperture and Compton imaging is highly dependent, are excellent among scintillators. The area of the $LaCl_3(Ce)$ scintillator is 50×50 mm which is wide enough to cover the scattering range of photons. The thickness of the scintillator in our simulation was 5 mm, which was the ideal size to maximize the difference between the amount of single and that of multiple interaction for dual collimation camera[8)]. The energies of the incident radiation were 122 keV, 364 keV, 662 keV and 1275 keV which are encountered in medical and environmental applications. The direction of the incident radiation is perpendicular to the front side of the scintillator. For each multi-scattering in the simulation, the distance between the first interaction position and the summed position was calculated by energy weighting of each interaction position(cf. eqn (1)) and recorded in a histogram matrix. The distance was considered only on the xy-plane because the z-direction, which is the depth information of the interaction, cannot be measured for the scintillator array of the dual collimation camera. The number of incident radiations for the simulation is set to 5×10^6.

$$X = \frac{\sum e_i x_i}{\sum e_i}, \quad Y = \frac{\sum e_i y_i}{\sum e_i} \qquad (1)$$

e_i is the deposited energy at interaction i

x_i and y_i are the position information at interaction i

X and Y are the summed position

Ⅲ. Results

Fig. 3 shows the distributions of the distances for the PED and the FED cases. The distributions of the FEDs are much broader than those of the PEDs for all radiation energies. The reason for this is that the FEDs, in which a quantum of radiation deposits all energy and then disappears, normally have more collisions than PEDs, in which radiation escapes from the scintillator. Another reason is that the final radiation scattering of the FED is a photoelectric absorption, in which the radiation deposits essentially all remaining energy, while that of PED is a Compton scattering, in which the radiation deposits only part of its remaining energy. Because the position estimation is weighted by the deposited energies at each interaction position, the final estimated positions of the FEDs are longer than those of the PEDs.

When the incident radiation energy increases, the ratio of PEDs to FEDs(the distance of PEDs / the distance of FEDs) increases(Fig. 3 (a), (b)). The energy dependency of the ratio is related to the probability of the photoelectric absorption and that of the Compton scattering. With an increase in the incident radiation energy, the probability of the photoelectric absorption declines more than that of Compton scattering, and therefore the relative ratio of Compton scattering to photoelectric absorption increases.

Another important factor to be addressed is the change of distribution width in relation to the incident radiation energy. As shown in Fig.3 (c) (d) and Table 1, the distributions broaden when the radiation energy increases from 122 keV to 364 keV, but narrow at energies higher than 364keV. This change in distribution can be explained by two factors - penetration and scattering direction -. The penetration of radiation increases with the radiation energy, which increases the distance between interactions. However, for high radiation energy, the scattered radiation direction of Compton scattering is biased towards the initial direction of the incident radiation. Because the initial direction is perpendicular to the xy plane of the detector, the distance between the radiation scattering on the xy plane decreases.

(a) PED

(b) FED

(c) PED in normalized scale

(d) FED in normalized scale

Fig. 3. The distribution of the distances between the 1^{st} and summed interaction positions.

Table 1. Distribution width due to multi−scattering

		122 keV	364 keV	662 keV	1275 keV
FWHM[mm]	PED	0.086	0.118	0.122	0.076
	FED	0.300	0.864	0.916	0.756
FWTM[mm]	PED	0.816	1.604	1.534	1.342
	FED	2.131	6.093	5.527	4.465
76% of data[mm] (Gaussian FWHM)	PED	1.380	2.400	2.520	2.020
	FED	2.080	6.560	7.060	5.660
σ[mm]	PED	0.863	1.571	1.652	1.308
	FED	1.183	3.793	4.018	3.140

As demonstrated in Fig. 3, the distributions of multi−scatterings are not Gaussian. The FWHMs (Twice the distance between the maximum count point and the half count point in Fig. 3) of Table 1 confirm the discrepancy − the FWHMs of the multi−scattering distributions are not matched with the distribution lengths that contain 76% of all data points.

To evaluate the position uncertainty caused by multi−scattering, therefore, the standard deviations of the distributions were chosen instead of the FW

HMs of the Gaussian model. In the case of PEDs, the standard deviations are about half of the minimum pixel size of the 1st detector, which means the uncertainty caused by PED multi−scattering is not significant. Because the effect of the PED multi−scattering is insignificant, the multi−scattering has little effect on the Compton imaging of dual collimation camera. In the case of FEDs, however, the standard deviation is about twice that of the minimum pixel size of the 1st detector, except at 122keV. If the standard deviation is larger than the unit element of a shadowgram cast on the 1st detector, the shadowgram will be blurred and the blur will create artifact in the reconstructed image. To avoid blurring in the shadowgram, the size of the shadowgram element should be larger than the standard deviations of the multi−scattering. The size of shadowgram element is almost equal to that of the coded mask element itself in the dual collimation system when the mask is very close to the detector and relatively far from the source plane. As a result, the size of mask element should be larger than the standard deviations of the multi−scattering to avoid artifact on the reconstructed image.

Ⅳ. Conclusion

The distributions of the FEDs are much broader than those of the PEDs for all radiation energies. When the incident radiation energy increases, the ratio of PEDs to FEDs increases because the Compton scattering to photoelectric effect ratio increases. The broadening widths of both PEDs and FEDs are also dependent on the incident radiation energy. The standard deviations of PEDs are less than 1~2 mm, but those of FED is about 4 mm except for 122 keV incident radiations. Therefore, in the design of gamma ray imaging device such as a dual modality gamma camera, the standard deviations caused by multi−scatterings should be considered to avoid artifact on the reconstructed image.

Reference

1. GJ. Schmid, DA. Beckedahl, JE. Kammeraad, JJ. Blair, K. Vetter and A. Kuhn : Gamma−ray com-pton camera imaging with a segmented HPGe, Nuclear Instruments and Methods, A459, 565− 576, 2001
2. EA. Wulf, J. Ampe, WN. Johnson, RA. Kroeger, JD. Kurfess and BF. Phlips: Depth measurements in a germanium strip detector, IEEE Transactions on Nuclear Science, 49, 1876−1880, 2002
3. Y. Du, Z. He, GF. Knoll, DK. Wehe and W. Li: Evaluation of a Compton scattering camera using 3−D position sensitive CdZnTe detectors, Nuclear Instruments and Methods, A457, 203−211, 2001
4. CE. Lehner: 4(Compton imaging using a single 3−D position sensitive CdZnTe detector, Ph. D. dissertation, Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI, 2004
5. JE. Gormley, WL. Rogers, NH. Clinthorne, DK. Wehe and GF. Knoll: Experimental comparison of mechanical and electronic gamma−ray collimation, Nuclear Instruments and Methods, A397, 440−447, 1997
6. A. Uritani, NH. Clinthorne, JE. Gormley and JW. LeBlanc: An electronically−collimated gamma camera with a parallel plate Collimator for Tc−99m Imaging, IEEE Transactions on Nuclear Science, 44 (3), 894 −898, 1997
7. LE. Smith, C. Chen, DK. Wehe and Z. He: Hybrid collimation for industrial gamma−ray imaging : combining spatially coded and Compton aperture data, Nuclear Instruments and Methods, A462, 576−587, 2001
8. W. Lee: Dual modality gamma camera using lanthanide scintillators, Ph. D. dissertation, Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI, 2007

• Abstract

복합 집속 카메라의 섬광체배열에서 다중산란에 의한 위치 불확실성

이원호

고려대학교 방사선학과

방사선 반응에서의 위치정보는 방사선 선원의 영상을 재구성하는데 있어서 매우 중요한 기본정보이다. 이에 대부분의 위치 검출 기술을 이용하여 검출기안에서의 일어난 단일 반응의 위치정보를 알아낼 수 있다. 그러나 섬광체 안에서의 다중산란의 경우 각각의 산란위치를 개별적으로 측정할 수 없고 여러 산란위치의 평균만이 구해질 수 있어서 측정된 방사능의 위치정보에 불확실성이 존재하게 된다. 이 논문에서는 이러한 다중산란에 따른 위치 불확실성을 몬테카를로 시뮬레이션으로 계산하였다. 시뮬레이션 모델은 복합 집속 카메라에 사용된 50×50×5 mm $LaCl_3$(Ce) 섬광체(pixel크기는 2×2×5 mm)이다. 복합 집속 카메라는 광전효과와 컴프턴 산란 모두에서 정보를 얻으므로 방사선의 반응에서 부분에너지만 (검출기에) 검출되는 경우와 모든 에너지가 검출되는 경우를 나누어 위치 불확실성을 계산하였다. 부분에너지만 검출되는 경우 (PED) 위치의 표준편차는 1~2 mm 미만으로 다중산란에 의한 불확실성이 크지 않다는 것을 알 수 있다. PED의 경우 다중산란의 영향이 크지 않으므로 이러한 다중산란은 컴프턴 카메라의 성능에 큰 영향을 미치지 않는다는 것을 알 수 있다. 그러나 모든 에너지가 검출되는 경우 (FED), 122 keV입사방사선의 경우를 제외하면, 그 위치의 표준편차가 1차 검출기의 pixel크기에 2배에 달한다. 그러므로 복합 집속 카메라의 코드화된 마스크를 설계하는데 있어 재구성된 영상의 잡음을 방지하기 위해 다중산란에 의한 표준편차가 고려되어야 한다. 모든 입사 방사선에너지에 대하여 FED에 의한 위치 불확실성은 PED에 의한 것 보다 크며 PED 대 FED의 비는 입사방사선의 에너지가 증가함에 따라서 커진다. PED와 FED의 경우 모두 위치의 불확실성이 입사방사선의 에너지에 따라 달라졌다.

중심 단어 : 다중산란, 위치 불확실성, 몬테카를로 시뮬레이션, 복합 집속 카메라