I. Introduction

A Method for Correcting the Depth-Interaction Blur in PET

Introduction

The blur in PET images is caused by the depth of interaction, which is the distance between the point of interaction of the gamma rays in the detector and the scintillation light which is detected. This blur can degrade the resolution and accuracy of PET images. A method for correcting this depth-interaction blur is proposed.

II. The New Method Applied to a Zg-Energy Block Detector

The new method uses a Zg-Energy block detector, which has a higher resolution compared to the conventional block detectors. The Zg-Energy blocks are placed in front of the PET scanner, and the depth of interaction is calculated based on the energy deposition in the Zg-Energy blocks.

The energy deposition in the Zg-Energy blocks is measured and used to correct the depth of interaction. The correction is applied to the PET images to reduce the blur and improve the resolution.

Conclusion

The proposed method for correcting the depth-interaction blur in PET images shows promising results. Further improvements are needed to optimize the correction algorithm and test the method in clinical settings.

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References


front (Fig. c-d) and back (Fig. e-f) of the block. This condition was not met in the conventional 64-crystal block or in the new 144-crystal block.

To test the method, a fan-collimated beam was used in two different geometries which duplicate the typical geometries of a PET camera imaging activity at the centre and at the edge of the FOV. The fan beam was formed by placing a Ge-68 point source at a distance of 12 cm from a pair of 5 cm thick Pb bricks which had a 1 mm wide vertical slit between their edges. When the plane of the fan beam was perpendicular to the face of the detector, the image of the beam was narrow, as it would be in imaging such activity at the centre of a PET camera. When the plane of the fan beam was inclined at a 25° angle to the normal, the image was broadened and shifted due to the depth-of-interaction variation in the detector. The desired objective of the correction method, which is the subject of this article, was to correct the broadened image to make it look more like the narrow image. The angle selected for this test was chosen to be 25° because this is a worst case maximum of the angles encountered in imaging activity distributions near the edges of the FOV of typical whole body PET cameras.

Figure 2 is a top-view schematic drawing of the beam impinging on one horizontal row of the 256-crystal block detector. A typical gamma ray is shown interacting in the small crystal number “10”, which would be the one identified by the decoding system. The identified crystal numbers for other gamma rays entering the block along the same line will vary randomly among the crystals intersected by the line, namely crystal number 17, 8, 9, 10, and 11. Only by measuring the depth-of-interaction, Z, can the crystal number be corrected by (ΔX = Z sin 25°) to what it would have been if the gamma had interacted at the front face of the block.

In order to correct the crystal number, the depth Z must be measured in units of the crystal’s spacing, 3.125 mm. Because each crystal has a different positron relative to the PMT’s, and therefore different light collection efficiency, a look-up-table was required to relate the measured photopeak ADC number to depth-of-interaction in mm. This look-up-table was a list of “most probable depth” as a two-dimensional function of crystal number and summed ADC pulse-height. It was formed from depth calibration measurements, which were separately acquired prior to analyzing the fan-beam gamma event records.

The table was obtained by analyzing the individual crystals’ pulse-height spectra, such as those shown in Fig. 1c-f. Each spectrum contains a single photopeak and a lower level Compton tail below the photopeak. The peak channel of the photopeak in each spectrum is the most probable pulse-height at the fixed depth of the calibration setup. A table of depths as a function of most-probable pulse-height was formed by linear interpolation between the two measured photopeak pulse-heights (e.g. Fig. 1c-f) in each crystal.

It was discovered that the optimum scale factor (which was used for converting Z to ΔX), was about 30% smaller than the expected sin 25°. This is believed to be due to an observed non-linearity in the relationship between depth-of-interaction and pulse-height. It was observed that the pulse-height changes more slowly as a function of depth near the front face than it does deeper in the block). The linear interpolation mentioned above was an approximation, adopted for simplicity.

The upper and lower pulse-height thresholds were carefully set in each crystal so as to maintain uniform efficiency across the block. The lower-level pulse-height threshold was set in each crystal to 0.92 of the photopeak pulse-height measured using the shallow depth (4 mm) calibration setup. The upper-level pulse-height threshold was set to 1.10 of the photopeak pulse-height measured using the deep depth (23 mm) calibration setup. This choice of thresholds produced a measured block average efficiency of 0.74 relative to the efficiency of the block with “wide-open” (i.e. 250 keV lower- and 750 keV upper-level) thresholds.

To account for efficiency differences and any possible crystal identification errors in the calibration setup map, a flood source of 511 keV gammas was used for normalizing the two fan-beam images. A point source of 511 keV gamma rays was positioned at a distance from the 256-crystal block so that a flood of gamma rays impinged on the block in a direction approximately normal to the front face. Two 16 × 16 arrays of counts were acquired from this flood source with the pulse-height thresholds just described, both with and without employing the depth correction method. The flood source counts in these 16 × 16 arrays were divided crystal-by-crystal into the corresponding 16 × 16 arrays of counts from the fan-beam phantoms to produce the final normalized projections.

III. Results and Discussion

Figure 3 shows one-crystal wide horizontal sections of the phantom images at three different (typical) positions on the face of the 256 crystal detector. The normal-contrast sections (Fig. 3a-c) are broadened and shifted by depth-of-interaction blurring (Fig. 3d-f), which is substantially improved using the above-described correction method (Fig. 3g-i). The improvement between the uncorrected sections (Fig. 3a-f) and the corrected sections (Fig. 3g-i) ranged from 17% to 30% over the face of the detector, averaging a 25% improvement in the FWHM.

It is believed that the variation in pulse-heights between shallow and deep-interacting gamma rays is due to the variation in the number of scintillation photons absorbed on the side walls of the crystals. The amount of variation could therefore be adjusted to be a larger fraction of the original scintillation light by reducing the reflectivity of the sides of the individual crystals making up the block. Although this would improve the depth-of-interaction resolution, such a “detrining” of the light collection would probably worsen the accuracy of the usual determination of the X- and Y-coordinates of the crystal of first-interaction. A range of trade-offs between XY-resolution and Z-resolution should be possible.

A fraction of events are under-corrected because the gamma energy was degraded by Compton outscattering from the block. This fraction can be roughly estimated as the fractional number of Compton-scattered events in Fig. 1a-b compared to photopeak events, 19% and 32%, respectively. The variation of this effect as a function of threshold was not measured, but it would certainly be increasingly important at lower thresholds. Gamma rays which have scattered in the object and therefore enter the block with degraded energy are similarly under-corrected. However, these gamma rays are already so disturbed in position that they form a smoothly varying background which can therefore be eliminated from the image using one of the existing object-scatter correction techniques [8]. Such low frequency image correction [8] would probably best be done after the depth-interaction correction, which affects more the high-frequency components of the image.
1. **Figure Captions**
Fig. 2

Fig. 3