Impact of DOI in a Clinical SPECT/MRI System: A Simulation Study

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***Abstract*—A novel SPECT/MRI scanner has been modelled and tested here using Monte Carlo simulation software, SIMIND. The INSERT SPECT/MRI system faces challenges with event reconstruction due to photon depth of interaction. The novel SPECT system is subject to parallax errors due to its crystal size and slit aperture collimator. We present a simple measure of the DOI errors through SIMIND experiments; by modelling the DOI layers we are able to improve the reconstruction of projection data in the INSERT scanner. A set of capillary phantoms are simulated to explore the impact of DOI on the resolution of the scanner and establish corrections in the system's reconstruction.**

I. Introduction

The INSERT scanner is a complete clinical single photon emission computed tomography (SPECT) brain imaging system, intended for integration with clinical Magnetic Resonance Imaging (MRI) systems [1]. The design is comprised of a stationary partial ring of 20 compact CsI:Tl detectors, with Silicon Photomultiplier (SiPM) readout, to ensure MR compatibility. The INSERT scanner makes use of a novel multi-slit-slat (MSS) collimator. The complete system has undergone initial testing as a stand alone SPECT scanner [2] and has been implemented within a clinical MRI.

Following recent experiments, we set out to improve planar image reconstruction by incorporating photon depth of interaction (DOI) [3]. The system implements a DOI algorithm, which makes use of a three dimensional coordinate system to model the event reconstruction with the addition of a crystal depth coordinate, h. The Beer-Lambert law defines a look-up table of light response within each detector; a scintillation event is categorised to the most likely DOI with this model. The result will produce a h coordinate for each event which corresponds to one of 4 DOI layers [4]. The DOI inclusion in the event reconstruction aims to improve angular sampling and reduce the parallax error within the SiPM readout.

Calculating the DOI is essential in the INSERT scanner, as its crystal thickness (8 mm) and slit aperture make the system susceptible to parallax errors. The system's image reconstruction models the photon trajectory; oblique photons entering through slit apertures introduce the parallax error. By calculating the DOI, the origin of an event can be determined through the sampling of 4 possible photon trajectories (Fig. 1).

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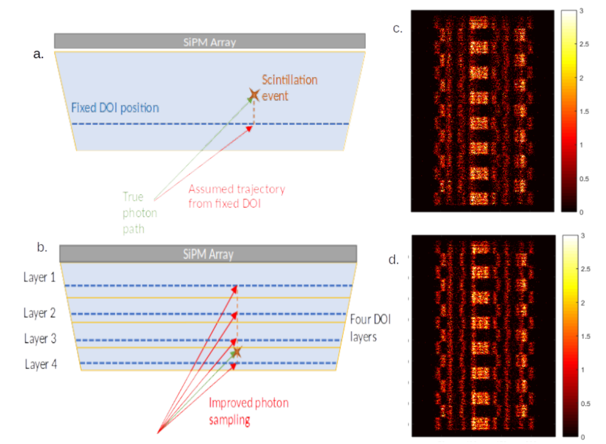

Fig. 1. (a) Photons travelling through the crystal at oblique angles are subject to parallax errors. (b) By splitting the crystal into layers the uncertainty is reduced in each layer. Uncorrected (c) and DOI corrected MSS projection data (d), corresponding to a number of line sources. The image shows improved contrast and reduced blurring after DOI correction.

In this paper the DOI has been explored through the use of Monte Carlo simulations using SIMIND [5]. A set of capillary phantom acquisitions were simulated and the data acquired were used to explore the impact of DOI on the INSERT system. The improvement of image reconstruction through the reduction of parallax error is explored by retrieving the exact position of simulated events. By assessing the use of DOI information in image reconstruction, we hope to be able to recreate the results in the real SPECT/MRI system and optimize the number of layers.

II. Methods

By recreating the INSERT detectors and collimator within SIMIND, we made use of the list mode data output, which provides an exact value of the x, y, and h coordinates of an event. The events were sorted according to the h values, corresponding to the 4 DOI layers within the scintillation crystal. The layers are chosen to account for the exponential distribution of the photon interactions within the crystal. The layer closest to the SiPM has the least events and so is thicker

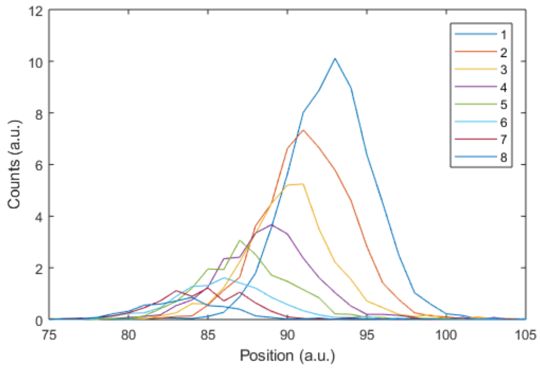

Fig. 2. Profiles of line source projection for a sequence of 1.0 mm thick DOI layers (1-8). The amplitude decreases due to attenuation in the crystal, while the peak position moves sideways due to the parallax effect.

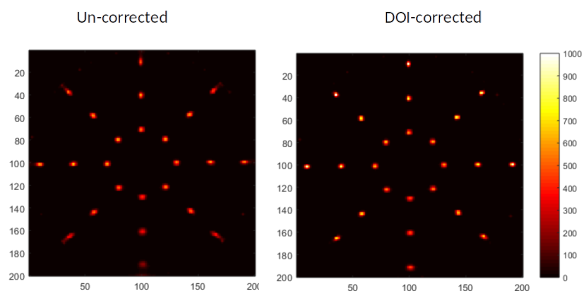

Fig. 3. Reconstructed images of 24 line sources without (left) and with DOI correction (right).

(3.5 mm), the remaining 3 layers are equal thickness (1.5 mm). The SIMIND list mode data are sorted into the 4 layers by measuring the closest values to the fixed DOI value in each layer.

Simulations of a capillary source phantom are used here to assess the difference in the planar projection for each DOI layer. The planar reconstruction is integrated along the axial direction to determine the detector signal for each DOI layer. The capillary is placed at 24 positions. Through this we demonstrate the parallax error in the INSERT system and its affect through the DOI layers. A maximum likelihood expectation maximisation (MLEM) reconstruction is then carried out to determine the reconstructed image resolution with and without DOI information.

III. Results and Discussion

Fig. 2 shows profiles at different crystal depths (h) for detected photons with an oblique incidence angle. The profiles illustrate how the peak shifts with increasing depth. Without DOI information, this effect would leads to a degraded resolution. The amount of shift depends on the angle of photon incidence.

Fig. 3 presents the reconstructed images for analytical simulations of 24 capillary sources. We observe an improved resolution in the image reconstructed with DOI information as compared to without DOI, especially for the source furthest

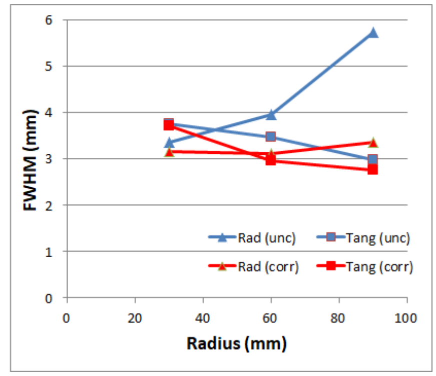

Fig. 4. The resolution of the capillary phantom reconstruction at each radial position.

from the centre of the FoV. Fig. 4 shows the radial and tangential resolution of the sources reconstructed with and without DOI information, the data was averaged across all sources at the same radial position. The inclusion of DOI information in the reconstruction visually improves the resolution. Interestingly the DOI primarily affects the radial resolution, while having little effect on the tangential resolution. This is because the latter is determined mainly from photon trajectories that are not affected by parallax. The resolution of the source positioned at (0,-90) mm is degraded due to the geometry of the INSERT system, which consists of a partial ring of detectors with a gap at the bottom.

We have shown that the DOI information can significantly improve resolution. Apart from 4 layers, we also evaluated the DOI correction based on 16 and 3 layers. We found that there was not a big difference between the 16- and 4-layer corrections, while the 3-layer correction was slightly worse. We have observed the low count noise and degraded resolution present in layers close to the SiPM, DOI measurements allow us to isolate these data and remove these events from our images. We can also improve collimator design as DOI correction allows a larger acceptance angle in the slit aperture. We aim to validate these corrections in SIMIND before implementing them in the physical system.

To conclude, we have shown it is possible to model DOI within the INSERT system and incorporate corrections in image reconstruction. The use of 4 DOI layers is adequate for image correction. We set out to implement these methods in the real INSERT system in order to improve the SPECT image quality.

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