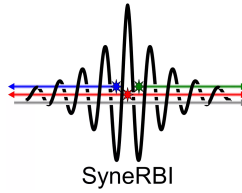




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CCP SyneRBI Student Exchange Programme

Scatter Correction for Long Axial Field of View PET Scanners in STIR Library

Report

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1 Background

Long Axial Field of View (LAFOV) Positron Emission Tomography (PET) scanners provide extended body coverage and improved detection sensitivity with the advantage of reduced radiopharmaceutical doses. In PET, scatter arises predominantly from Compton interactions, in which one or both annihilation photons undergo an interaction with matter before detection. This accounts for about 30-35% of the detected events in standard scanners, while in total-body PET scanners, this fraction increases to 50-60% due to the larger acceptance angle resulting from the extended field of view (FOV). This leads to increased background and reduced image contrast. Thus, this scatter background needs to be accurately estimated and taken into account during reconstruction.

Various scatter correction methods exist, ranging from Monte-Carlo simulations to machine learning techniques. Monte Carlo based methods provide highly accurate scatter estimations but are computationally intensive for clinical applications. Recent developments in deep learning based methods have shown promising results; however, they often disregard important information of underlying PET physics and may introduce artefacts or bias. The analytic method, Single Scatter Simulation is the most widely used scatter correction approach in clinical practice. It is based on direct calculation of scatter distribution from estimates of activity and attenuation distributions obtained from raw data. The method assumes that all scatter arises solely from single Compton scatter events and uses the Klein-Nishina formula to model the scatter distribution.

2 Objectives

The Single Scatter Simulation (SSS) method implemented in Software for Tomographic Image Reconstruction (STIR) was originally designed for scanners with a short axial field of view (aFOV) [1, 2]. This implementation is limited to estimating scatter in direct planes and approximates scatter from oblique planes by nearest-neighbour interpolation, which is an inaccurate approximation for LAFOV PET systems. In LAFOV scanners, scatter contributions from oblique planes become significant, and the scatter distribution varies with both the axial length and the axial angle of the system. SSS doesn't model multiple scatters or scatter originating from outside the FOV. Explicit 3D modelling would improve accuracy but requires substantial computation time and extensive tail fitting, often limited by poor statistics in high attenuation regions.

In total-body PET scanners, accounting for both direct and indirect Lines of Response (LORs), makes scatter estimation computationally intensive, requiring careful upsampling and scaling strategies. The primary objective of this exchange project is to extend the SSS method for LAFOV PET scanners with a focus on speed, accuracy and memory efficiency. In the long term, the goal is to develop the scatter correction method for time-of-flight (TOF) PET scanners with LAFOV.

3 Limitations

The project initially aimed to use the Synergistic Image Reconstruction Framework (SIRF); however, technical issues related to the software prerequisites were encountered during the setup process. To avoid potential delays, STIR was used instead. Due to the technical challenges, it was not possible to complete the planned work within the originally proposed timeline of the exchange program. However, the remaining work is currently being carried out remotely.

4 Progress to Date

4.1 Performance assessment of SSS in STIR

- ECAT 931 is a small aFOV PET scanner widely used in oncology, neurology, and cardiovascular research. The SSS method in STIR was tested on a phantom image in ECAT 931 scanner and obtained reasonably good scatter estimate.
- Due to increased number of detector rings in LAFOV systems, scatter simulation and estimation require huge memory. To reduce computational load, a downsampled version of the Siemens Biograph Vision Quadra was integrated into STIR for testing purposes. The total number of rings was reduced by a factor of 8, from 320 to 40, while maintaining the length of the scanner. A detailed comparison of the scanner parameters for the downsampled Siemens quadra and the actual scanner is given in the table below.

Parameters	Siemens Biograph Vision Quadra (No downsampling)	Downsampled Siemens Quadra (user defined)
Number of rings	320	40
Maximum number of non-arc corrected bins	520	65
Default number of non-arc corrected bins	520	65
Number of detectors per ring	798	114
Inner ring radius (mm)	410	410
Average depth of interaction (mm)	7	7
Ring spacing (mm)	3.29114	26.32912
Bin size (mm)	1.6	12.8
Intrinsic tilt	0.0	0.0
Number of axial blocks per bucket	1	1
Number of transaxial blocks per bucket	1	1
Number of axial crystals per block	10	10
Number of transaxial crystals per block	21	21
Number of axial crystals per singles unit	10	10
Number of transaxial crystals per singles unit	21	21
Number of detector layers	1	1
Energy (keV)	511	511
Timing resolution (ps)	214	214

Table 1: Properties of the scanner [3, 4].

- SSS method was applied to Downsampled Siemens Biograph Vision Quadra for a uniform cylindrical phantom image generated using STIR. Both 2D SSS and fully 3D SSS was performed separately. 2D SSS takes approximately 2 minutes and fully 3D SSS takes 4-5 minutes for scatter estimation. Reconstructed images from both simulated and estimated data and the corresponding sinogram profiles were analysed. The framework appears to model scatter reasonably well for 2D SSS. The residual sinogram profile plots (shown in figure 1) show an overestimation in the tails of the profile for fully 3D SSS.

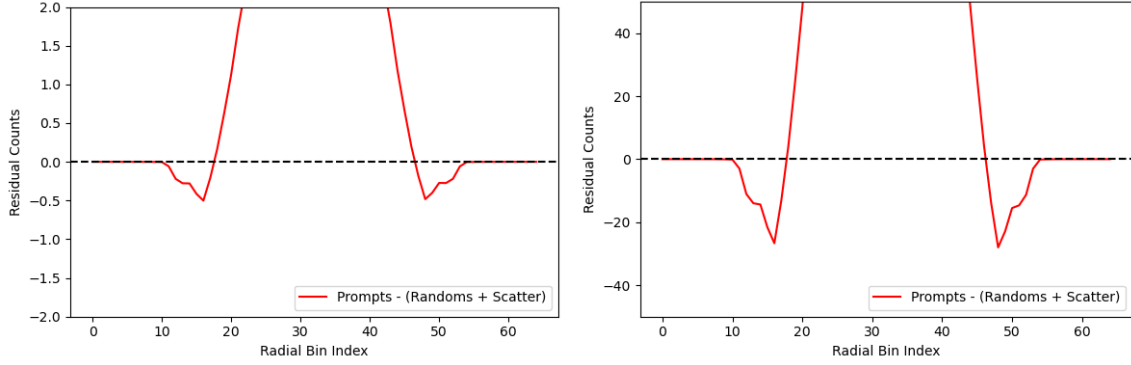


Figure 1: Residual sinogram profile plots for 2D SSS and fully 3D SSS respectively.

SSS tail fitting method proposed by Bal et al could address these issues [5,6]. This method was slightly modified and is currently in the final stages of implementation in the STIR library. This method will be compared with fully 3D SSS to evaluate whether it offers significant advantages in terms of computation time and power.

4.2 Implementation of SSSTF method

The 2D SSS method provides an accurate estimate of scatter originating from direct planes. The SSS tail fitting (SSSTF) method uses this estimate to account for scatter from oblique planes. This approach effectively separates the direct (2D) scatter and the oblique (3D) scatter. 2D sinogram data is generated from the first three segments of the Quadra and this excludes oblique scatter from both the data and the reconstruction. The 2D sinogram data is combined with the corresponding 2D SSS scatter estimate to perform an analytic reconstruction and obtain the scatter corrected image estimate. Scatter for oblique segments is then computed as the difference between the normalised net trues (prompts - randoms) from the entire dataset and the forward projected scatter corrected image estimate.

In SSSTF approach, 3D-Direct Inversion Fourier Transform (3D-DIFT) is used for image reconstruction. However, this method is computationally intensive and challenging to implement in STIR. Therefore, an alternative analytic reconstruction method, FBP was considered. For 3D sinogram data, either FBP3DRP or FBP2D could be applied. FBP3DRP, however, failed with a backprojection error for the downsampled Quadra which has odd number of views (57). Upon investigation, it was found that in the current release of STIR, the backprojector fails when the number of views is not even, explaining the FBP3DRP failure. Therefore, Fourier Rebinning or Single Slice Rebinning followed by FBP2D was used, as FBP2D processes only segment0 data.

5 Discussion and Outlook

The method is currently in the final stages of the optimisation process. Preliminary scatter sinograms obtained from SSSTF in STIR are shown in figure 2.

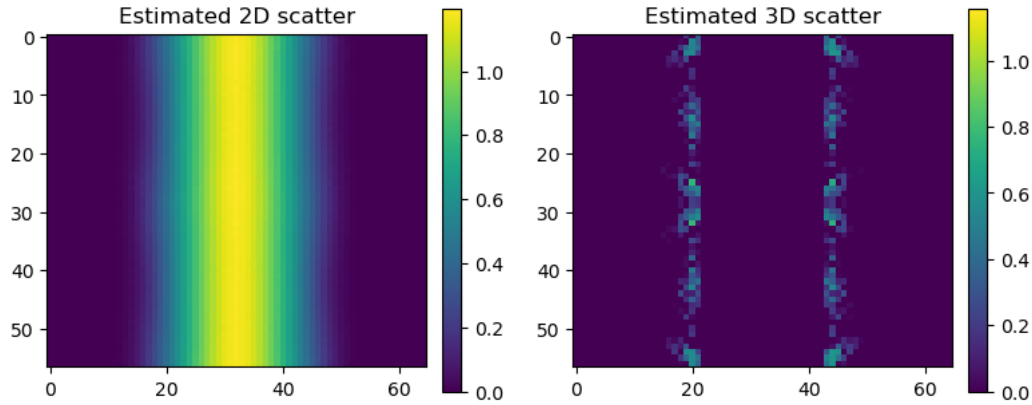


Figure 2: Middle slices of direct and oblique scatter sinograms respectively

After the optimisation, the results will be compared with scatter estimates from fully 3D SSS to evaluate the improvements. Additionally, the project aims to explore and integrate alternative scatter correction methods into the framework, with the goal of improving the speed and accuracy of scatter estimation. If successful, the method will be extended to consider time-of-flight information.

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