

Incorporation of a two metre long PET scanner in STIR

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Abstract. The Explorer project aims to investigate the potential benefits of a total-body 2 metre long PET scanner. The following investigation incorporates this scanner in STIR library and demonstrates the capabilities and weaknesses of existing reconstruction (FBP and OSEM) and single scatter simulation algorithms. It was found that sensible images are reconstructed but at the expense of high memory and processing time demands. FBP requires 4 hours on a core; OSEM: 2 hours per iteration if ran in parallel on 15-cores of a high performance computer. The single scatter simulation algorithm shows that on a short scale, up to a fifth of the scanner length, the assumption that the scatter between direct rings is similar to the scatter between the oblique rings is approximately valid. However, for more extreme cases this assumption is not longer valid, which illustrates that consideration of the oblique rings within the single scatter simulation will be necessary, if this scatter correction is the method of choice.

1. Introduction

Data acquisition for Positron Emission Tomography (PET) produces three-dimensional images but only at a limited axial field of view (approximately 20cm). Currently in order to perform full body PET, multiple images at different bed positions are acquired [1]. The pioneering ‘Explorer Project’ proposes that a total body PET scanner needs to be built so that the entire human body can be imaged at once. The ‘Explorer Project’ is an international consortium of scientists developing a 2m long PET scanner: <http://explorer.ucdavis.edu/>. The predicted effective sensitivity of such a scanner will be 40-fold higher than current scanners. This can result in as low radiation dose as 150 μ Sv, which could have huge implications for the justification of imaging humans even at healthy conditions or at prenatal phase [2]. The technology is currently being developed and image reconstruction techniques need to be advanced in order to process the large amount of data and produce the highest quality images possible.

2. Aim

This project aims to provide a preliminary evaluation of reconstruction and correction methods of the open access Software for Tomographic Image Reconstruction (STIR) for the total-body PET scanner [3]. First we assess the reconstruction settings and computational times for this scanner. Second we explore the extent of validity of using the current scheme of the single scatter simulation (SSS) algorithm for scatter correction, which assumes that scatter between indirect rings is similar to scatter within the same ring.

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3. Materials and Methods

All simulations and reconstructions of phantom data were performed using the STIR library (release 3.0) on a 3040-core high performance computer at the University of Leeds (ARC2): 8-core Intel E5-2670 2.6 GHz processors. Each job has access to 32 GB of memory.

3.1. Phantom

We employed the XCAT 2.0 total-body anthropomorphic phantom [4], which assigned realistic F18-FDG PET values as well as representative attenuation values to serve as input images for the simulation. In this experimental setup both images consisted of $195 \times 195 \times 1150$ voxels with sizes $3.42 \times 3.42 \times 1.71$ mm³.

3.2. Total-body scanner

The simulated total-body PET system consists of 36 block rings and 48 block modules per ring in which each detector block consisted of a 15×15 array of $3.42 \times 3.42 \times 20$ mm³ LSO crystals [5]. The inner diameter of the system is 80 cm corresponding to a 70 cm trans-axial FOV. The axial FOV is 196 cm with one crystal gap (3.42 cm) between adjacent rings. We set the energy window as 440 keV to 665 keV and energy resolution as 13%. The corresponding parameters that are incorporated in STIR are provided in the Appendix section.

3.2.1. Simulation of attenuated line integrals

The emission and attenuation sinograms were estimated using the corresponding forward-projection STIR functions and the attenuated emission data were produced. Poisson noise was inserted to empirically simulate two noise levels: (A) 500 million counts of data (no randoms or scatter), which are expected to be obtained from a 20 min F18-FDG scan (10 MBq total activity); (B) approximately 2.5 billion counts (no randoms or scatter), which resembles a scan with higher activity. The forward projection and calculation of the attenuation factors required approximately 5.5 hours. We used a number of compressions to reduce memory demands: Span: 11, Max ring difference: 336, Mash: 2, Rays tracing per bin: 1 transaxially \times 2 or 3 axially.

3.2.2. *Scatter simulation.* Running the SSS algorithm in STIR requires substantial down sampling of the scanner detectors in order to achieve reasonable computational times and memory requirements [6]. The number of total rings was reduced by a factor of 25: from 575 to 23, maintaining the length of the scanner. SSS was performed for all ring differences to assess how the scatter profile depends on the ring difference. More details on the scatter simulation parameters are provided in the Appendix. The attenuation map was down-sampled to produce the scatter-points map: $29 \times 29 \times 288$ voxels with sizes $24.4 \times 24.4 \times 6.84$ mm³. The fully 3D SSS used 24,268 scatter points and required 50 minutes and 680 MB of memory.

3.3. Reconstruction

The reconstruction algorithms that have been selected for this study are: filtered back projection with 3D reprojection (FBP-3DRP with defaults settings for any scanner as in STIR: release 3.0) and attenuation pre-corrected 3D OSEM (8 iterations, 15 subsets). The computational time and memory for FBP-3DRP was approximately 4 hours and 500 MB. 3D OSEM on a single core required 9 hours per full iteration and 5 GB of memory, while when ran using the parallel message passage interface (MPI) implementation of OSEM on 15 cores it required a little more than 2 hours per full iteration and 15 GB of memory. The reconstructed images have the same size as the simulated images.

4. Results

Figure 1 demonstrates coronal view of the reconstructed whole body simulated F18-FDG images using FBP-3DRP and OSEM for both noise levels. Figure 2 demonstrates one slice of the single scatter probability sinograms between the same ring and one for ring difference 13 of the down sampled scanner detectors (i.e. equivalent to 325 ring difference for the original total-body scanner). Figure 3 provides summed line profiles through the central sinogram plane for each ring difference.

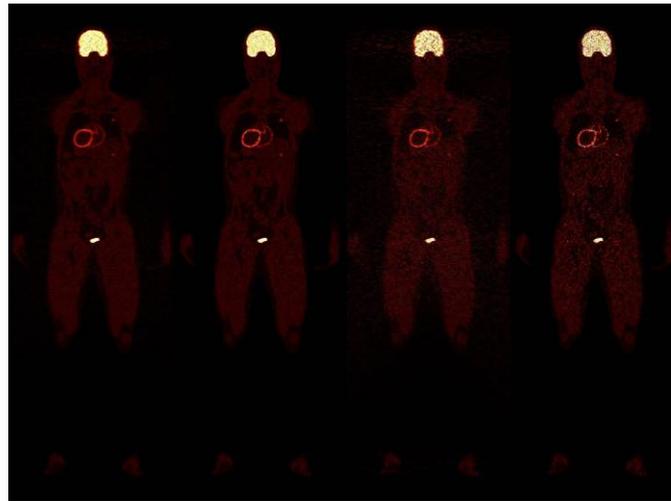


Figure 1: Coronal view of the total-body reconstructions. From left to right-hand side: FBP-3DRP 2.5×10^9 counts, OSEM 2.5×10^9 counts, FBP-3DRP 5×10^8 counts, OSEM 5×10^8 counts

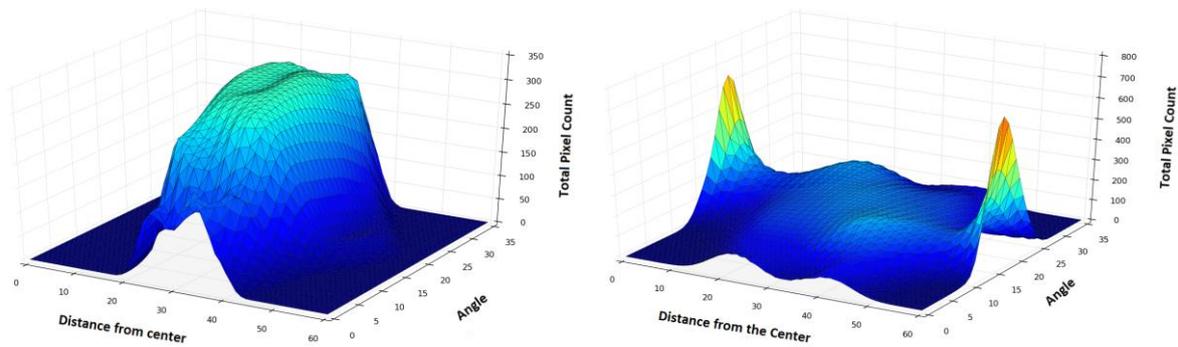


Figure 2: 3D plot of the scatter sinogram for direct rings (left-hand side) versus the scatter sinogram for thirteen 'compressed' ring difference (i.e. equivalent to 325 ring difference) sinogram (right-hand side)

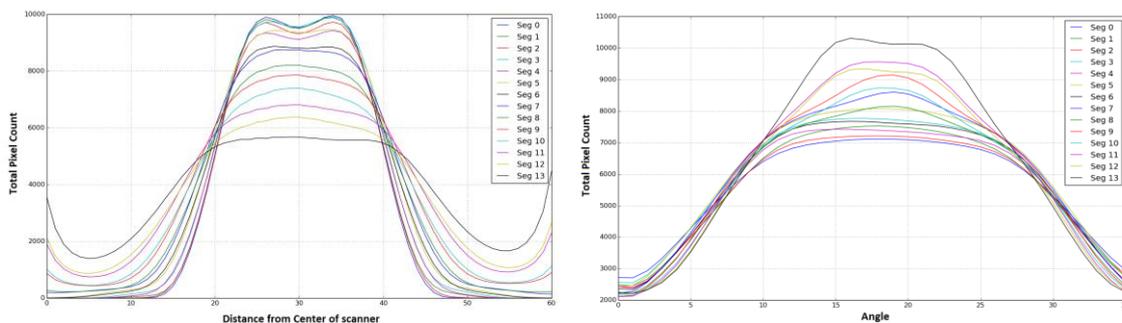


Figure 3: Profiles for 0 to 13 'compressed' ring difference: transaxial-direction profiles summed along angular-direction (left-hand side); angular-direction profiles summed along transaxial direction (right-hand side)

5. Discussion and Conclusion

The aim of this project was to test the reconstruction performance of STIR 3.0 library for a total-body system and investigate the validity of the current scatter simulation method for such a scanner. Through the simulations ran with the STIR library it was concluded from figures 2 and 3 that the method of approximating the scatter between oblique sinograms to the direct sinograms was imperfect, for large angles. For ring difference between 100 and 150, the discrepancy of scatter between direct and indirect rings is around 10%. Higher ring difference creates larger discrepancy and the accuracy of the reconstructed image is likely to be affected. Due to this it is clear that the scatter algorithm needs to be updated to deal with large oblique angles in the longer scanner.

Reconstruction of the total-body simulated data reflects the necessity of parallel computational processing for speeding up the computations. The analytical FBP-3DRP reconstruction algorithm for compressed sinogram data with span 11 and mash 2 requires about 4 hours to produce images, while the MPI version of the 3D OSEM reconstruction algorithm takes 2 hours per full iteration. Future work will focus on the parallel processing implementation of the projectors and scatter simulation algorithm. As the current version of interpolating the scatter sinograms will not provide valid results, appropriate oblique sinograms sampling and interpolation will be necessary, which will introduce more computing requirements. In addition, scatter simulation needs further exploration, as for example multiple scatter may be more significant for the total-body PET scanner. It may be the case that Monte Carlo based scatter correction methods is more appropriate for this scanner. Furthermore, incorporating additional information from time-of-flight, point-spread-function and depth-of-interaction will be essential to maximise the potential of this novel system. In order to include all this information, list-mode based iterative reconstruction will be more efficient. In conclusion, although the STIR library is capable in producing data that can be useful to researchers, it requires a series of major updates to cope with the large amount of data acquired from a total-body PET imaging system.

6. References

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Appendix: Inserting the scanner in STIR

Part of the Scanner Information Configuration:

```
case UltraPET: set_params(UltraPET, string_list("UltraPET","UPET"), 575, 244, /* (15*36)
+35 */ 229,15*48, 400.F, 8.F, 3.42F, 3.42F, 0.F, 0, 0, 0, 0, 0, 0, 0, 1);
```

Part of the Scatter Template Interfile Information:

```
Segments: 27; Views: 36; Axial coordinate range: From 10 to 23; Tangential coordinate:
61; Minimum & Maximum ring difference per segment: From -13, to 13; Number of rings:
23; Number of detectors per ring: 72; Inner ring diameter: 80; Distance between rings
(cm): 8.55; Default bin size (cm): 1.368; Maximum number of non-arc-corrected bins: 61;
Default number of arc-corrected bins: 57; effective central bin size (cm): 0.712
```