Report for exchange programme at University College London (UCL)

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1 Summary

This exchange programme was proposed to contribute towards the current developments in Synergistic Image Reconstruction Framework (SIRF) to read and reconstruct positron emission tomography (PET) raw data from GE SIGNA PET/magnetic resonance (MR) scanner. There were three main challenges that were faced during PET data reconstruction with SIRF for real data produced by GE SIGNA PET/MR scanner prior to this exchange programme. These challenges included:

1. Random data correction: Randoms correction could not be carried out for the data acquired by GE SIGNA scanner.
2. Rotated images: There was a view angle offset between GE reconstructed image and SIRF for reconstructed images.
3. Time of Flight (ToF) reconstructions: Reconstructions with recent ToF code (to be included in SIRF) for real phantom data from the scanner was not validated. This ToF code will allow SIRF users to be able to reconstruct real ToF-PET data from GE SIGNA PET/MR (a scanner with 390 ps timing resolution) with all data corrections.

This visit was aimed to resolve all the above challenges. Additionally, PET/MR datasets were acquired using VQC calibration phantom provided by GE with GE SIGNA scanner located at Imanova, UK with the help of Dr. Gaspar Delso. This VQC phantom data was used to validate the rotation angle between GE and STIR. The dataset was also used to validate the random correction after the code was included in STIR. This dataset will prove to be beneficial for PET and MR data alignment that will be included within SIRF and will be made open source via Dementia Platform United Kingdom (DPUK). Another dataset with 2 GE-68 spheres as discussed in section 2.2, was collected at Imanova and this was used to validate the ToF code as discussed later in this report. Finally, all the code-based developments and outcomes of the visit are aimed to be available within SIRF as a part of this exchange programme.

The VQC Phantom (P/N 5450562) is used for MR and PET Image Alignment. This special phantom contains five small spheres (1) embedded in the phantom that are a source of low radiation (0.7 MBq Germanium-68 per sphere, total 3.5 MBq) and Nickel Chloride ($NiCl_2$). The average life of the VQC Phantom is 2 years. It should be replaced when replacing the Annulus Phantom.

Illustration 1: VQC Phantom

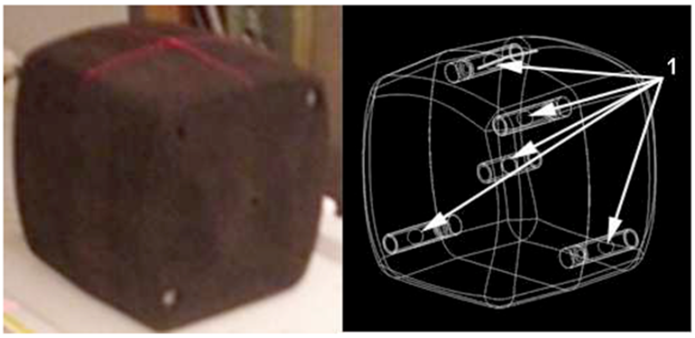

Illustration: Courtesy Dr. Gaspar Delso

2 Activities

2.1 Redefining of GE SIGNA PET/MR Scanner

GE SIGNA PET/MR scanner in `Scanner.cxx` for GE SIGNA PET/MR Scanner was redefined during this visit.

2.2 Data Collection

As a part of this exchange programme, phantom experiments were carried out at one of the GE SIGNA PET/MR site in UK, Imanova. There were two phantom datasets that were collected at Imanova using two different phantom types. The aims to collect these datasets were:

- To be able to validate the translational and rotational alignment between PET and MR images for GE SIGNA PET/MR scanner.
- To be able to validate TOF code by checking the positions of the point sources in phantom in back-projected images, and matching it to the images from the scanner.
- To be able to validate the unlisted sinogram with Software for Tomographic Image Reconstruction (STIR) by comparing it to Toolbox sinogram.

There were two main experiments that were carried out at Imanova:

1. VQC Phantom Experiment- VQC Phantom as shown in Illustration 1, is an alignment quality control phantom that is provided by GE along with GE SIGNA PET/MR scanner. This phantom consists of five small Ge-68 spheres embedded in MR visible tubes. These are low radiation spheres with 0.7 MBq activity in each sphere, everything encased within a cube. The scan was acquired with PET/MR simultaneous acquisition. PET

data was acquired over 10 minutes with 5x10^6 prompts. The phantom was placed with an offset to the scanner axis. It was placed approximately 11 cm off center and 9.7 cm above the bed along y-axis. PET and MR raw data along with uncompressed PET list mode file was obtained as a result of the scan. Console reconstructed PET and MR images were also saved. Console acquired PET image has matrix size 256x256x89 with voxel size 1.95x1.95x2.78 mm^3. This phantom study was utilized to test the ToF code. This was done by histogramming the listmode file into 5D ToF sinogram and comparing this with the forward projected 5D ToF sinogram for the same dataset. It was used to validate bin positioning, by selecting a point source which was off-center and measuring its distance from the center of the scanner. This distance should have been same as the distance of TOF bin approximately. This would tell if the point source is in correct TOF bin. It was seen that TOFbinunlisted=2 x TOFbinprojector. This inconsistency was successfully resolved later in the ToF code.

2. Ge Spheres Experiment- 2 68-Ge spheres were placed at the scanner wall for this experiment. This experiment was conducted for a very short duration of less than 1 minute and 17000 prompts were collected as a result. PET raw data, uncompressed listmode file and console based reconstructed images were acquired as a result of this scan.

2.3 Randoms Data Correction

Apart from ToF code validation, other challenge that was resolved was random data correction. The existing code available in STIR to correct for the random events, was able to correct for randoms using delayed event channel, where delayed event signal is used to eliminate true and scattered events [1]. Although, it was possible to correct for randoms using this for data acquired from Siemens mMR scanner, GE SIGNA PET/MR scanner does not use this method to calculate randoms. This scanner uses singles rates per crystal to estimate randoms as in equation 1, which is rather a noiseless method.

$$R_{xy} = 2\tau/T_{acq}S_xS_y \tag{1}$$

where R_{xy} represents the number of random events (or counts) detected by the detector pair x and y, τ represents the coincidence time window, T_{acq} represents the total acquisition time, S_x and S_y represents the single events detected by crystal x and y respectively. The single rates per crystal is measured as a part of the scan and saved in the listmode file for each scan. A new code was included in the local STIR library that would soon be included in SIRF. This code was developed to be able to read the HDF5 file and extract singles information for every crystal. This extracted singles information would be used in the algorithm as in equation 1 to calculate randoms sinogram using listmode file as the input from this scanner. New utility can be used to do this which is called `construct_randoms_from_GEsingles` which can be used to calculate randoms sinogram. There is another utility which was developed which could print the single events on the screen for a particular detector pair and is called `list_singles`. Validation of this code was done by comparing the randoms sinogram for segment 0 with the randoms sinogram extracted from the toolbox for the same listmode file. There are some minor issues that are under analysis regarding the sinogram bin positioning compared to toolbox which would hopefully be included in the code in future. This further analysis was needed as it was discovered that there was around 20% difference between GE random sinogram and STIR random sinogram.

2.4 Validation of TOF reconstruction

Apart from the validation that is discussed under the section Data Acquisition, a new test was included in the local `TOF_UCL_sino` which formalised the findings of ToF bin positioning and would detect the issue during testing.

2.5 Internal Meeting

On the first day of this programme, there were various meetings that were arranged to discuss the main objectives that would be tackled during this visit. Discussions were also carried out regarding the main subtasks including redefining the scanner parameters, validating TOF-PET reconstructions with real data and collecting real data at Imanova. Subsequently, during the week, Skype meetings were organised with Dr. Gaspar Delso, regarding the experiments at Imanova. Apart from this, there were mini meetings during the week to successfully install STIR with MATLAB, as there were issues prior to the visit regarding this. To solve the problem, I had to disable ITK, HDF5 Support and RDF in CMakeList. Apart from this, swig from `https://github.com/KrisThielemans-/swig.git` was used instead of `https://github.com/jaeandersson/swig.git`. This was due the fact that swig pointer was not created with the latter version. There was a final meeting that was held, where I gave a presentation on what had been done during the visit and what was achieved regarding randoms correction, TOF-PET reconstruction validation and data collection. There was a lot of support by Dr. Kris Thielemans for the entire exchange programme.

3 Results

The main results of this visit included:

- Successful phantom data acquisition and collection that will be made open source via DPUK and can be used for future investigations and analysis.
- Successfully redefining the GE SIGNA PET/MR scanner in STIR.
- Successfully installing STIR with MATLAB which was an issue prior to the visit.
- Utilization of the acquired phantom data to validate TOF code.
- Development of the randoms from singles code which could be used in future to extract the randoms sinogram.
- Successfully reconstructing real data with STIR including all data corrections such as normalisation, scatter, attenuation and randoms.

- Validation of the unlisting of sinograms with STIR for GE SIGNA PET/MR scanner and detecting the issues that are still to be resolved.
- Scripts to be made available to reconstruct real data acquired from this scanner with all data corrections. Particularly, attenuation correction by rotating the attenuation image by the offset angle between STIR and Toolbox reconstructed images.
- Including additional testing for TOF code in local `TOF_sino_UCL`.

References

[1] Bettinardi, V., Presotto, L., Rapisarda, E., Picchio, M., Gianolli, L. and Gilardi, M.C., 2011. *Physical Performance of the new hybrid PET/CT Discovery-690*. Medical physics, 38(10), pp.5394-5411.

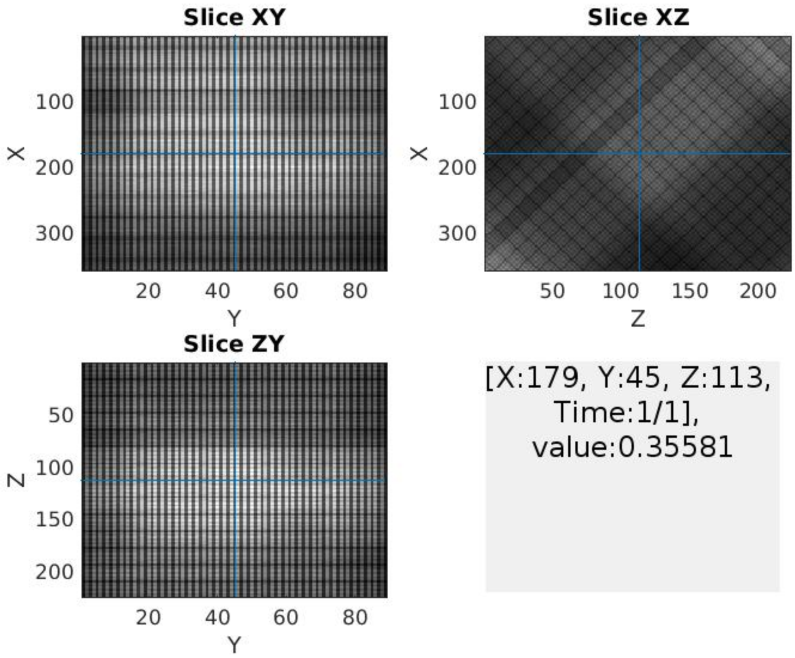

Figure.1 Randoms correction sinogram extracted from GE Toolbox.

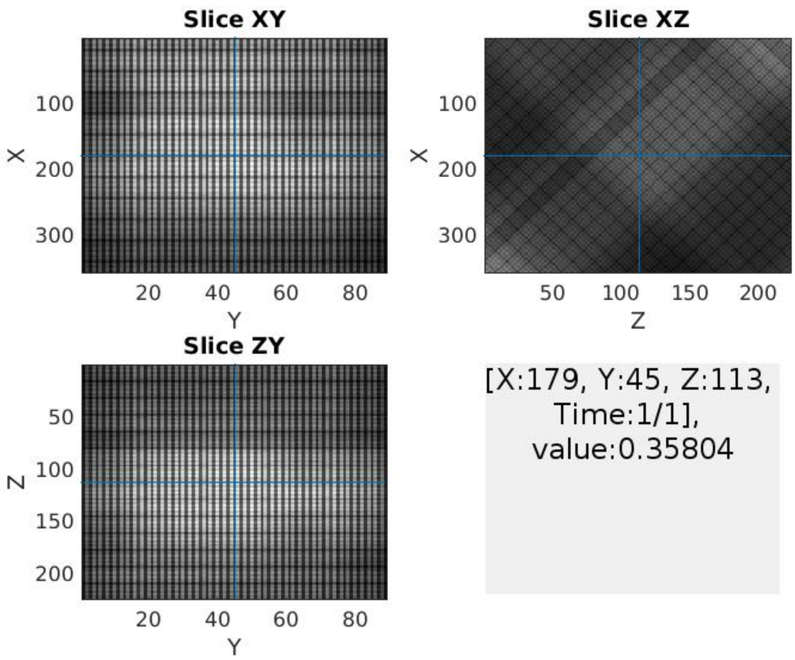

Figure.2 Randoms correction sinogram extracted from STIR- developed code during this exchange programme. The sinogram extracted using STIR is segment 0 sinogram. The X axis in the figure displays the tangential_pos_num, Y axis displays the axial_pos, and Z axis displays the view_num. The value at the cross is displayed in the second box at the bottom row. This value can be compared with the value in figure 1. The figure can be used to visually compare segment 0 of GE and STIR sinograms.