CCP PET-MR Research Exchange Report

PhD candidate - Harry Marquis
Research Exchange Visit: 7th November – 24th November 2019
From: School of Physics, University of Sydney (USYD), Sydney
Visiting: Institute of Nuclear Medicine, University College London (UCL), London
(Supervision: Kris Thielemans)

Purpose of exchange visit:

The purpose of the research exchange visit to UCL was to familiarise myself with the algorithms developed within the CCP PET-MR for PET reconstruction with MR side-information, and to investigate PET-MR synergistic reconstruction using the SIRF software. Another purpose of this visit was to see if these algorithms could be extended to SPECT reconstruction using PET side-information as a potential method for Partial Volume Correction (PVC) in theranostic PET/SPECT studies, for improved activity estimates in small lesions in the reconstructed SPECT image.

Summary of visit:

After attending the SIRF conference/symposium in Chester I headed down to London to begin my research exchange visit to UCL. The first few days of my visit was spent setting up SIRF and STIR natively on my Macbook so that I could begin testing and debugging the implementation of anatomical priors using the algorithms developed within the CCP for PET-MR. Once I had STIR and SIRF installed on my laptop I started investigating PET and SPECT reconstruction using Daniel Deidda's Hybrid Kernelised Expectation Maximisation (HKEM) algorithm developed for PET reconstruction using MR side-information as an anatomical prior. A few bugs and potential improvements were discovered throughout my investigations; this led to several Github issues raised as well as suggestions for future additions and alterations to the HKEM algorithm implemented in STIR.

Since my visit to UCL I have been using the HKEM algorithm in STIR to investigate the potential of PET-SPECT synergistic reconstruction for the theranostic pairing Copper-64 (Cu-64) PET and Copper-67 (Cu-67) SPECT as a method for PVC; using clinical data from a meningioma cohort. The initial results have been very promising and has led to an abstract submission to the SNMMI 2020 conference: "SPECT/CT-based Dosimetry in PRRT: Using Theranostics to Minimise the Impact of the Partial Volume Effect".

Activities:

- I attended the IEEE NSS-MIC conference and STIR users and developers meeting.
- Attended the SIRF symposium in Chester (http://synergimrecon.org/) and associated training school (using SIRF for PET-MR reconstruction).
- Implementation, testing and validation of anatomical priors used in PET-MR synergistic reconstruction. Focused on testing Daniel Deidda's HKEM algorithm.
- Explored the STIR/SIRF software with Kris Thielemans, Daniel Deidda and Ashley Gillman and investigated the feasibility of reconstructing SPECT images using PET images as side information.

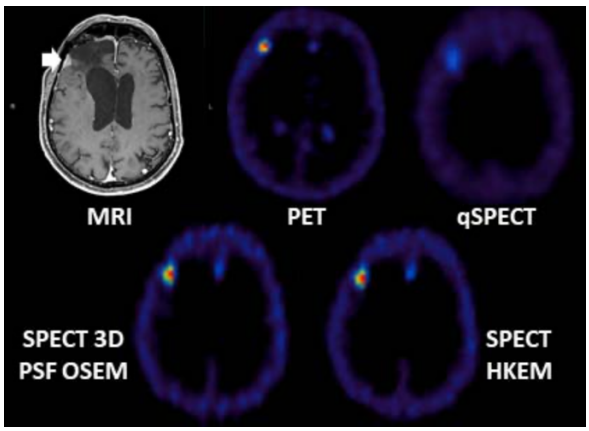
- PVC methods: Familiarised myself with Ben Thomas' PETPVC software and compared the results to other iterative 3D deconvolution software I have been using (deconvolutionLab2).

Results:

- Using the HKEM algorithm I found that the reconstruction time for even number of nearest neighbours was the same as the odd number preceding it (3 and 4 NN produced same result and took same amount of time to run). We found that the number of neighbour's parameter represents the diameter of the search window and should always be odd so as to be centred at the voxel of interest. Ashley Gillman raised a GITHUB issue pointing this out and suggesting that diameter of search window kernel (number of voxels) might be better descriptor for this parameter.
- I found that setting the anatomical image to a uniform image (to get no anatomical information) causes the image to be completely filled with NaN values after a single iteration. This led to Daniel Deidda implementing KEM with no anatomical prior into the HKEM algorithm (Pull request **#422 only functional HKEM**).
- It was found that setting the h=0 (KEM) can take significantly longer than h=1 (HKEM). I cannot quite make sense of this at the moment as it seems counter intuitive. I need to investigate this further to diagnose the exact issue.
- Masks were used to drastically speed up the reconstruction time. Significant image artefacts can arise when using masks in HKEM; massive artefacts occur at the edges of the mask, especially with higher values of sigma_p. I am working on developing a way around this by generating an output mask that removes these artefacts.
- Investigated using Cu-64 PET images as an anatomical prior for Cu-67 SPECT HKEM reconstruction. The initial results have been promising, showing increased uptake in small lesions due to reduced partial volume effects. Compared to OSEM with 3D-PSF modelling we showed a higher increase in SUVmean and SUVmax with the same number of iterations, as well as reduced Gibbs artefacts.

Table 1. Comparison of Volumes and Uptake

Scan	VOI Threshold (%)	Volume Measured (cc)	SUV(max)	SUV(mean)
MRI (T1 VIBE)	-	0.66	-	-
PET	20	0.65	17.9	12.1
qSPECT	50	5.1	3.2	2.1
SPECT 3D PSF OSEM	30	1.4	16.4	9.1
SPECT HKEM	30	1.2	17.0	10.2



Future Work:
Implementation of the HKEM algorithm for PET/SPECT synergistic reconstruction is being explored. There are plans to undertake a large-scale phantom and point source study for a wide range of PET and SPECT isotopes, with a particular focus on theranostic isotope pairings such as Ga-68/Lu-177 and Cu-64/Cu-67. We intend to explore synergistic reconstruction of these data sets using STIR and SIRF with the hope of improving the resolution of our SPECT reconstructions by reducing PVE's.

Since my visit to UCL I have shifted the main focus of my PhD to partial volume correction methods in theranostics using the improved spatial resolution of PET images to help guide and reconstruct the raw SPECT data. This will directly feed into the research I conducted in the first year of my PhD project; which focused on developing dosimetry software for theranostic pairings. I will soon look at dosimetry estimates to small lesions using this HKEM approach where I will compare the results to GATE simulations of Cu-64 PET data where the activity is simulated as Cu-67 (pre-therapy Cu-67 dosemaps using the Cu-64 PET image data).

Acknowledgements:
Many thanks to Kris Thielemans, Brian Hutton, Richard Brown, Ashley Gillman, Daniel Deidda, Ben Thomas, Rebecca Gillen and everyone else who I met during my exchange visit to UCL. Everyone was very hospitable and eager to help. I made some great connections within the INM at UCL and learnt so much during my visit. I hope to return the favour and have someone come visit the Royal North Shore Hospital and the University of Sydney. Overall the experience was invaluable and has contributed to a great sense of achievement and renewed sense of direction and purpose in my PhD research project.