Ep/M022498/1 –Tomographic Imaging, 2018

Non-destructive 3D X-ray, Neutron, PET and MR imaging are essential tools in many areas of science with diverse applications from Energy, to Healthcare to Security and across all Materials Science topics.

The CCPi network was established in 2012 to support the emerging UK tomography community with a toolbox of algorithms to increase the quality and level of information that can be extracted by computed tomography. There are four major open source software parts supported: pre-processing techniques for image calibration and noise reduction; reconstruction techniques to create a 3D volume data set from projections; segmentation/quantification techniques that can extract relevant objective values from these 3D volumes; and a software framework development to enable the exploitation across a wide range of imaging devices.

Key outcomes in last twelve months:

- The CCPi team has joined code base and development with the RTMCT (Flagship grant, see Appendix A) developer group and ongoing work is combining this structure with the CCPPETMR code base in terms of naming schema and structure. This choice was made to integrate with relevant third party software like Savu and allow users to migrate between platforms. CCPi code is integrated within ISIS/IMAT beamline structure and through the Savu framework used in the DLS (Diamond Light Source) – new users within the CCPi community network have been recruited to these national facilities.

Good software development practices have been implemented, including software code project management, version control, issue tracking, and systematic code testing and builds. We have made public releases through Anaconda of the Python software CIL; http://cil.readthedocs.io/en/latest/

- We have hired two new PDRA to replace the original team in SCD/STFC. The replacement hiring process took longer than anticipated and both staff members are in place from February 2019.

- Network t-conf meetings occur continually, with updated website, and regular newsletters, talks and training events. The size of our community has risen from ~250 in 2013 to over 400 by the end of 2018; ***over 60% growth.***

- As well as the 5 papers for the RTMCT grant code (https://doi.org/10.1088/1361-6420/aaba86 https://doi.org/10.1016/j.softx.2018.05.003 https://doi.org/10.1063/1.5044393 https://doi.org/10.1088/1361-6501/aafcae https://doi.org/10.1137/18M1166833) we have

- Exploring the potential of neutron imaging for life sciences on IMAT, https://doi.org/10.1111/jmi.12761
- Enabling three-dimensional densitometric measurements using laboratory source X-ray micro-computed tomography, https://doi.org/10.1016/j.softx.2018.03.004
- Posters and exhibition stand at ToScA 2018
- …and new datasets for: laminography (10.5281/zenodo.2540508) ring-artifact data reduction (10.5281/zenodo.1443568) and new lab-based protocols (10.5281/zenodo.1204088)

- Four funded Fellowship visitors; Brian Bay (Oregon State University [week visits in July & September 2018]) Digital Volume Correlation code being incorporated within the CIL, Llion Evans (University of Swansea) sponsored events (22 May & 3-6 Sep 2018, Image-based Modelling IBFEM-

4i) and speakers at RAL (14-15 June 2018) Francois Hild (University Paris-Saclay) and Maxime Moreau (French Institute of Petroleum).

Externally supported EPSRC/SSI exchange UK-USA collaboration scheme: included a presentation and poster at the SSI workshop (24 April 2018). Funded Fellowship Parmesh Gajjar to USA, England and Wales on Nikon hacking training/code.

- Four funded Student Fellowships for code exploitation; Catherine Disney (DVC code, Jan 2019) Sarah Fisher (Laminography at Manchester)and Jake Minns (summer students on ML for XCT imaging datasets).

- Two new co-linked UKRI funded organisations have been supported from proposal; Dr Llion Evans – Fellowship awarded at Swansea University, on industrial-scale tomography (kick-off 22 May 2018) and Bioimaging Network, Prof Peter Lee (CoI on CCPi) http://mecheng.ucl.ac.uk/imagingbiopro/ kick-off (25 June and 5 July 2018).

- Collaborated with creation of the EPSRC Roadmap on XCT and supported and on governance board for Warwick, WMG, shared "New fast XCT facilities and Applications".

Training: Network training activities included for year 2018;

- A specialist workshop on 'fibre reinforced composites' (15 May 2018); **Attendance 34**; held at Royce Institute on knowledge exchange - UK researchers and technicians

- Avizo visualisation hands-on session at RAL (17 May 2018) **Attendance 8**; held at STFC national facilities - UK researchers and technicians

- Avizo courses at UoM (6-7 March 2018, 5-6 June 2018, 28-29 November 2018) **Attendance 14x3**; indirect support, advertisement etc.., held at Royce Institute: UK researchers and technicians

- Course at Manchester DVC (Digital Volume Correlation) by Kamel Madi (Thermo Scientific™ Amira-Avizo) (16-18 October 2018) **Attendance 10**, funded trainers for course from CCPi, held at Royce Institute: UK researchers and technicians

- CCPi sponsored food and drink; IBFEM-4i at Swansea (3-4 [training] and 5-6 [users' workshop] September 2018) http://ibfem.co.uk/2018/ **Attendance 25 training and 37 workshop**; for UK researchers

- Advanced X-ray Imaging Workshop and Fringe Meeting (14-15 June 2018, organised by DLS / MDC); **Attendance 19**, CCPi hosted one-day Fringe event for UK researchers and Technicians: at STFC national facilities

- Dimensional XCT conference (2-3 July 2018, organised by NPL); and ToScA Symposium (10-12 September 2018, organised by RMS). CCPi had an exhibition stand and supported events for UK and international researchers: **visitor footfall ~70 + ~80**

- Monthly Lunch-and-Learn sessions (Royce Institute) and software-show-tell events at RAL (Harwell Campus); for local knowledge exchange
http://tyne.dl.ac.uk/twiki/bin/view/Visualisation/VisSeminars

- ... 11 meetings at Royce Institute, (total **attendance 226** - two video conferenced)
- ... 6 meetings at STFC national facilities (total **attendance ~49**)
- ... and 1 meeting at UoM Mathematics department (total **attendance 11**)

- Parmesh Gajjar to USA, England and Wales on Nikon hacking training/code. Publicity at lunch-and-learn (accounted for above) and funded a training session at Swansea (**attendance 5**) - UK technicians.

Appendix A - Flagship summary RTMCT, 2018 (Draft)

In 2018 5 papers have been published acknowledging the RTMCT grant code

- Joint image reconstruction method with correlative multi-channel prior for x-ray spectral computed tomography , https://doi.org/10.1088/1361-6420/aaba86
- TomoPhantom, a software package to generate 2D–4D analytical phantoms for CT image reconstruction algorithm benchmarks, https://doi.org/10.1016/j.softx.2018.05.003
- New software protocols for enabling laboratory based temporal CT, https://doi.org/10.1063/1.5044393
- Laminography in the lab: Imaging planar objects using a conventional X-ray CT instrument, https://doi.org/10.1088/1361-6501/aafcae
- Analyzing reconstruction artifacts from arbitrary incomplete X-ray CT data, https://doi.org/10.1137/18M1166833

We have made a public release through Anaconda of the first version of the central outcome of the RTMCT project, namely the Python software CIL, enabling reconstruction of multichannel tomographic data. A new object-oriented Python framework has been designed and implemented to allow easy experimentation with a host of different reconstruction algorithms for both conventional single channel and multichannel tomography data. A lot of work has gone into restructuring existing CCPi code into the new framework. A range of demos show the software capabilities both on simulated data and for a number of open access single and multichannel tomography data sets.

The RTMCT team has joined code base and development with the CCPi core developer group. This choice was made to integrate with and build on existing code from the outset with the goal of simplifying integration of software with relevant third party software like Savu. Furthermore, good software development practices have been implemented, including for example software managed on the GitHub platform with code project management, version control, issue tracking, systematic code testing and builds in order to ensure consistently high quality software.

We have won a 5-day beamtime at the ISIS Neutron and Muon Source taking place mid February where valuable multichannel neutron time-of-flight tomography test data will be acquired. A test sample has been carefully designed and produced and to produce high-quality data of a well-specified structure to enable careful testing and optimisation of reconstruction algorithms. The same sample will subsequently be used to acquire test data at the second of the two data cases of the RTMCT project, namely the Manchester Colour Bay instrument for multichannel X-ray tomography, as well as applying for beamtime at the Diamond Light Source.

We organised a minisymposium on “Multi-channel image reconstruction approaches” at the SIAM conference on Imaging Science IS18, 5-8 June 2018, Bologna, Italy, in which Daniil gave an oral presentation, whereas Jakob at the same time also gave an invited minisymposium oral presentation. Jakob also gave an invited talk at the 6th IMA Conference on Numerical Linear Algebra and Optimisation, Birmingham, 27-29 June 2018 and an oral presentation as well as a poster at the 6th Tomography for Scientific Advancement (ToScA) Symposium, Warwick, 10-12 September 2018. Furthermore, Jakob was invited and gave an oral presentation at the prestigious invitation-only

Oberwolfach Conference on Tomographic Inverse Problems: Theory and Applications, MFO, Oberwolfach, Germany, 27 Jan – 2 Feb. Results were also presented at oral presentations in the UK.

We have hired two new PDRA to replace the two original PDRAs and Researcher Co-Investigators Daniil and Jakob, who have both moved to permanent roles as Software Developer at the Diamond Light Source and Presidential Fellow at the University of Manchester respectively; accomplishments significantly aided from the RTMCT grant. The replacement hiring process took longer than anticipated, for example due to delays in obtaining visa, causing a gap of several months on both posts. Both PDRAs have now commenced in their roles and currently being trained in the project area and starting to contribute to the software.

In February 2018 we/the CCPi invited Dr. Joan Duran from the University of the Balearic Islands to visit the project and give seminars both in Harwell and Manchester. The visit helped clarify certain reconstruction approaches used by Duran to help us implement a variant for our problems. A number of ideas of joint projects were discussed and some preliminary work carried out.

Jakob was invited by Prof. Joost Batenburg visit to the CWI Institute in Amsterdam and visited on 1-2 May 2018 and gave a seminar on the RTMCT project work and results. Many software aspects and ideas for joint projects and software were discussed including the use of machine learning techniques for multichannel reconstruction