THE MAXWELL ADVANCED TECHNOLOGY FUND

The Maxwell Advanced Technology Fund

2018

THE UNIVERSITY of EDINBURGH

THE MAXW ADVANCED TECHNOLOGY FUND

PhD project

Final

Report

Enhancing Cancer Imaging Technology

Jonathan H Mason

Research project overview

In the UK alone, there are over 350,000 new cases of cancer each year, of which 27% are treated with radiotherapy [1]. In order to enhance the efficacy and reduce the toxicity to healthy tissue, treatments can be carefully planned with the use of accurate imaging, where the interactions can be computationally simulated ahead of time. A common imaging technology built onto many commercial radiotherapy systems is cone-beam computed tomography (CBCT), which allows real time X-ray imaging of the patient to verify positioning, but carries a reputation of being very inaccurate and is typically insufficient as a basis for calculating a treatment plan. In this project, we are researching methods for enhancing the quality of CBCT imaging, in order for it to become a suitable modality for increasing the accuracy of radiotherapy planning, to enable more successful cancer treatment.

This work has had two main threads of research: exploiting previous images of the same patient for correcting artefacts and reducing the amount of information required from a fresh scan; and direct quantitative imaging from the raw measurements, to facilitate the radiotherapy planning process. In the first case, we have developed a framework for both using previous scans to account for scatter – the leading cause of errors in CBCT – and to regularise the new reconstruction, which may be considered as finding the difference between the scans instead of forming an entirely new image.

The second area of research has been in quantitative imaging, where the pixels of the reconstructed image have physical meaning. Since the quantity for calculating treatment plans is the density of electrons, we have developed a method for directly measuring the electron density of a patient from raw X-ray measurements. Although this turns out to be a physically impossible task for all materials, we have found a model that works very well for human tissues, exploiting a piecewise linear fitting shown in Figure 1. Not only this, but the model can be extended to correct for artefacts caused by metal implants, which is a large problem in pelvic cancers when a patient has prosthetic hips. We have demonstrated this method on two clinical imaging systems, and are currently extending it to simultaneously correct for scatter also.

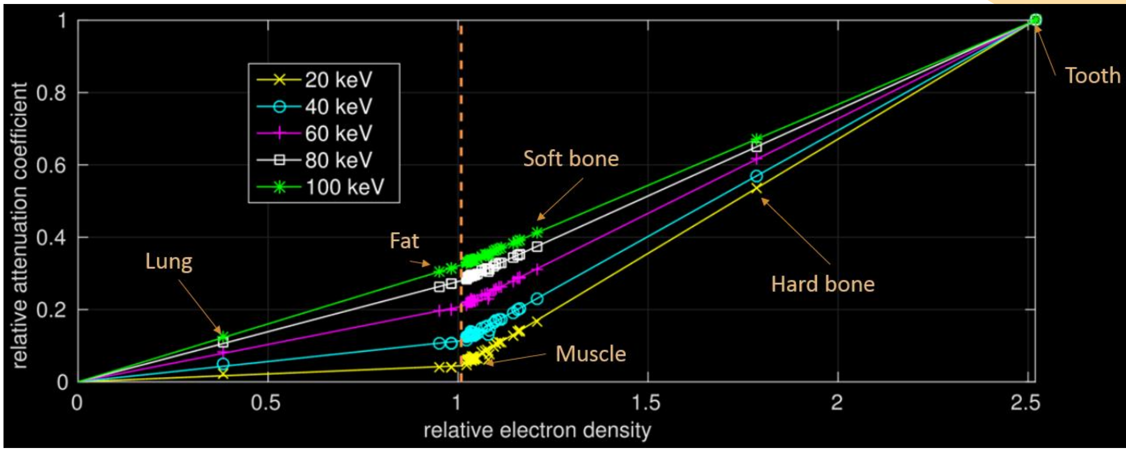

Figure 1: Nonlinear X-ray attenuation against electron density for human tissues according to [2], where each colour represents various photon energies. A piecewise linear fit has been superimposed with a consistent transition point.

Results

Illustrative results from the quantitative approach are shown in Figures 2 and 3.

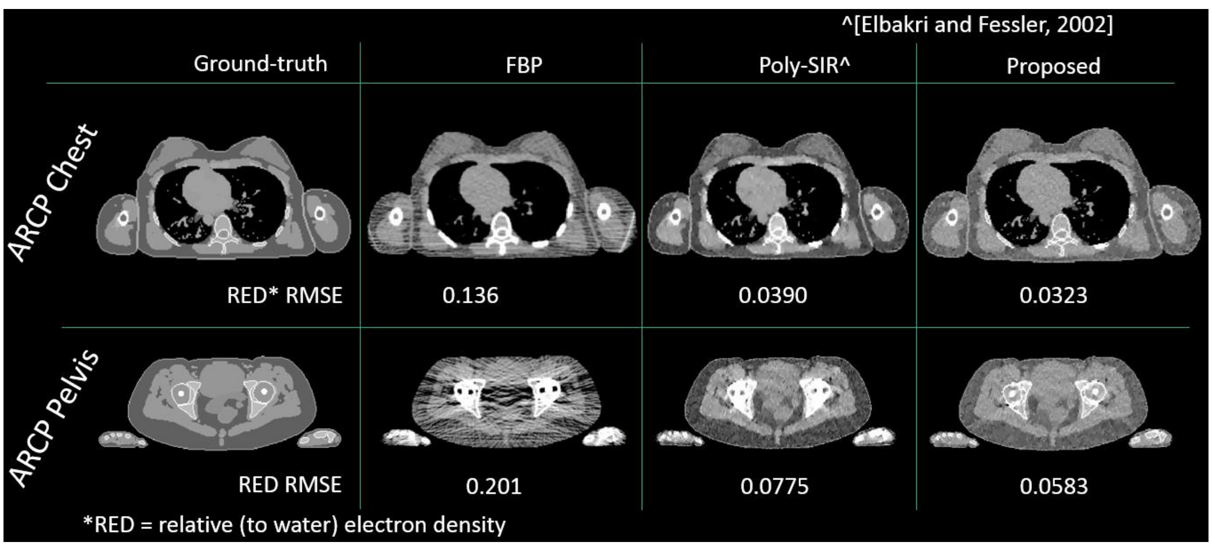

Figure 2: Illustrative results from simulated CT data using the adult reference computational phantom (ARCP) [3] of chest and pelvis with metal implants. We compare against filtered back-projection (FBP) the most common commercial technique, and a competing statistical technique Poly-SIR [4].

Figure 2 shows reconstruction from data generated from detailed physical simulation of a CT scanner. The two cases are for a chest and for the pelvis region with double metallic implants. Both visually and quantitatively from the relative electron density (RED) root mean squared error (RMSE), the advantage of the proposed approach can be seen, especially with the metal implant case.

In Figure 3, results from a commercial CT scanner are shown. The chest phantom illustrates a gain in uniformity throughout the homogeneous tissue like material. In the head phantom case, where a metallic pin in placed in the centre of the phantom, we validate the ability of our approach to mitigate real metal artefacts.

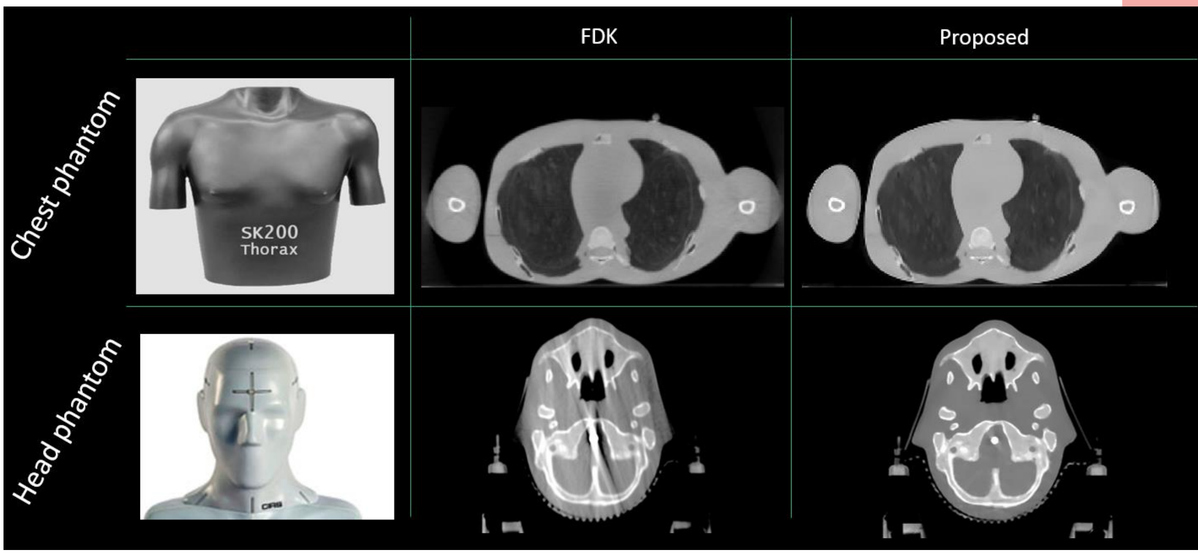

Figure 3: Results on real data from anthropomorphic phantoms scanned using a Varian TrueBeam imaging unit on a radiotherapy system. The head phantom includes a stainless steel pin at its centre to introduce metallic streak artefacts. Feldkamp-Davis-Kress [5] is the commercial CBCT reconstruction method used.

Output and achievements

To date, this project has resulted in 3 conference papers [6,7,8], 2 abstracts to the leading European radiotherapy meeting, and an article published in Physics in Medicine and Biology [9], which is ranked in the top 3 journals in the field. On top of this, our work on quantitative imaging for radiotherapy was awarded the **best paper prize** at the Medical Image Understanding and Analysis conference in 2017 [6].

Another achievement has been in using data from CBCT scanners at the Western General Hospital in Edinburgh with the help of Bill Nailon, and collaboration from the manufacturer. With this, we have been able to verify our methods, and demonstrate them to be superior to the current commercial techniques, as were shown in Figure 3.

During November 2017, I also had a secondment with medPhoton, a CBCT scanner manufacturer in Salzburg, where I was able to evaluate the effectiveness of our methods with large metal objects with their proprietary CBCT system. During this time, I also wrote a **software implementation for a popular open source CT reconstruction package** in C++, to enhance the replicability and impact of the research.

Ongoing and Future Work

Now that I have completed the project, submitted the thesis and graduated successfully in November 2018, there are still a couple of areas of current and future research. Firstly, we will complete an experiment to validate the radiotherapy dose delivered by a commercial therapy system, and whether our improvements to CBCT images enable accuracies that match that of planning CT. Secondly, we have entered a reconstruction challenge looking at 4D CBCT of the lungs, where each stage of the respiratory phase is separated into 3D images.

We already believe the research completed in this project has the potential to make tangible improvements to cancer therapy treatment, to which we are extremely thankful for the Maxwell scholarship funds for allowing it to happen.

References

[1] Cancer Research UK 2017 Cancer statistics for the UK http://www.cancerresearchuk.org/health-professional/cancer-statistics-for-the-uk

[2] ICRP 2002 Basic anatomical and physiological data for use in radiological protection reference values. Publication 89 *Ann. ICRP* **32**

[3] ICRP 2009 Adult reference computational phantoms. Publication 110 *Ann. ICRP* **39**

[4] Elbakri I A and Fessler J A 2002 Statistical image reconstruction for polyenergetic x-ray computed tomography *IEEE Trans. Med. Imaging* **21** 89–99

[5] Feldkamp L A, Davis L C and Kress J W 1984 Practical cone-beam algorithm *J. Opt. Soc. Am.*A **1** 612

[6] **[Best paper Award] Mason J H**, Perelli A, Nailon W H and Davies M E, 2017, Quantitative Electron Density CT Imaging for Radiotherapy Planning. Medical Image Understanding and Analysis (MUIA) 2017.

[7] **Mason J H**, Perelli A, Nailon W H and Davies M E, 2017, Can Planning Images Reduce Scatter in Follow-Up Cone-Beam CT? Medical Image Understanding and Analysis (MUIA) 2017.

[8] **Mason J H**, Nailon W H and Davies M E, 2017, A Monte Carlo Framework for Low Dose CT Reconstruction Testing. Simulation and Synthesis in Medical Imaging (SASHIMI), 2017, in Lecture Notes in Computer Science (LNCS), vol. 10557.

[9] **Mason J H**, Perelli A, Nailon W H and Davies M E, 2017, Polyquant CT: direct electron and mass density reconstruction from a single polyenergetic source. *Phys. Med. Biol.* **62** 8739.

Development and Alumni
The University of Edinburgh
Charles Stewart House
9-16 Chambers Street
Edinburgh EH1 1HT

Tel: 0131 650 2240

Email: development@ed.ac.uk
www.friends.ed.ac.uk