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DOCTORAL THESIS

Dual energy image reconstruction and systems for application in proton therapy treatment planning

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Dual energy image reconstruction and systems for application in proton therapy treatment planning

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Doctor of Philosophy

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by

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Publications and Submitted Papers Contained Within Thesis

Published

P1. Zhu, Jiahua, and Scott N. Penfold. "Review of 3D image data calibration for heterogeneity correction in proton therapy treatment planning." Australasian Physical & Engineering Sciences in Medicine (2016): 1-12.

P2. Zhu, Jiahua, and Scott N. Penfold. "Dosimetric comparison of stopping power calibration with dual-energy CT and single-energy CT in proton therapy treatment planning." Medical Physics 43.6 (2016): 2845-2854.

P3. Zhu, Jiahua, and Scott N. Penfold. "Total Variation Superiorization in Dual-energy CT Reconstruction for Proton Therapy Treatment Planning" Inverse Problem, Vol 33, No.4 (2017)

Submitted

P4. Zhu, Jiahua, and Scott N. Penfold. "Europium-155 as a source for dual energy cone beam computed tomography in adaptive radiotherapy: a simulation study" Submitted to Medical Physics

These publications and papers submitted are included within this thesis. When referred to in the text the reference number is prefixed by a ‘P’. For example, the first publication in this list is referred to P1.

Grants and Scholarships

- Australasian College of Physical Scientists and Engineers in Medicine (ACPSEM) Student Scholarship to attend the annual Engineering and Physical Sciences in Medicine (EPSM) Meeting 2013.
- Chinese Government Award for Outstanding Self-financed Students Abroad 2016

Conference Presentations

- Zhu J., Penfold S., *An Alternative Material Definition Scheme for Monte Carlo Radiotherapy Dose Calculation*, EPSM 2013, Perth, Australia

- Zhu J., Penfold S., *Investigation Into Robustness of Stopping Power Calculated by DECT and SECT for Proton Therapy Treatment Planning,* AAPM Annual Meeting, 2015, Anaheim, CA, USA

Other Presentation

- Zhu J., Penfold S., *The optimization of dose calculation by DECT in proton therapy*, ACPSEM Student Night 2015, Adelaide, Australia [Second Prize]

- Zhu J., Penfold S., *Effective atomic number calculation by DECT*, ACPSEM Student Night 2014, Adelaide, Australia [Second Prize]

Abstract

Proton therapy is the use of a proton beam rather than a traditional X-ray beam in the treatment of cancer. This technique is being developed all over the world due to the unique Bragg peak feature of proton beams. In order to guarantee accurate dose delivery to the tumour, the stopping power ratio (SPR) of the tissue must be known. This parameter is dependent on the electron density and effective atomic number of the material and describes the energy loss per unit length in the tissue. In current clinical practice, the SPR of patient tissues is obtained through single energy CT (SECT) scanning. The SECT scan results in a map of kilovoltage X-ray attenuation coefficients relative to the attenuation coefficient of water for the beam energy. This quantitative information is then converted to SPR via an empirically derived look-up table. If the patient tissues do not have a similar chemical composition to the materials used to generated the look-up table, this approach can lead to diminished dose calculation accuracy. As a result, the patient may experience increased normal tissue complication or decreased tumour control probability. An alternative approach that has been suggested recently is the use of dual energy CT (DECT).

DECT is an emerging imaging modality that makes use of CT spectra to create two sets of CT images simultaneously. DECT relies on the energy independence of relative electron density, and the energy and atomic number dependence of X-ray interaction atomic cross-sections. Post processing of the two reconstructed CT images results in two separate images quantifying electron density and effective atomic number. The SPR of the tissue can be calculated once electron density and effective atomic number are known. In theory, the use of DECT for SPR estimation should be more robust than SECT combined with an empirically derived look-up table. This hypothesis has been tested with phantoms of known composition in the current work.

Unfortunately, the post processing of DECT images results in effective atomic number images with a low contrast to noise ratio, which can affect SPR calculation accuracy. To counteract this, an iterative DECT image reconstruction approach has been developed. Two image reconstruction algorithms, FBP and TVS-DROP, are implemented to reconstruct the

CT images, where an advanced parallel calculation code was designed for TVS-DROP to improve work efficiency. The iterative reconstruction algorithm was also applied to a radioisotope form of cone beam DECT. A feasibility study into the use of this novel imaging method in adaptive proton therapy was conducted.

In summary, the objective of this thesis is to examine the application of DECT for proton therapy treatment planning, develop improved image reconstruction techniques for DECT, and investigate the feasibility of a novel radioisotope-based form of cone beam DECT for adaptive proton therapy.

Table of Contents