

S.N. Penfold, *Image Reconstruction and Monte Carlo Simulations in the Development of Proton Computed Tomography for Applications in Proton Radiation Therapy*, Ph.D. dissertation, Centre for Medical Radiation Physics, University of Wollongong, **2010**.

<http://ro.uow.edu.au/cgi/viewcontent.cgi?article=4305&context=theses>.

## Abstract

Proton therapy is a rapidly expanding form of cancer treatment. Because protons have a finite range in matter, this treatment modality allows for a greater degree of conformality than conventional external beam X-ray therapy. To maximize the inherent advantages of proton therapy, the range of protons inside the patient must be able to be predicted with millimetre resolution. In current clinical practice, proton therapy treatment plans are made with pre-treatment X-ray CT scans of the patient. To convert the X-ray CT Hounsfield units to proton relative stopping powers, which are required by the treatment planning software, an empirically derived calibration function is used, which is specific to each X-ray CT machine. However, because of the different dependence on  $Z$  and the  $Z/A$  ratio of X-ray attenuation and proton energy loss, the relationship between Hounsfield units and relative stopping powers is not unique. This conversion process leads to range uncertainties at treatment time. A preferable scenario is one in which the relative stopping power of each patient is reconstructed directly. This is the goal of proton computed tomography (pCT).

Proton CT was first proposed in the 1960s but a clinical system is yet to be realised. Difficulties experienced in previous projects included long acquisition times and substandard spatial resolution relative to X-ray CT. The current pCT development project makes use of advances in high energy physics detector technology and focuses on generating pCT specific image reconstruction algorithms to counteract the aforementioned issues. The work presented in this Doctoral Thesis will focus on two aspects of the pCT development project; image reconstruction and Monte Carlo simulations to aid in the design of the first generation preclinical system.

The current image reconstruction approach for our pCT concept is to treat individual proton paths as line integrals through the unknown object. The path of individual protons are predicted with a most likely path (MLP) formalism, which is based on spatial measurements made upstream and downstream of the object.

Advances presented in this thesis include a more flexible derivation of the MLP, a more accurate implementation of the MLP in iterative reconstruction algorithms, the use of parallel compatible iterative reconstruction algorithms to speed up the image reconstruction process with parallel processing and the adaptation of other state-of-the-art image reconstruction principles to the pCT

task. Furthermore, Monte Carlo simulations are presented that have guided the design of the preclinical pCT system.

Finally, suggestions are proposed for the future directions in pCT, both in respect to the image reconstruction task and the design of the next generation system.