Proton CT reconstruction

The CA4PH phantom is reconstructed from 200 MeV proton data taken in May 2015 at CDH. The reconstruction employed a filtered back-projection (FBP) algorithm followed by an iterative reconstruction (TVS with DROD) that makes use of the tracking information of individual protons to define a mask-like path (MLP) through the phantom.

PET/CT Image Reconstruction

PET/CT images are acquired using a hybrid PET-CT scanner that combines positron emission tomography (PET) and computed tomography (CT) technologies. The PET component allows the detection of positron-emitting radioactive tracer molecules, which emit gamma rays when they undergo annihilation. These gamma rays are detected by the PET detectors, and the information is used to create a 3D image of the tracer distribution within the body. The CT component provides anatomical images of the body, which can be fused with the PET images to improve diagnostic accuracy.

The PET/CT images are reconstructed using various algorithms, including filtered back-projection (FBP), iterative reconstruction methods, and hybrid techniques. These algorithms attempt to reconstruct the original distribution of tracer activity from the detected gamma rays. The quality and accuracy of the reconstructed images depend on several factors, including the characteristics of the PET/CT scanner, the quality of the acquired data, and the reconstruction algorithm used.

Summary

Proton CT (pCT) is an evolving technology that promises to improve proton treatment planning by addressing the range uncertainty problem. Several research groups have attempted to develop an integrated relative stopping-power (RSP) measurement that uses reconstituted data to build a map of RSP values. This study uses data collected from a 200 MeV proton beam to investigate the feasibility of using pCT to reconstruct a RSP map. Our work has shown that pCT can be a valuable tool for improving proton treatment planning.

pCT Scanner in the CDH Proton Beam Line

Rotation Stage

Trackers

5-Stage Energy Detector

The pCT scanner consists of two trackers, one preceding and one following the object being imaged, and an energy/range/depth detector that measures the Water Equivalent Path Length (WEPL) of the material through which the protons have passed in traversing the object. Together, the two trackers measure the incoming and outgoing proton trajectories, from which the geometric path-length of the object can be estimated. The stage rotates the object being imaged.

5-Stage Energy/Range Detector

Dividing the energy range into five stages can significantly reduce the energy resolution requirement, allowing effective use of fast plastic scintillators. Stages through which the protons pass directly measure contributions to integral range, so the last segment, in which the protons stop, need measure only a small residual range, with only a relaxed precision requirement. Each custom board behind digitizes the signals from three scintillator-PMT pairs (see the photograph at the left). Each 24-bit ADC can operate at rates up to 60 Mrad. The FPGA board digitizes data and, upon receipt of a trigger, reduces the data by summing 8 samples around the peak (the pulse before and after). A separate amplitude-discriminator chain in each channel provides asynchronous signals for the trigger logic.

WEPL Calibration

A polystyrene “phantom” with 3 stepped pyramids is used to calibrate the measurement of Water Equivalent Path Length (WEPL). In practice, two separate runs are executed with the stepped pyramids combined with 0, 3, 6, 9 or 12 polystyrene blocks. The tracking system is used to correlate each proton track with the correct step and with the reconstructed signals from the energy/range detector. The ultimate aim is to be able to reconstruct an RSP map of a patient, with a 3.7 mm at the 1% level, to the 3% level due to stochastic range straggling of 2.75 mm for 200 MeV protons.

Spatial Resolution Study: Edge Phantom

A phantom was designed and fabricated for the purpose of measuring a modulation transfer function (MTF).

Spatial Resolution

The spatial resolution is limited by the size of the pixel in the detector (1 mm x 1 mm), and the voxel size in the image reconstruction algorithm. The spatial resolution of the image is also affected by factors such as the beam size, the energy of the protons, and the distance from the source to the detector.

DAQ Performance

The MTF is a function of relative modulation sensitivity max, with the following definition:

where:

is a non-linear scaling function,

is the cutoff frequency of the system.

is the spatial frequency of the system.

is the spatial frequency of the system.

The MTF is used to characterize the performance of the detector system, with values close to 1 indicating excellent performance.

Operations at Loma Linda U. (LLU) Synchrotron

Continuous beam with small intensity modulations

Continuously recorded signal with 1/sr/min.

The DQAU for the CDH pCT scanner is accepted as a test for the scanner’s performance.

3-D Reconstruction for in-room Position Verification and image-guided Proton Therapy in Progress

The authors acknowledge the support of Dr. Mark Pankuch during data taking at CDH.

Work in progress is employed to create 3D reconstructions of the CT volume using live catheter images and process the data to generate 3D images of the catheter's position. This allows for real-time guidance of the catheter throughout the procedure, improving the accuracy and efficiency of the procedure.

Note that these images were taken in two separate scans displayed in the vertical direction. There are some artifacts in these images, which are currently being addressed in the reconstruction algorithms and in the WEPL calibration, usually in the middle range energy region of the detector.