Image reconstruction for ion computed tomography with the TIGRE toolbox

Stefanie Kaser[a,*], Thomas Bergauer[a], Ander Biguri[b], Wolfgang Birkfellner[c], Sepideh Hatamikia[c,d,e], Albert Hirtl[f], Christian Irmler[a], Benjamin Kirchmayer[f], Felix Ulrich-Pur[a,g]

[a]Institute of High Energy Physics, Austrian Academy of Sciences, Vienna, Austria
[b]Department of Applied Mathematics and Theoretical Physics (DAMTP), University of Cambridge, Cambridge, United Kingdom
[c]Center for Medical Physics and Biomedical Engineering, Medical University of Vienna, Vienna, Austria
[d]Austrian Center for Medical Innovation and Technology (ACMIT), Wiener Neustadt, Austria
[e]Research Center for Medical Image Analysis and Artificial Intelligence (MIAAI), Department of Medicine, Danube Private University, Krems, Austria
[f]Atominstitut, TU Wien, Vienna, Austria
[g]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

Introduction

Radiotherapy with ions is a well-established method to treat deep-seated tumors in cancer therapy. However, treatment planning is typically based on an x-ray computed tomography (CT) scan, which results in an image in Hounsfield units (HU). For treatment planning, the HU must be converted to relative stopping powers (RSP). This process introduces range errors, which result in increased safety margins around the tumor in treatment planning. Measuring the planning CT with ions would allow to extract the RSP values from the scan directly and hence offer the potential to improve treatment planning. However, the non-straight ion paths, which result from multiple Coulomb scattering, have to be considered in the CT reconstruction process.

Materials and Methods

The open-source and GPU-based reconstruction toolbox TIGRE, initially developed for x-ray CT image reconstruction, was extended to allow ion CT image reconstruction. An existing approach for radiographic ion imaging was refined and implemented as pre-reconstruction binning step to the framework. To test the code extension, an ion CT setup was modelled with Monte Carlo simulations (using GATE and Geant4). Imaging data was created under idealized conditions and under realistic assumptions. A mono-energetic beam using 200 MeV protons was used as ion source in the simulations. As phantoms, Catphan® modules (CTP528 and CTP404) and an anthropomorphic phantom were used in this study.

Results

Regarding spatial resolution and RSP accuracy, the reconstructed images showed an improvement as compared to a previous ion CT reconstruction approach with TIGRE, which did assume a straight-line ion path to simplify the reconstruction process. Up to 8 lp/cm could be resolved under ideal conditions and the mean average percentage error of the RSP was found to be below 1%. The newly written and GPU-based code allowed for a pre-reconstruction binning time below 1s per projection. It was published as part of the open-source TIGRE toolbox.

Discussion

With the newly implemented code extension for the TIGRE toolbox, the framework is able to account for the non-straight ion paths in the reconstruction process. As compared to a previous ion CT reconstruction study with TIGRE, spatial resolution and RSP accuracy could be increased, while the overall reconstruction time was kept in the order of minutes. Furthermore, the particle fluence could be reduced (from 800 protons per mm^2 to 225 protons per mm^2 and only 50 protons per mm^2 for the anthropomorphic phantom). Future studies should focus on further refinement of the ion CT reconstruction process in TIGRE and applying it to measurement data.