Monte Carlo Dose Calculation on Deforming Anatomy

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Introduction

For radiation therapy of tumours in abdomen and thorax, accurate dose calculation is challenging because of organ motion. Such motion includes changes in size, shape and position of the organ, and can be caused by patient motion, organ activity (breathing, digestion) and by changes in the organ itself (tumour growth, shrinking). When calculating radiation dose for moving targets, the resulting dose distributions change over time due to the dynamic anatomical situation. Previous work using analytical dose calculation algorithms on different images of a 4D-CT dataset [1] by means of dose warping approaches [2] showed dosimetric errors especially in regions with high dose gradients. An alternative approach is tracking the motion of the corners of each voxel. The aim of this work is the development, implementation and validation of a Monte Carlo (MC) methodology using motion tracking for each voxel in a patient dataset to calculate dose depositions on deformed voxel grids.

Material and Methods

Tracking the motion of the corners of each voxel leads to a deforming voxel grid (changes in voxel shape and density) which preserves correspondence between voxels in the different image volumes of the 4D-CT dataset [3]. Using this approach, we have implemented a dose calculation algorithm for irregularly-shaped voxels within the Swiss Monte Carlo Plan (SMCP) framework [4]. Using computer vision methodology, the deformed voxels are represented as triangular surfaces. MC particle transport and dose deposition are calculated on this modified voxel definition. The validation methodology first establishes the equivalence with existing algorithms for a static scenario and then investigates the aspects of particle path calculation and handling of density changes on three specifically developed computational phantoms. Dose calculation is performed for pencil beams of electrons and photons of 6 and 10 MeV.

Results

Comparison with existing algorithms on a non-deformed voxel grid shows equivalent results. By calculating a dose deposition on a phantom with irregular voxels which are contained in a larger, regular grid, correctness of the particle path calculation is shown. The handling of voxel density changes is investigated on the third phantom and comparison with an analytical dose summation method shows similar results.

Discussion

Based on the validation results, we conclude that our implementation provides correct dose calculation on deformed voxel grids. The representation of organ deformation through deforming voxels avoids interpolation problems and temporal sampling of the deformation vector fields allows for real 4D-MC dose calculation. The combination of the presented algorithms and non-rigid image registration methods enables accurate dose calculation for moving anatomy and could be used for dose planning in advanced radiation therapy treatments.

References

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