Quantitative magnetic resonance imaging for staging and adaptive treatment planning

Venkata Veerendranadh Chebrolu

Non-invasive quantitative magnetic resonance imaging (MRI) holds significant potential for diagnosis, staging, adaptive treatment planning, evaluating treatment response and accelerating drug development for various diseases such as Alzheimer's, cancer, fatty liver, hemochromatosis and multiple sclerosis. The focus of this dissertation is the design and implementation of MRI based auto-segmentation algorithms for real-time applications in adaptive treatment planning for lung cancer radiation therapy and on the development of MRI chemical-shift based fat quantification algorithms for non-invasive staging of non-alcoholic fatty liver disease.

Automated delineation of gross target volume (GTV) and quantitative assessment of changes in volume/position of the GTV during different phases of the breathing cycle were achieved using a novel Morphological Processing and Successive Localization (MPSL) approach. MPSL was shown to successfully segment the regions-of-interest (tumors, lung and body) from four-dimensional (4D) MRI images with both high and low signal-to-noise ratios. Average computational time for achieving automated lung segmentation using MPSL on one phase volume (128×128×128) of 4D Hyperpolarized Helium-3 ($HP^{3}He$) MRI data was 0.5 sec. The average time for achieving automated segmentation of body and lung on one phase volume (128×128×128) of proton-density 4DMRI data was 2 sec.

MRI can quantify liver fat as long as multiple confounding factors such as T_2 * decay and spectral complexity are addressed. Most MRI methods that correct for T_2 * decay assume a common T_2 * ("single-T_2 *") for water and fat. In this dissertation, a modified Gauss-Newton algorithm was developed to estimate the T_2 * for water and fat independently ("dual-T_2 *"). Reduced bias in the quantification of fat was demonstrated with the dual-T_2 * correction for water and fat using phantom experiments. The tradeoff between bias and variance for the different T_2 * correction methods was analyzed using the Cramér-Rao bound analysis.

The automated segmentation achieved in this dissertation is well suited for reducing the time required for contouring the target volume, improving the reproducibility of the segmentation results and for real-time quantitative assessment of target motion. With the computational speed of the order of seconds for achieving automated segmentation, MPSL has significant potential for application in real-time image-guidance for adaptive radiotherapy.