PhD Thesis title: 'Robust optimization of radiation therapy accounting for geometric uncertainty'

Author: Albin Fredriksson
Email: albfre@kth.se
Institution: KTH Royal Institute of Technology, School of Engineering Sciences, Department of Mathematics, Optimization and Systems Theory
Supervisors: Anders Forsgren
Graduation Date: June 5, 2013
Available on line: http://kth.diva-portal.org/smash/get/diva2:621570/FULLTEXT01.pdf

ABSTRACT:
Geometric errors may compromise the quality of radiation therapy treatments. Optimization methods that account for errors can reduce their effects.

This thesis introduces minimax optimization to account for systematic range and setup errors in intensity-modulated proton therapy. The minimax method optimizes the worst case outcome of the errors within a given set. It is applied to three patient cases and shown to yield improved target coverage robustness and healthy structure sparing compared to conventional methods using margins, uniform beam doses, and density override. Information about the uncertainties enables the optimization to counterbalance the effects of errors.

A more general framework for robust treatment planning has also been developed. In this framework, random setup errors of uncertain distribution were considered in addition to the systematic range and setup errors. The framework enabled scaling between expected value and minimax optimization. Experiments on a phantom show that the best and mean case tradeoffs between target coverage and critical structure sparing are similar between the methods of the framework, but that the worst-case tradeoff improves with conservativeness.

Minimax optimization only considers the worst-case errors. When the planning criteria cannot be fulfilled for all errors, this may have an adverse effect on the plan quality. Therefore, a method was introduced that modifies the set of considered errors to maximize the probability of satisfying the planning criteria. For two cases treated with intensity-modulated photon and proton therapy, the method increased the number of satisfied criteria substantially. Grasping for a little less sometimes yields better plans.

Moreover, the theory for multicriteria optimization was extended to incorporate minimax optimization. Minimax optimization is shown to better exploit spatial information than objective-wise worst case optimization, which has previously been used for robust multicriteria optimization.

Finally, two methods for improving treatment plans were introduced: one for deliverable Pareto surface navigation, which improves upon the Pareto set representations of previous methods; and one that minimizes healthy structure doses while constraining the doses of all structures not to deteriorate compared to a reference plan, thereby improving upon plans that have been reached with too weak planning goals.

References to author publications that relate specifically to the dissertation:

1. A Fredriksson, A Forsgren, and B Hårdemark “Minimax optimization for handling range and setup uncertainties in proton therapy,” *Medical Physics* 38(3): 1672-1684, 2011.
2. A Fredriksson, ”A characterization of robust radiation therapy treatment planning methods—from expected value to worst case optimization,” *Medical Physics* 39(8): 5169-5181, 2012.
3. A Fredriksson, A Forsgren, and B Hårdemark, ”Optimizing the scenario positions for robust radiation therapy treatment planning,” Technical report TRITA-MAT-2012-OS5, Department of Mathematics, KTH Royal Institute of Technology, 2012.
4. R Bokrantz and A Fredriksson, ”Controlling robustness and conservativeness in multicriteria intensity-modulated proton therapy optimization under uncertainty,” Technical report TRITA-MAT-2013-OS5, Department of Mathematics, KTH Royal Institute of Technology, 2013.
5. A Fredriksson and R Bokrantz, “Deliverable navigation for multicriteria intensity-modulated radiation therapy planning by combining shared and individual apertures,” Technical report TRITA-MAT-2013-OS4, Department of Mathematics, KTH Royal Institute of Technology, 2013.
6. A Fredriksson, “Automated improvement of radiation therapy treatment plans by optimization under reference dose constraints,” *Physics in Medicine and Biology* 57(23): 7799-7811, 2012.