

A SEQUENTIAL MIXED-INTEGER OPTIMIZATION FRAMEWORK FOR PERMANENT BRACHYTHERAPY IMPLANTS

Warren D'Souza

Under the supervision of Assistant Professor Bruce R. Thomadsen and Professor Robert R. Meyer
at the University of Wisconsin-Madison

Ultrasound-guided transperineal radioactive implantation of the prostate is one of the fastest growing medical procedures in the country. The number of yearly implants is projected to increase to over 100,000 by 2005. Conventional treatment planning for interstitial brachytherapy is generally a trial and error process in which improved treatment plans are generated by iteratively changing via expert judgement the configuration of approximately 100 sources within the target volume in order to achieve a satisfactory dose distribution while minimizing damage to normal tissue. Stochastic algorithms such as simulated annealing and genetic algorithms have been proposed as a means of generating three-dimensional treatment plans for permanent implants. The limitation of these algorithms is their inability to guarantee global optima in a finite amount of time. Additionally, these algorithms have only been tested with regular geometric shapes. Most commonly, the 3-D prostate volume is approximated by an ellipsoid.

In this work a sequential mixed-integer programming (MIP) optimization framework is proposed using the branch-and-bound algorithm as a viable clinical technique of generating treatment plans for permanent implants. This approach uses real anatomical data acquired from the ultrasound scanner and transferred to the treatment planning computer via a frame-grabber. The rapidity of falloff in dose from an interstitial radioactive source necessitates a fine sampling (1 mm) of the dose calculation space. This increases the size and complexity of the problem so that it cannot be solved as a single 3-D problem. To counter this, an iterative sequential approach that optimizes pseudo-independent 2-D ultrasound slices one at a time by considering dose contribution from other slices is described in order to achieve 3-D optimization. The optimization is facilitated by using the General Algebraic Modeling System (GAMS) and the commercial CPLEX mixed-integer programming solver. Treatment plans using this approach can be optimized in 20-45 minutes on a 200 MHz processor. Within this framework, several mixed-integer models have been presented that take into account various aspects of the dose distribution. This approach has been compared with the conventional approach and the results indicate that the basic optimized approach generally performs better. In the event that the critical structure dose distribution from the basic MIP model is unsatisfactory, the use of dose-volume constraints in the optimized approach yields excellent results. While the optimization is based on an initial set of anatomical information acquired weeks before the day of the implant procedure, it does not take into account patient setup uncertainties as well as reproducibility of the ultrasound imaging probe position in the rectum on the day of the implant. A re-optimization technique that utilizes information acquired from the pre-treatment plan is used to re-optimize the treatment plan via the sequential approach in the operating room. Re-optimization times vary from 10-12 minutes on a 200 MHz processor but this time can be significantly reduced on a faster processor. The flexibility of the described optimization framework has allowed the

investigation of dose homogeneity in permanent implant treatment plans along with the evaluation of treatment plans using the concept of equivalent uniform dose.