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Innovative Applications of O.R.

Adaptive and robust radiation therapy optimization for lung cancer

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ABSTRACT

A previous approach to robust intensity-modulated radiation therapy (IMRT) treatment planning for moving tumors in the lung involves solving a single planning problem before the start of treatment and using the resulting solution in all of the subsequent treatment sessions. In this paper, we develop an adaptive robust optimization approach to IMRT treatment planning for lung cancer, where information gathered in prior treatment sessions is used to update the uncertainty set and guide the reoptimization of the treatment for the next session. Such an approach allows for the estimate of the uncertain effect to improve as the treatment goes on and represents a generalization of existing robust optimization and adaptive radiation therapy methodologies. Our method is computationally tractable, as it involves solving a sequence of linear optimization problems. We present computational results for a lung cancer patient case and show that using our adaptive robust method, it is possible to attain an improvement over the traditional robust approach in both tumor coverage and organ sparing simultaneously. We also prove that under certain conditions our adaptive robust method is asymptotically optimal, which provides insight into the performance observed in our computational study. The essence of our method – solving a sequence of single-stage robust optimization problems, with the uncertainty set updated each time – can potentially be applied to other problems that involve multi-stage decisions to be made under uncertainty.

1. Introduction

Lung cancer is the leading cause of death due to cancer in North America, killing an estimated 180,000 people in 2010 (American Cancer Society, 2010; Canadian Cancer Society's Steering Committee, 2010) and accounting for over 25% of all cancer deaths. Lung cancer is often treated using radiation therapy (Toschi, Cappuzzo, & Janne, 2007). Of the different types of radiation therapy, one of the most commonly used in practice for treating cancer in general is intensity-modulated radiation therapy (IMRT) (Mell, Mehrotra, & Mundt, 2005). In an IMRT treatment, the patient is irradiated from multiple beams, each of which is decomposed into a large number of small beamlets. The beamlet intensities can be controlled through the use of a multileaf collimator (MLC) that moves metal leaves in and out of the beam field in order to block certain parts of the beam. By appropriately setting the beamlet intensities, the volume that is irradiated can be made to closely conform to the shape of the target. The basic problem in planning an IMRT treatment is to determine how the beamlet intensities or weights should be set so that the target receives an adequate dose while the healthy tissue receives a minimal dose. This is known as the beamlet weight optimization problem or the fluence map optimization problem. Since the inception of IMRT, much research has focused on modeling and solving this problem as a mathematical program (see Romeijn & Dempsey, 2008 for a comprehensive overview).

In practice, the beamlet weight optimization problem is complicated by the presence of uncertainties, such as those arising from errors in beam positioning and patient placement, internal organ motion during treatment, and changes in organ position between treatment sessions. All of these factors affect the relative position of the tumor with respect to the beams, which in turn affects how much dose is deposited in the tumor and the healthy tissue. For tumors in the lung, the most significant uncertainty arises from breathing motion. During treatment, the patient is constantly breathing, and the tumor moves with the expansion and contraction of the patient's lungs. Furthermore, the patient's breathing pattern during treatment is not known exactly beforehand and can vary from day to day. If a treatment is planned with a specific breathing pattern in mind but a different pattern is realized during treatment, the tumor may end up being underdosed and the quality of the treatment may thus be greatly compromised (Lujan, Balter, & Ten Haken, 2003; Sheng et al., 2006). At the same time, if the treatment is designed to deliver the prescription dose to the tumor

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