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A hybrid approach to beam angle optimization in intensity-modulated radiation therapy

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ABSTRACT

Intensity-Modulated Radiation Therapy is the technique of delivering radiation to cancer patients by using non-uniform radiation fields from selected angles, with the aim of reducing the intensity of the beams that go through critical structures while reaching the dose prescription in the target volume. Two decisions are of fundamental importance: to select the beam angles and to compute the intensity of the beams used to deliver the radiation to the patient. Often, these two decisions are made separately: first, the treatment planners, on the basis of experience and intuition, decide the orientation of the beams and then the intensities of the beams are optimized by using an automated software tool. Automatic beam angle selection (also known as Beam Angle Optimization) is an important problem and is today often based on human experience. In this context, we face the problem of optimizing both the decisions, developing an algorithm which automatically selects the beam angles and computes the beam intensities. We propose a hybrid heuristic method, which combines a simulated annealing procedure with the knowledge of the gradient. Gradient information is used to quickly find a local minimum, while simulated annealing allows to search for global minima. As an integral part of this procedure, the beam intensities are optimized by solving a Linear Programming model. The proposed method presents a main difference from previous works: it does not require to have on input a set of candidate beam angles. Indeed, it dynamically explores angles and the only discretization that is necessary is due to the maximum accuracy that can be achieved by the linear accelerator machine. Experimental results are performed on phantom and real-life case studies, showing the advantages that come from our approach.

1. Introduction

Intensity-Modulated Radiation Therapy (IMRT) consists of delivering radiation to cancer patients by modulating the intensities of the rays (*beams*), which are typically delivered from five to seven different directions (*angles*). The tumor shape is analyzed by the doctor, who outlines the so-called *target volume* and decides the *prescribed dose* that must be delivered to the tumor cells. Each beam is divided into *beamlets*, all having the same direction but which can be assigned different intensities, achieved by sliding the leaves of a multi-leaf collimator in the beam path while the beam is on or by using the step and shoot approach (in which the radiation is off whenever the leaves move). The intensities of the beamlets are optimized with the aim of achieving the prescribed dose requested by the doctor for the target volume while sparing the *organs at risk* (OARs).

This technique is increasingly becoming common in the hospitals and it requires an automated tool which captures many different features, in order to produce good treatment plans. Three can be considered as the main phases for building a planning process (see [11] for a survey on this topic):

- the selection of the number of beams and the directions from which to deliver the radiation
- the selection of the intensities for the beamlets
- the selection of a delivery sequence

The aim of the first phase is to find the best selection of radiation angles. Once the directions have been obtained, the intensities are determined. While the process of optimizing the intensities is generally automated, the selection of the beam angles is often

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