Planning and Navigation for Robotic Radiosurgery

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Abstract

Stereotactic radiosurgery uses focused beams of radiation from multiple spatial directions to ablate brain tumors. To plan the treatment, spatial directions of the beams must be determined in a first step. The set of such beam directions should be chosen such that the dose to surrounding healthy tissue remains minimal, and the tumor absorbs a homogeneous dose throughout its volume. In addition to choosing the beam directions, one must find the weight for each such beam direction, i.e. the activation duration for the beam.

Earlier systems for stereotactic radiosurgery are inherently limited to treat lesions in the brain. The first goal of robotic radiosurgery is to improve conventional stereotactic radiosurgery with respect to accuracy. A second, more important goal is to allow for treating lesions anywhere in the body.

In the first part of this talk, we present planning methods for robotic radiosurgery. Our methods are based on linear programming. Linear programming gives a fast and globally convergent optimisation strategy. It has been proposed as a planning technique in radiation therapy applications by several authors. In robotic radiosurgery, up to 1500 beam directions are used for a single treatment, and the beam can be moved in space with full kinematic flexibility. We show that the general approach of linear programming is practical for robotic radiosurgery, where a very large number of beam directions is used. An implementation of our methods has been incorporated into the Cyberknife robotic radiosurgery system. Several thousand patients with tumors of the brain, the spine and the lung have been treated with the described linear programming based planning system.

The second part of this talk addresses the problem of navigation for robotic radiosurgery. Conventional stereotactic radiosurgery is limited to the brain. Tumors in the chest and the abdomen move during respiration. The ability of conventional radiation therapy systems to compensate for respiratory motion by moving the radiation source is inherently limited. Since safety margins currently used in radiation therapy increase the radiation dose by a very large amount, an accurate tracking method for following the motion of the tumor is of utmost clinical relevance. We investigate methods to compensate for respiratory motion using robotic radiosurgery. Thus, the therapeutic beam is moved by a robotic arm, and follows the moving target tumor. To determine the precise position of the moving target we combine infrared tracking with synchronized X-ray imaging. Infrared emitters are used to record the motion of the patient's skin surface. A stereo X-ray imaging system provides information about the location of internal markers. During an initialisation phase (prior to treatment), the correlation between the motions observed by the two sensors (X-ray imaging and infrared tracking) is computed. This model is also continuously updated during treatment to compensate for other, non-respiratory motion. Experiments and clinical trials suggest that robot-based methods can substantially reduce the safety margins currently needed in radiation therapy. Our correlation

based navigation method has since been incorporated into the Cyberknife robotic radiosurgery system. Our new module is in routine clinical use at a growing number of sites worldwide.

Figure 1: Robotic radiosurgery system (Osaka University Hospital). Stereo X-ray imaging system, infrared position tracking system.

References

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