TU-D-BRA-05

Incorporating Organ Deformation/patient Setup Into Inverse Planning (I): Algorithm and Implementation

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The dose distribution in an organ of interest cannot be correctly reconstructed without knowledge of internal organ motion/deformation, setup inaccuracies, and temporal density variations in the patient, thereby limiting the capability of conventional inverse planning optimization. We have developed an inverse planning system which constructs the optimal dose distribution by considering organ/patient temporal geometric variation, as determined from multiple CT and portal image feedback. This inverse planning system consists of the following components: (1) organ subvolume registration and occupancy frequency reconstruction, which accounts for both organ motion/deformation and setup error, (2) fraction and cumulative dose distribution reconstruction in the organ, which accounts for both the temporal position of organ subvolumes and temporal density of the patient, and (3) objective function and constraint evaluation, which incorporates the temporal information of organ dose distribution.

The inverse planning system was tested on prostate cancer patients, each with multiple CT images (15~18 CTs) and daily portal images acquired during the treatment course. The optimal treatment plan produces a heterogeneous dose in regions adjacent to target/critical normal structure boundaries to spare normal tissue and compensate for target dose loss. The gradient of the dose distribution in this region depends on the occupancy density of both the target and normal organs. The plan demonstrates significant improvement of both tumor control and normal tissue complication probability. In summary, incorporation of treatment-imaging feedback into inverse planning shows great potential for treatment optimization and dose escalation.

TU-D-BRA-06

Fusion-Aligned Reprojection: A Method to Compensate for Limited-Data Radiotherapy Images

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In order to account for patient anatomy changes, it is particularly helpful for a radiotherapy system to feature on-board imaging. However, many such systems suffer from limited-data, typically limited field-of-view (LFOV) due to hardware limitations or the desire to reduce patient dose. Such LFOV images can have severe bowl artifacts that affect their utility. Moreover, the lack of peripheral data means that dose calculations using the fraction images do not properly account for attenuation and scatter.

The method of fusion-aligned reprojection (FAR) largely resolves these issues. It is possible to use certain automatic fusion techniques to align the incomplete-data image with a reference image, where the reference image was acquired on a scanner with a broader FOV. Once the images are aligned, it is possible to reproject the planning image into a sinogram, and use that sinogram data to estimate the missing data from the fraction image sinograms. An improved FAR treatment image can then be reconstructed.

The benefit of the FAR images is that they closely approximate the complete-data images that ideally would have been collected. Anatomy changes within the LFOV scan region are detected, and un-obscured by bowl artifacts. Beyond the LFOV scan region, the patient is imaged sufficiently well to make dose reconstruction possible.

Ultimately, FAR improves one's ability to monitor patient changes during image-guided radiotherapy, for LFOV and other limited-data cases. The image improvements are useful both to visualizing changes in the patient's anatomy, and calculating the dose delivered to the patient in the treatment position.

TU-D-BRA-07

A Fluence Adjustment Strategy For Adaptation of Dose Distributions

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The numerous conflicting demands for optimization of a fluence pattern for a radiotherapy delivery can sometimes lead to sub-optimal areas in the resultant dose distribution. For example, after the optimization process, there may be a small number of target voxels with dose values that are below a desired minimum. Likewise, there may be some voxels in a region-at-risk (RAR) that are overdosed. In this work, we discuss and present results from a fluence adjustment strategy (FAS) that aims to adjust such voxels without performing re-optimization.

FAS starts by identifying the RAR or target voxels that are outside of a predefined dose threshold. The required change in dose is translated into a modification in TERMA for each voxel. This TERMA change is divided among the pencil beams that contribute to the voxel. The requested change in TERMA for each pencil beam is converted into an adjustment in their incident energy fluence. Dose is then recomputed. The entire process requires under five seconds, thus FAS can be very useful for interactively investigating the possible delivery trade-offs.

Simulations were performed for a patient with a nasopharyngeal tumor. Targets included a primary target and a large regional field. Sensitive structures were the parotid glands and the spinal cord. Analysis of the optimization results found that 26 voxels in the regional field, and 29 voxels in the parotids were outside of their respective limits. Applying FAS corrected all erroneous voxels without major degradation of the DVH.

TU-D-BRA-08

An Automatic 3D Set-Up Error Estimator for Radiotherapy Using Mutual Information

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We have investigated a fully automatic set-up error estimation method that aligns DRRs (Digitally Reconstructed Radiographs) from a 3D planning CT image onto 2D radiographs that are acquired in a treatment room. We have chosen a MI (Mutual Information)-based image registration method to overcome the gray scale differences between the DRRs and the radiographs. The MI-based estimator is fully automatic since it is based on the image intensity values without segmentation. To test this method, an anthropomorphic chest phantom was scanned at 1 mm slice thickness. The phantom was then positioned on a linear accelerator with controlled offsets, and a series of radiographs were acquired using an active matrix flat panel imager. MI-based alignment was performed, as well as a verification of the controlled offsets through alignment of multiple fiducial markers placed at the periphery of the imaged fields. The fiducials were not present in the image regions used for MI-based registration. The average differences between the proposed method and the fiducial marker-based verification were smaller than 1mm for translations and 0.8 degree for rotations. The empirical standard deviations of estimates from the proposed method were smaller than 0.3 mm and 0.07 degree for the translation parameters and the rotation parameters, respectively.

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Cone-Beam CT with a Flat-Panel Imager: Dosimetric Considerations

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Kilovoltage (kV) cone-beam computed tomography (CT) based upon flat-panel imager (FPI) technology offers fully volumetric imaging of patient anatomy in an adaptable form. This imaging technology can be readily adapted to conventional medical treatment devices such as an isocentric radiation therapy unit or an isocentric C-arm for volumetric image-guided therapy. Investigations of cone-beam CT imaging performance demonstrate