Incorporating Prior Knowledge into IMRT Beam Orientation Optimization

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Fixed gantry IMRT

9-field head and neck Treatment
Things need to be optimized

- Number and incident directions of beams
- Beam modality
- Beamlet weights
Beam orientation optimization

• Clinically, beam orientations are selected empirically.

• Excessive computational time is required for full beam orientation optimization.

\[ F = \sum_{n=1}^{N} \sigma [D_c(n) - D_0(n)]^2 \]

\[ D_c(n) \text{ --- function of beamlet weights, beam orientation.} \]
Initial set of beam orientations, beam profile optimization

Randomly vary beam orientations to obtain a trial set

Beam profile optimization and dose calculation

Accept / Reject the trial beam configuration

Optimized solution

Reduce temperature

No

Temperature low enough?

Yes
Beam orientation optimization

• More intelligent and less computationally intensive methods of beam orientation selection are needed.
Beam’s-Eye-View Dosemetrics (BEVD) for IMRT Beam Selection

- BEV volumetrics in conventional radiotherapy.

Only prior geometric information of the system is used.
• We extend the original BEV to IMRT with consideration of

1. prior geometric and dosimetric information of the system, and

2. beam intensity modulation.
Beam’s-Eye-View Dosemetrics (BEVD) for IMRT Beam Selection

- BEVD for IMRT.


Both prior geometric & dosimetric knowledge of the system are used.
BEVD

- For each organ at risk (OAR), assign a tolerance dose.
- For every possible beam orientation, calculate single beam dose distribution that can be achieved without exceeding the tolerances of OARs and normal tissue.
BEVD Calculation

- Divide a beam into bixel map.
- Introduce an empirical score function to evaluate the goodness of each beamlet/beam.
- Obtain BEVD score for each incident beam direction.
- Select peaks of the BEVD score function, taking into account the principle of maximum beam separation.
- Perform beam intensity profile optimization.
BEVD ranking for an IMRT treatment of paraspinal tumor (Coplanar beam)

- Five beams with high BEVD score.
- Selected gantry angles: 225°, 175°, 140°, 85°, 260°
BEVD ranking for an IMRT treatment of paraspinal tumor (Non-coplanar beam)

- Selected beams (gantry, table):
  (180,20) (180,-20) (230,20) (230,-20) (130,0)
Liver
Kidney
GTV

PBEV Selected Beam Orientations

Beams (gantry,table): (180,20), (180,-20) (230,20), (230,-20) (10,0)

Equiangular Beam Orientations

Gantry angles: 40, 110, 180, 255, 325

180°
Beam orientation selection

225° (15MV), 180° (6MV), 140° (6MV), 85° (15MV), 260° (15MV)
Results

- Nasopharyngeal cancer
  - BEVD method applied to the selection of coplanar beams
Dose distribution of two-stage optimization
Results III

• Model cases
  – 2D.
  – Simplified dose model.
  – beam orientations are selected using BEVD method.
Dose distribution of five IMRT beams selected with BEVD
Dose distribution of five IMRT beams selected with BEVD

Equally spaced five beams
BEVD-guided beam optimization for IMRT

- In IMRT, the quality of a beam direction can be measured by a BEVD score.

- Select beams with the highest BEVD score, taking into account the angular separation of the beams.

- BEVD is a computer assisting tool, not an automated tool. It can, however, be used as *a priori* knowledge of the system to improve the beam orientation calculation.
BEVD-Guided Beam Orientation Optimization

A. Simulated annealing (SA) optimization

1. Initial set of beam orientations
2. Vary a gantry angle randomly
3. Beam intensity profile optimization
4. Accept or reject the trial beam configuration based on SA probability

Optimized plan

B. BEVD-guided simulated annealing optimization

1. Initial set of beam orientations
2. Vary a gantry angle randomly
3. Calculate probability of acceptance based on BEVD score
4. Accept or reject trial beam configuration

Beam intensity profile optimization

Accept or reject the trial beam configuration based on SA probability

Optimized plan

Temperature low enough?

Reduce temperature

No

Yes
• Number of iterations is reduced by a factor of 10.
• BEVD-guided optimization improves convergence behavior of the system.
• Speed depends weakly on the cooling schedule.
• Results are consistent with BEVD ranking.
• Formalism is applicable for functional imaging-guided IMRT.
Conclusions

- A practical BEVD tool has been developed for beam orientation selection in IMRT.
- The technique allows one to select beam orientations without paying the excessive computing overhead of computer beam orientation optimization.
- The approach has considerable potential for simplifying the IMRT planning process to maximize the potential of IMRT.
Conclusions

• Incorporation of prior knowledge significantly improves the calculation: speed and convergence.
• The methodology also applies to the optimization of other system parameters, like beamlet weights.
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