Using a research real-time control interface to go beyond dynamic MLC tracking

Dr. Simeon Nill

Joint Department of Physics at The Institute of Cancer Research and the Royal Marsden NHS Foundation Trust
London

Disclaimer

- ICR/RMH has a research agreement with Elekta on MLC tracking
- ICR/RMH is a member of the Elekta Atlantic Research Consortium
Overview

- Introduction to Elekta linacs
  - Brief overview of the control system
  - Options to deliver non-clinical research plans

- Introduction to MLC tracking
  - Real time tracking interface
  - Evaluation of system latency
  - Multi-institutional tracking comparison

- Online dose reconstruction
  - Framework for online dose reconstruction
  - First results for simulated prostate and lung tracking

- Summary / Outlook

Elekta Digital Linac

- Fully digital control system
- 160 leaf Agility MLC
- 5 photon energies (3xFF/ 2xFFF)
- 5 electron energies
- Hexapod (6D couch)

Possibility to dynamically change the MLC, Diaphragm, Gantry and Collimator movement during irradiation
Elekta Digital Control System

From: Elekta corrective maintenance manual

Elekta Linac Interfaces

Integrity Dicom conformance statement: https://www.elekta.com/software-solutions/dicom-conformance-statements.html
### Elekta Linac Dicom Interface

- Generate Dicom plan using your research software
- Ensure conformance to Elekta Dicom statement
- Send to linac
- Deliver as stored beams within service mode
- Not limited by R&V restrictions

Integrity Dicom conformance statement: [https://www.elekta.com/software-solutions/dicom-conformance-statements.html](https://www.elekta.com/software-solutions/dicom-conformance-statements.html)

### Dicom Example

VMAT FFF plan
- Dynamic change of collimator angle (0->5->0)
- Change of energy during arc delivery (6->10->6)
Elekta Linac Research Interfaces

- Research agreement with Elekta required
- Provides a tailored customised handbag
- No need for a dedicated research linac

Clinical to Research to Clinical

- Research supported linacs may switch between configurations and software builds and back again with minimal effort
- **Entire** machine configuration, calibration and identity is contained on a removable hard disk

Courtesy of Elekta
MLC Tracking Handbag

MLC Tracking: Overview

- Detect target motion
- Compensate for system latency
- Calculate / adapt optimal beam parameters
Experimental set-up: Maple

Results: Summary

<table>
<thead>
<tr>
<th>Type</th>
<th>Motion*</th>
<th>Effective latency [ms]**</th>
<th>RMSE [mm]**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf-only</td>
<td>LR</td>
<td>56-61</td>
<td>0.6-1.6</td>
</tr>
<tr>
<td>Jaw+leaf</td>
<td>SI</td>
<td>71-76</td>
<td>0.7-1.5</td>
</tr>
<tr>
<td>DLG+leaf</td>
<td>LR</td>
<td>57-73</td>
<td>1.9-3.3</td>
</tr>
</tbody>
</table>

*assuming gantry & collimator angles at 0°

**depending on target update frequency and maximum target speed

Cross-platform real-time adaptive radiotherapy performance characterization

Slide courtesy of Emma Colvill

Lung and Prostate Cases

Median volume Hansen Acta Onc 2014

Median volume Ng IJROBP 2012

Slide courtesy of Emma Colvill
Patient-Measured Motion Files

Lung

- Typical Lung
- Predominantly Left Right Lung
- High Frequency Lung
- Baseline shift Lung

Cyberknife-measured lung tumor motion
Suh PMB 2008

Prostate

- Stable Prostate
- Continuous Drift Prostate
- High Frequency Prostate
- Erratic Prostate

Calypso-measured prostate motion
Langen IJROBP 2008

Slide courtesy of Emma Colvill

Experimental set-up: Agility MLC
Adaptation systems 2%/2mm


Beyond dynamic MLC tracking: Online dose reconstruction

- Applications not limited to MLC tracking
- Designed with MRI-Linac in mind
Research RT software platform at ICR

DynaTrack
Tracking / delivery

µKonRad
Fast dose calculation / plan optimization based on dose influence data

DynaPlan
Treatment planning software

qMC
Fast Monte Carlo dose calculation engine

Machine parameters

Plan data

Plan geometry

Patient geometry

Deformation fields

Dose influence data

Respiratory phase data

Plan data / plan data

Dose data / plan data

Plan data

Plan data

Commercial TPS
Interface to scripting API

Plan geometry

Deformation fields

Dose influence data

Simulated Patient Case

Planning CT
- Phase-binned 4DCT
- 10 phases

Planning strategies
- Conventional ITV + 5mm
- Motion Target Volume (MTV) + 5mm
- RTOG 1021 (3-Fx, 9-beam)
- 18 Gy to 95% of PTV per fraction
ITV vs MTV concept

Overlay of all GTVs

Overlay of all rigidly aligned GTVs

Unified maximum = Internal Target Volume (ITV)

Unified maximum = Motion Target Volume (MTV)

Results

Computation time

- Dose calculation time: ≤ 10 ms (voxel size: 2x2x2 mm³)
- EMT dose accumulation: ≤ 30 ms
- Memory throughput: ≤ 90 GB/sec on single workstation computer

- Pre-calculated dose influence data with 5x5 mm² beamlet resolution for each individual 4DCT phase (Monte Carlo algorithm)
- Dose deformation through Energy-Mass Transfer
- Single workstation with 2x Intel Xeon CPU E5-2697 v3
Prostate case: Online dose accumulation

CTV-to-PTV margins:
- 1, 3 & 5 mm isotropic
- 3 mm posterior + 5 mm else

RTOG 0938: 36.25 Gy in 5 fx
7-beam IMRT
CTV: 55 cm³


Prostate motion patterns

Calypso-measured prostate motion
Langen et al. (2008) IJROBP

Rotations about LR (centre of prostate)
-20° → 20°
(1° increments)

Motion simulated as VOI shift
Results: translations (tracked) + rotations

- Impact of rotations can be significant for smaller margins


Next step: Online replanning

Online Inter-Beam Replanning Based On Real-Time Dose Reconstruction

Corijn Kamerling TH-CD-202-12
Today 11:50AM Room: 202
Summary:

Elekta linacs provide different options to develop dynamic delivery techniques

MLC Tracking with Agility MLC shows excellent results for motion compensation

Online dose reconstruction is a powerful tool for online plan QA and online plan adaption

[Acknowledgements]
Uwe Oelfke  
Martin Fast

Peter Ziegenhein  
Corijn Kamerling  
Martin Menten

Adrian Smith  
Emma Colvill

NIHR Biomedical Research Centre for Cancer

Cancer Research UK Programme Grant C33589/A19727

Medical Research Council (MRC)

ICR/RMH is a member of the Elekta Atlantic Research Consortium