Notes

- 3 timescale slide from Jaffray, intrafraction, online, interfraction - give sites
- Add physiological targeting
- Break up into two problems:
  - Knowledge or estimation of anatomy
  - Replanning or redirecting to optimize delivery to anatomy given constraints of delivered dose, mechanical etc.
  - Give formalism and include correction for errors immediate or distributed

Abstract

Educational objective

... finally Dr. Keall will discuss the latest advances in imaging, adaptation, and novel treatment delivery techniques in image-guided radiation therapy.
IGS trends

OR 2020

- Expected increase in workload by up to 47%
- ... equipment in today’s OR is inefficiently used
- ... lack of interchangeable equipment
- ... limited communication between treatment team

OR 2020

- Trends
  - ↑ information flow and system integration
  - ↑ real-time systems
  - ↑ telecollaboration
  - Smaller, cheaper robots with better haptic feedback
  - Integrated view of navigation and physiologic information

OR 2020

- Trends
  - Improved in-room imaging: 2D→3D, molecular imaging
  - Building atlases, real-time deformable registration and patient model building
  - Bioinformatics and decision support tools
IGS vs. IGRT: differences

<table>
<thead>
<tr>
<th>Image guided surgery</th>
<th>Image guided radiotherapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Treatment team in room</td>
<td>• No others in room</td>
</tr>
<tr>
<td>– Space and dose issues</td>
<td>• ‘Fixed’ imaging systems</td>
</tr>
<tr>
<td>• Mobile imaging systems</td>
<td>– Increased stability</td>
</tr>
<tr>
<td>– Collision, space, operation</td>
<td>• Non-invasive (except brachy/fiducials)</td>
</tr>
<tr>
<td>• Invasive: anatomic changes</td>
<td>• No anesthesia (generally)</td>
</tr>
<tr>
<td>• Anesthesia</td>
<td>• Lower radiation dose concern</td>
</tr>
<tr>
<td>– Patient room impact</td>
<td>• Multiple treatments</td>
</tr>
<tr>
<td>• High radiation dose concern</td>
<td></td>
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<tr>
<td>• Single treatment</td>
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</tbody>
</table>

IGS vs. IGRT: similarities

1. Patient: common anatomic and physiologic variations
2. Require registration of patient with imaging and therapy systems
3. Can synchronously use multiple image streams to estimate patient state
4. Desire real-time information about anatomic/physiologic state and adapt treatment plan in real time
5. Workflow, cost and safety very important
IGS vs. IGRT: similarities

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EM-guided IGRT/bronchoscopy
IGS vs. IGRT: similarities

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kV/MV/Optical combinations

No IGRT

Optical alone
IGS vs. IGRT: similarities

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Volumetric anatomic guidance

- SSFP/trueFISP
- Acquisition time per volume = 1 sec
- Voxel dimensions in mm: 2.3 x 4.7 x 5 (x, y and z).
- No. of Slices: 8

Courtesy Amit Sawant
Thoracic IGRT 2020
Example:

**kV alone real-time IGRT**

- **kV alone guidance for IMAT**
  - kV option on new C-arm linear accelerators
  - Not controlled in real-time
  - Not using prior data
  - But potentially could…

Estimation of target trajectory

- **Known:**
  - 2D target projections

- **Unknown:**
  - 3D trajectory

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Poulsen PMB & IJROBP 2008, 2009
Estimation of target trajectory

Known:
- Target is lying on ray line between 1) X-ray focus point \( f \) and 2) Projection point \( p_i \)

Gaussian target PDF

Assume:
- 3D Gaussian PDF

\[ g(r) = \frac{1}{(2\pi)^{3/2}|\Sigma|^{1/2}} \exp\left(-\frac{1}{2}(r-f)^T \Sigma^{-1} (r-f)\right) \]

Nine unknowns \( \hat{\theta} \) and \( \hat{\Sigma} \)

\[ \Rightarrow \text{Estimate by MLE} \]

1D Gaussian PDF along each ray line

3D Gaussian \( \Rightarrow \) 1D Gaussian along ray line \( L \):

\[ \hat{g}_{1D}(x) = K \times e^{-\frac{(x-x_0)^2}{2\sigma^2}} \]

- \( K = \frac{\sqrt{\text{det} \Sigma}}{(2\pi)^3} \)
- \( \mu = \frac{(x_0 - \hat{\mu})^T \hat{\Sigma}^{-1} (x_0 - \hat{\mu})}{\sigma^2} \)
- \( \sigma = \frac{1}{\sqrt{\text{det} \hat{\Sigma}}} \)

Unit vector \( \hat{\phi} = \frac{\hat{f} - \hat{p}}{|\hat{f} - \hat{p}|} \)

Estimation of 3D PDF by MLE

Projection probability:

\[ P_{\text{prob}} = \sum_{i=1}^{n} P_i \]

MLE objective function:

\[ F_{\text{MLE}} = -\log \prod_i P_i(\theta) \]

Minimize \( F_{\text{MLE}} \)

\[ 3D \text{ Gaussian PDF} \]
Estimation of target trajectory from 3D PDF

Estimate:
- the target position along each ray line as its expectation value

MLE optimized PDF

\[ \hat{\mu} = \frac{\int f(x) \delta(x-\mu) \, dx}{\int f(x) \, dx} \]

RESULT:
Target Trajectory

Rotating view acquisition with markers

Foulsen PMB & IJROBP 2008
Rotating view acquisition with markers

Summary of 12 experiments

Integrated DMLC tracking system accuracy
Summary

- There are many similarities- and differences- between IGS and IGRT
- Growing interaction between fields
- Trends towards
  - Automation
  - Minimally invasive
  - Combining multiple image streams
  - Use of prior information
  - Real-time anatomic estimation and correction
  - Functional targeting

OR 2020

- The operating room of the future will require integrated systems and technological developments to improve surgical workflow and provide better patient care.

IGRT 2020

- The radiosurgery room of the future will require integrated systems and technological developments to improve radiosurgery workflow and provide better patient care.