Dynamic x-ray beam positioning for low-dose CT

Computer Integrated Surgery II
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Mentor: J. Web Stayman Ph.D.
• CT has vast diagnostic utility in medicine
• # procedures growing >10% per annum
• 15% of all radiological exams, but 50% of effective dose
• Publicly recognized need for dose reduction methods
• “One size fits all”
• Fluence field modulation (FFM) strategies promise dose reduction without loss of image quality
Beers-Lambert Law

\[ I = I_0 e^{-\mu \ell} \]
Background

Bowtie filters
- Shape via variable thickness
- Variety of possible materials
- Reduce dynamic range of data
- Help to homogenize noise

Multiple aperture device (MAD)
- Binary filter (0% or 100% pass)
- Spectrally neutral
- Compact design (few mm of tungsten)
- Large scale shaping with small actuation
Background
Need & Significance

- Patient often miscentered within bore
  - Average 3cm below center
  - 25.8% dose increase
  - up to 22% noise increase
- Dose and image quality consequences
- Requires repositioning and retaking images
- Impractical in emergency medicine
- Bowtie filters often simply removed -> increased dose

Toth et. al. Med. Phys. 2007
Habibzadeh et. al. IFMBE Proceedings, 2010
To achieve dynamic x-ray beam positioning in low-dose CT acquisitions and quantitative performance assessment for arbitrary patient positioning in emergency medicine applications
Technical Approach

2D Scout Scans → Compute filter trajectory → Projection data with beam filter actuation → Reconstruction → Performance Assessment
• Object assume to be ellipse
• Parameter vector $\vec{x}$: ellipse center, width, height, $\mu$
• $\arg\min ||P\vec{x} - g||^2$
• $P$ is forward projection operator, $g$ is the data
• Filter trajectory computed via optimization on bowtie translation to obtain flat fluence at detector at each angle
Minimum

• Constructed test bench setup & control software
• Working dose assessment and image reconstruction frameworks
• Calibration of object position in FOV using multiple view low-dose scans
• Computed beam filter trajectory for 360° acquisition

Expected

• Simulated image reconstructions on digital phantoms
• Performance assessment on phantom acquisitions using bowtie filters

Maximum

• Artifact correction for MAD imaging (*potential pitfall*)
• Performance assessment on phantom acquisitions using a single MAD
• Dependencies for simulations and image reconstruction
  • Access to GPU workstation (Met)
  • Access to CUDA tools (Met)
  • Digital phantom data (Met)

• Dependencies for physical phantoms
  • Access to prototyping facility (Met)
  • Access to beam filters (Met)
  • Access to CBCT test bench (Met)

• Advising dependencies
  • Mentor availability (Met)
    • Weekly meetings on Friday 2-3pm
<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
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<tbody>
<tr>
<td>3/1/17</td>
<td>Finish literature review</td>
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<tr>
<td>3/3/17</td>
<td>Finish test bench setup</td>
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<tr>
<td>3/10/17</td>
<td>Working dose assessment and image reconstruction frameworks</td>
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<tr>
<td>3/17/17</td>
<td>Working calibration of patient position</td>
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<td>3/17/17</td>
<td>Computed beam filter trajectories for CT acquisitions (<strong>minimum</strong>)</td>
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<tr>
<td>3/31/17</td>
<td>Simulated image reconstructions using digital phantoms</td>
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<td>4/7/17</td>
<td>Complete phantom acquisitions with bowtie filters (<strong>expected</strong>)</td>
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<td>4/21/17</td>
<td>Working MAD artifact correction</td>
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<td>4/28/17</td>
<td>Complete phantom acquisitions with MAD filters (<strong>maximum</strong>)</td>
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<td>5/5/17</td>
<td>Final report</td>
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## Management Plan

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<thead>
<tr>
<th>Activity</th>
<th>Andrew</th>
<th>Will</th>
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<tbody>
<tr>
<td>Image reconstructions</td>
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<td>Scout scans &amp; filter trajectories</td>
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<td>Phantom acquisitions</td>
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<td>Performance assessment protocol</td>
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<td>Test bench setup &amp; control software</td>
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<td>MATLAB functions for each step of technical approach</td>
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<td>Version Control using Git</td>
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<tr>
<td>Weekly Mentor Meetings</td>
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<td>10+ hours at JHMI per week</td>
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