Enhancement of US-CT registration accuracy for spinal surgery

Eduardo A. Gonzalez

Mentor: Muyinatu Bell

Project proposal – Advanced Computer-Integrated Surgery (601.656)

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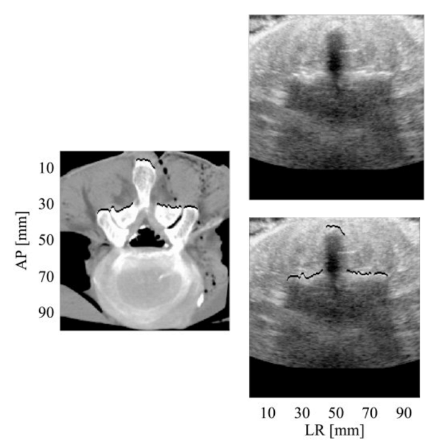
Background / Challenge

1. Preoperative plan → ? → Intraoperative situation

2. **Ultrasound** Imaging (US)
   - ✓ **Good intraoperative** imaging technique : **low cost** and simplicity of use
   - ✗ **Poor signal-to-noise ratio** (SNR)
     Reflection from tissues with high acoustic impedance
     Deformed imaged due to physician pressure

3. **US/CT registration**
   - **Intensity-based** registration (MRI applied in brain/ CT applied in kidney)
   - Feature extraction (Sobel **gradient**)
   - **Multi-component similarity** measurement



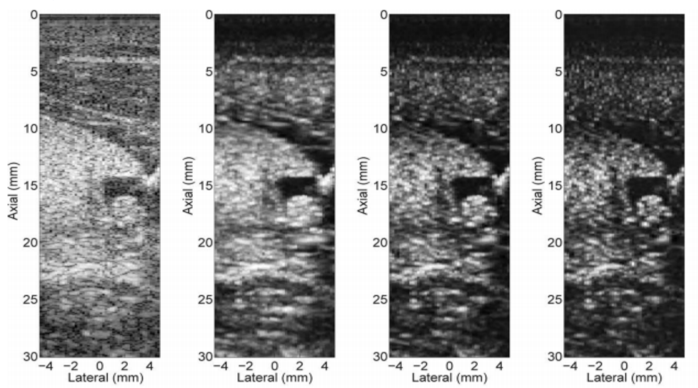
Brendel et. al, 2002

Proposed solution: Enhance edges

Conventional Ultrasound

Short Lag Spatial Coherence (SLSC)

Thyroid



Adjusted Constrast

Lediju et. al, 2011

Objective

Explore methods to improve accuracy of US-CT image registration through improved US image resolution

Specific Aims:

1. Enhance bony features in US images to improve resolution for automatic registration
2. Develop a robust beamformer to improve the appearance of bone in US images
3. Explore registration improvement when considering additional information from Photoacoustic (PA) images

Technical Approach

PULSE
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Conventional beamforming: Delay and Sum (DAS)

$$\tau(x_1, x, z) = \left(z + \sqrt{z^2 + (x - x_1)^2}\right)/c,$$

$$s(x, z) = \int_{x-a}^{x+a} RF\left(x_1, \tau(x_1, x, z)\right) dx_1.$$

Advanced beamforming: Short lag spatial coherence (SLSC)

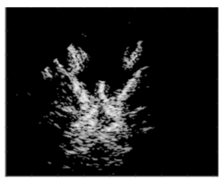
$$\hat{R}(m) = \frac{1}{N-m}\sum_{i=1}^{N-m}\frac{\sum_{n=n_1}^{n_2} s_i(n)s_{i+m}(n)}{\sqrt{\sum_{n=n_1}^{n_2} s_i^2(n)\sum_{n=n_1}^{n_2} s_{i+m}^2(n)}}$$

$$R_{\rm sl} = \int_1^M \hat{R}(m)\mathrm{d}m \approx \sum_{m=1}^{M}\hat{R}(m)$$

Feature extraction → **Fuzzy C-means segmentation** →
- **Bone** (desired region)
- **Water** (and undesired reflections)
- **Regions outside** imaging boundaries (for phased arrays)

US image

=



Bone (desired region)

+

Water

+

Regions outside

Technical Approach

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Control the **quality** of US image →
- **Dynamic range** of log compression for **DAS**
- **Cumulative summed lag** value for **SLSC**
- **Regularization parameter** for **robust SLSC**

Registration → **Mattes Mutual Information**

Evaluation → **Mean Square Error (MSE)**

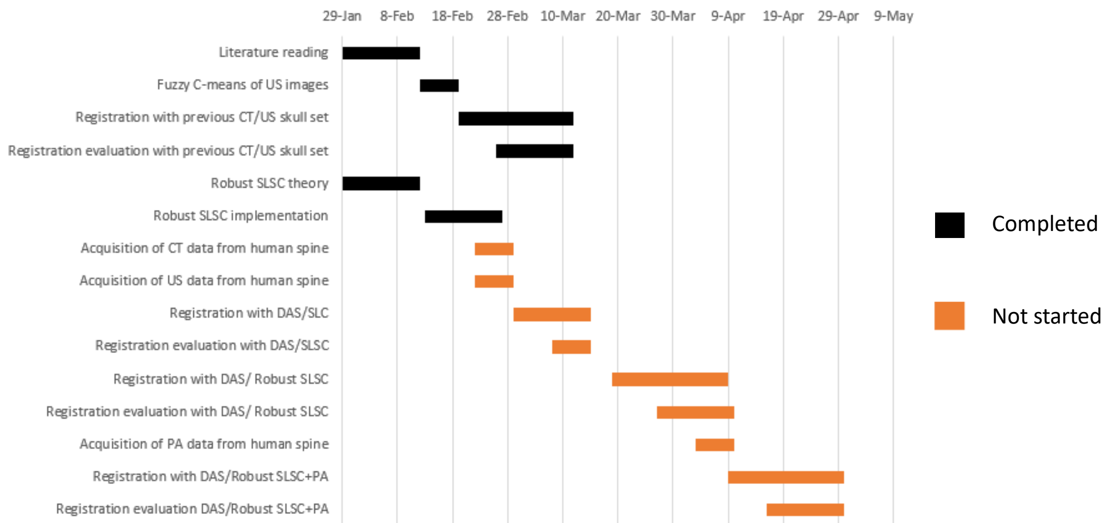
Deliverables

Minimum (March 8th)	Expected (April 5th)	Maximum (April 19th)
Images: Automatic registration of SLSC/DAS US images to CT images of spine specimen (hard tissue)	**Images:** add robust SLSC to registration framework	**Images**: add PA to registration framework
Equation: Propose algorithm for a robust SLSC technique		
Graph: Show registration performance when varying quality parameters for SLSC and DAS	**Graph:** add quality parameters for robust SLSC (e.g., kernel size and regularization parameters)	**Graph**: compare CT-PA and CT-US registration performance using PA images

Dependencies

- Acquisition of CT images of human spine
  - Scheduling use of CT machine options:
    - Medical campus (Professor Siewerdsen and his postdoc)
    - Homewood campus (Michelle Graham, CAMP Lab Members)
  - Cannot acquire CT myself because did not take the CT training course
- Calibration phantom to validate registration methods (ground truth)
- Availability of the spine sample
  - Coordinate with Blackberrie Eddins

Work plan



Bibliography

- Roche et al. **"Rigid Registration of 3-D Ultrasound With MR Images: A New Approach Combining Intensity and Gradient Information"**, 2001
- Wein et al. **"Simulation and Fully Automatic Multimodal Registration of Medical Ultrasound"**, 2007
- Wein et al. **"Automatic CT-ultrasound registration for diagnostic imaging and image-guided intervention"**, 2008
- Bell et al. "**Short-Lag Spatial Coherence of Backscattered Echoes: Imaging Characteristics"**, 2011
- Wong et al. "**Real-time ultrasound-guided spinal anesthesia using the SonixGPS needle tracking system: a case report**", 2013
- Shubert et al. "**A novel drill design for photoacoustic guided surgeries"**, 2017