Autonomous Placement of Ultrasound Probe for Spinal Surgeries

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Project Goals

• Autonomously place an ultrasound probe onto a patient’s spine via robot
• Use this probe placement to intraoperatively track a needle inside vertebrae using photoacoustic imaging (and adjust probe placement using this feedback)
The Plan

1. Calibrate and Register a Kinect v2
2. Develop Human Outline Segmentation
3. Develop IK for robot; demonstrate probe placement
4. Explore Viability of Photoacoustic Imaging in vertebrae
5. Perform Visual Servoing to Track a needle in vertebrae
6. Demonstrate entire system (Placement and Tracking)
Step 1 - Kinect v2

- Kinect v2 will be mounted on top of the sawyer robot
- Camera intrinsic parameters will be determined using camera calibration
- Point cloud - Point cloud registration will then be performed between kinect and robot base
- This will allow the robot to know the 3-D location of any pixel in the kinect depth image
Step 2 - Human Outline Segmentation

- Using kinect depth image, threshold out depth values lower than the depth values of the table the ‘patient’ is laying on.
- Will then perform body part detection on the resulting image as demonstrated by Plagemann et al in “Real-time Identification and Localization of Body Parts from Depth Images”.
Step 3 - IK and Probe Placement

- Use segmented spine location as destination for Sawyer robot’s built in IK routine
- Use force control to ensure a gentle touchdown of the ultrasound probe over the spine
Step 4 - Explore PAI in Spine

- Obtain spine / vertebrae sample
- Test to see if possible to get a signal through vertebrae
- Compare bare fiber signal to fiber-in-needle signal
Step 5 - Visual Servoing

- Use previously developed needle tip segmentation algorithm to segment needle tip location from PA image, and display it overlayed on a ultrasound B-Mode image
- Use segmented coordinates of needle tip to move the ultrasound probe such that it remains centered over the needle tip
Step 6 - Demonstrate Entire System

• On either a cadaver or a human-shaped spinal phantom, perform in sequence:
  – Initial placement of the probe onto the patient’s spine
  – Track the movement of the PA imaged bone biopsy
The plan

Sawyer

Kinect v2

Sawyer Controller

Ultrasound Scanner

US Probe

Spine

Biopsy Needle

Laser Source

PULSE

PHOTOACOUSTIC & ULTRASONIC SYSTEMS ENGINEERING LAB
Background – Spinal Fusion
Background – Spinal Fusion

- 150,000 per year
- Bone grafts taken from iliac crest or tibia
- Used to ‘fuse’ two vertebrae together
- Repeated X-rays are taken to verify pedicle screw placement
Background - Vertebroplasty

750,000 Vertebral Fractures per year!

Fracture

Cement Injection
Background - Kyphoplasty

1. Balloon inserted into fractured vertebra
2. Balloon inflated inside damaged vertebra
3. Special material injected into fractured vertebra
4. Special material hardens, stabilizing vertebra
Deliverables

Maximum

- Robot Control Software with:
  - Needle Segmentation
  - Visual Servoing to track needle
  - Visual display of PA image coregistered to Ultrasound in GUI
  - Demonstration on Spine Phantom

Expected

- If it is possible to do PA imaging, Images of the needle tip inside the vertebrae (perhaps registered to Ultrasound)
- Results of applying previously developed needle segmentation algorithm to detect needle in PA image
- If not possible, report of what I attempted (laser energies and wavelengths)

Minimum

- Robot Control Software with:
  - Human Shape segmentation
  - Inverse Kinematics for Probe Placement
  - Force Feedback
  - A nice GUI
  - Demonstrations of probe placement and segmentation algorithm
## Dependencies

<table>
<thead>
<tr>
<th>Maximum</th>
<th>Expected</th>
<th>Minimum</th>
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| • Intentionally damaged spine in phantom (Need) | • A Spine (Need)  
• Powerful Laser Source  
• Hollow-bore Needle  
• Optical Fiber | • Ultrasound Scanner + (Calibrated!) Probe  
• Sawyer Robot  
• Kinect v2 |
## Timeline

<table>
<thead>
<tr>
<th>Date</th>
<th>Task Description</th>
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<tbody>
<tr>
<td>Feb 20</td>
<td>Kinect Calibration and Registration - Start + Finish / Explore PA in Spine - Start</td>
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<tr>
<td>Feb 27</td>
<td>Human Outline Segmentation - Start / Explore PA in Spine</td>
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<td>Mar 6</td>
<td>Human Outline Segmentation / Explore PA in Spine</td>
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<td>Mar 20</td>
<td>Inverse Kinematics and Probe Placement - Start + Finish</td>
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<tr>
<td>Mar 27</td>
<td>Visual Servoing - Start</td>
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<td>Apr 3</td>
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<tr>
<td>May 15</td>
<td>Demonstrate Entire System - Finish</td>
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Timeline
References

• B. Karan, “Calibration of Kinect-type RGB-D Sensors for Robotic Applications” FME Transactions 2015