Autonomous Placement of Ultrasound Probe for Spinal Surgeries

Student: Josh Shubert
Mentor: Dr. Muyinatu Bell

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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)

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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)

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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

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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*”

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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

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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

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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

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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

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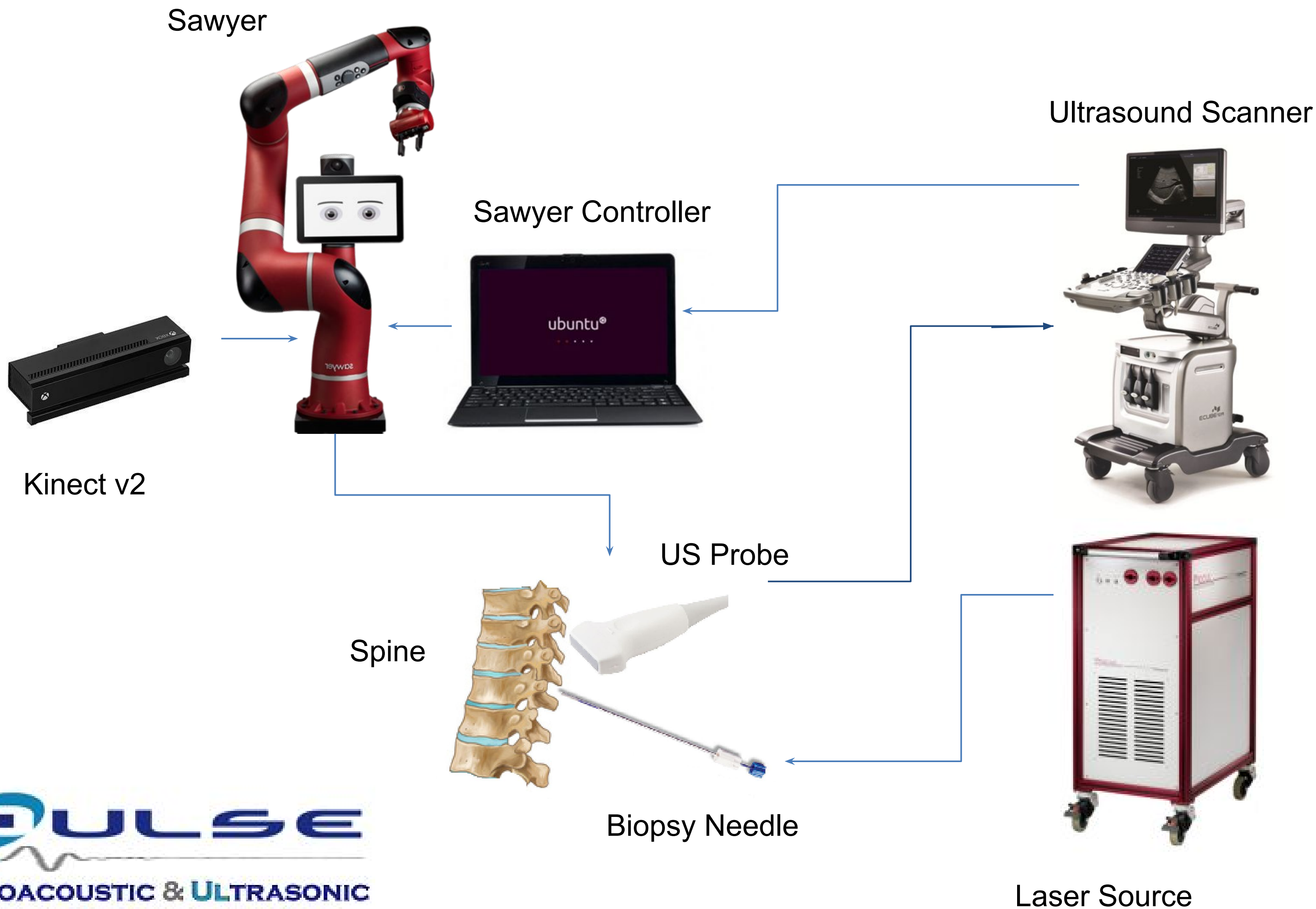
The plan



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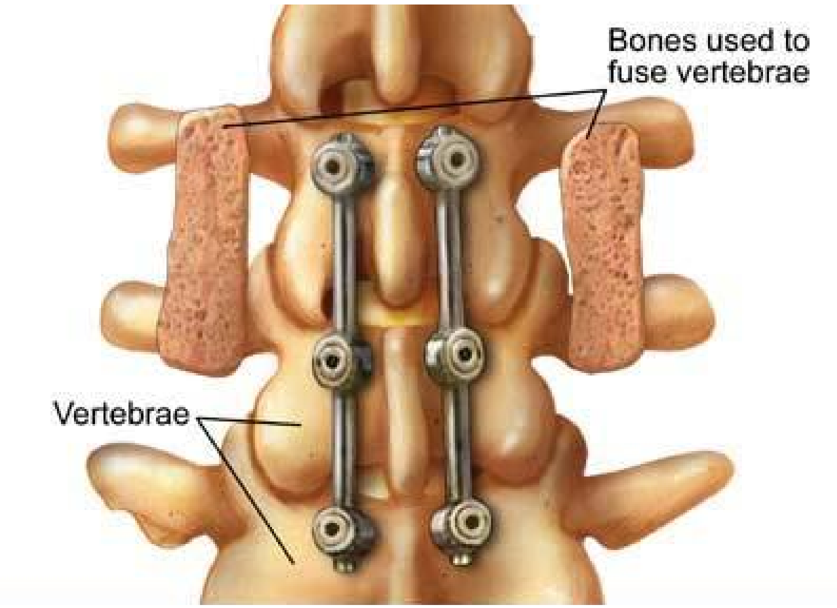
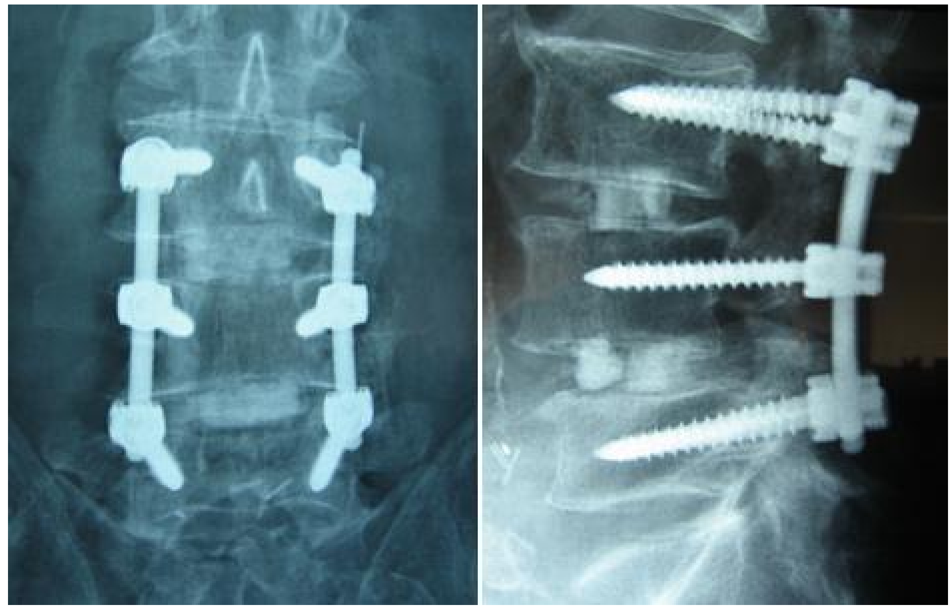
Background – Spinal Fusion





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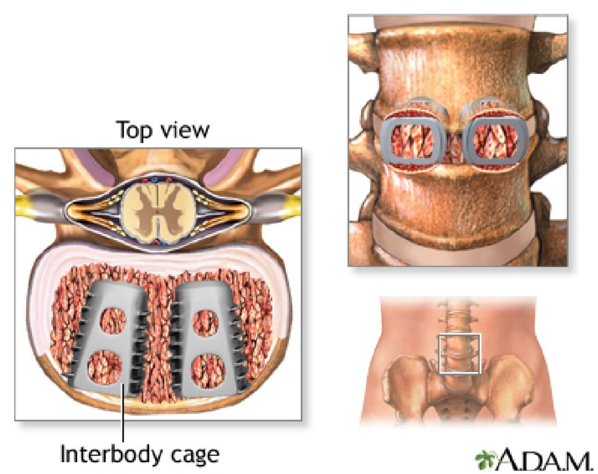
Background – Spinal Fusion

- 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



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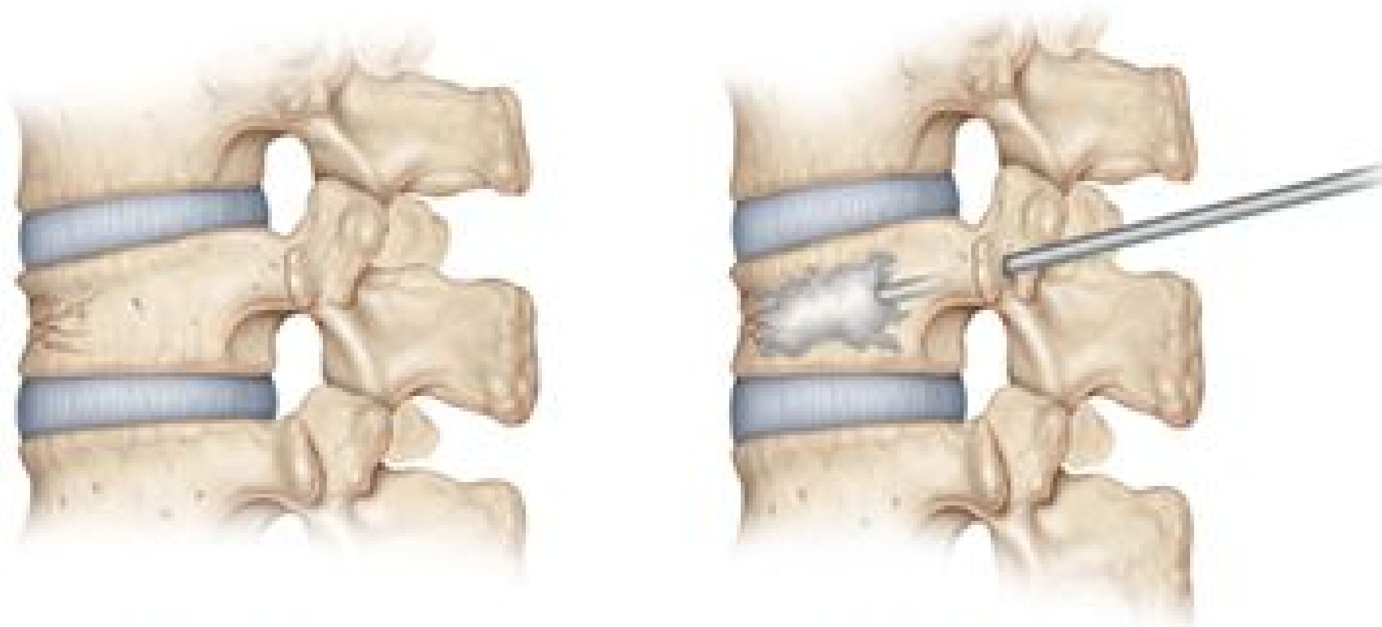
Background - Vertebroplasty

750,000 Vertebral Fractures per year!



Fracture   Cement Injection

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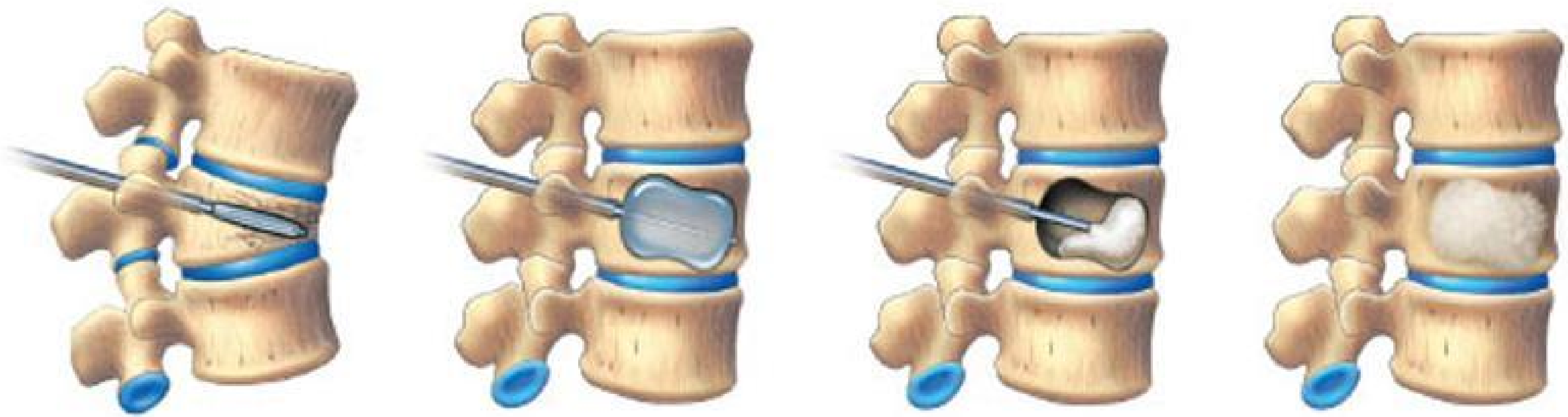
Background - Kyphoplasty



Balloon inserted into fractured vertebra

Balloon inflated inside damaged vertebra

Special material injected into fractured vertebra

Special material hardens, stabilizing vertebra

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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

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Dependencies

Maximum

- Intentionally damaged spine in phantom (Need)

Expected

- A Spine (Need)
- Powerful Laser Source
- Hollow-bore Needle
- Optical Fiber

Minimum

- Ultrasound Scanner + (Calibrated!) Probe
- Sawyer Robot
- Kinect v2

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Timeline

Feb 20	Kinect Calibration and Registration - Start + Finish / Explore PA in Spine - Start
Feb 27	Human Outline Segmentation - Start / Explore PA in Spine
Mar 6	Human Outline Segmentation / Explore PA in Spine
Mar 13	Human Outline Segmentation - Finish / Explore PA in Spine - Finish
Mar 20	Inverse Kinematics and Probe Placement - Start + Finish
Mar 27	Visual Servoing - Start
Apr 3	Visual Servoing
Apr 10	Visual Servoing
Apr 17	Visual Servoing - Finish
Apr 24	Demonstrate Entire System - Start
May 1	Demonstrate Entire System
May 8	Demonstrate Entire System
May 15	Demonstrate Entire System - Finish

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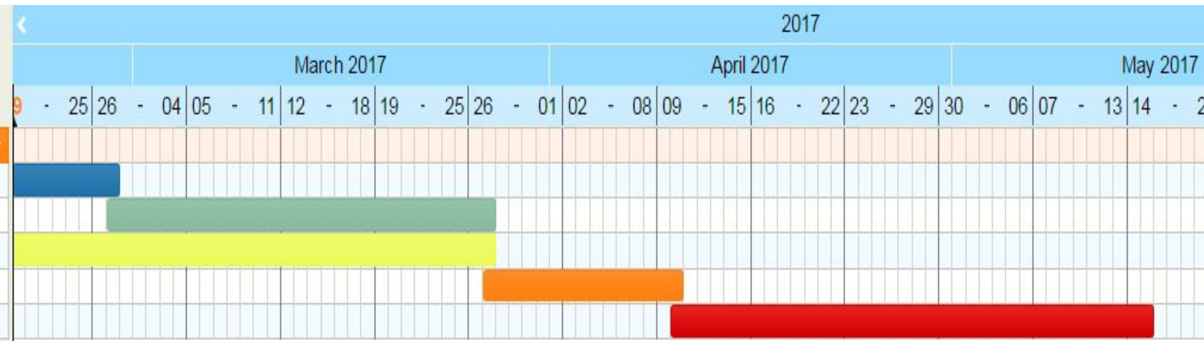
Timeline

Activity	Status
Project - Calibrate Kinect to Robot	WIP
Project II - Develop Segmentation Algorithm	NS
Project III - Explore Spinal PAI	WIP
Project IV - Create Visual Servoing Algorithm for Spinal Tracking	NS
Project V - Create Phantom and Demo the whole system	NS



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References

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- S. Lipson, "*Spinal-Fusion Surgery – Advances and Concerns*" N Engl J Med 2004
- R. Deyo et al, "*Spinal-Fusion Surgery – The Case for Restraint*" N Engl J Med 2004
- R. Buchbinder et al, "*A Randomized Trial of Vertebroplasty for Painful Osteoporotic Vertebral Fractures*" N Engl J Med 2009

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