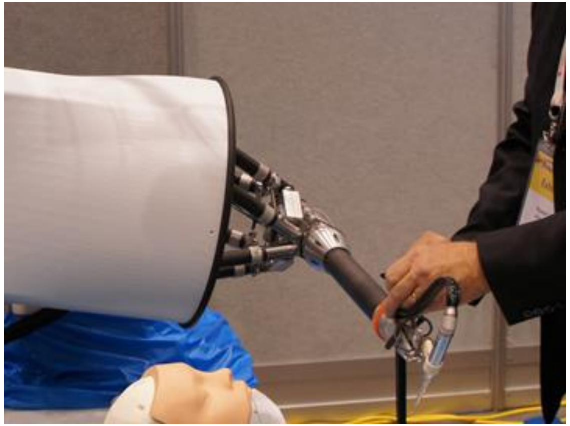
Force Sensing Drill/Cutter Tool for Skull Base Surgery

Prasad Vagdargi, Brandon Tran, Nick Skacel
Midpoint Presentation

Overview

- **Galen Robot:** Hand-over-hand cooperatively controlled surgical robotic system used for head and neck microsurgery.
- For some applications it is useful to measure and control the **tool-to-tissue** forces as well.
- **Goal:** To sense these forces and integrate this data for better control of the Galen robot
- **Applications:**
  - Visualization of forces
  - Safety limits
  - Surgical skill evaluation
  - Unbiased comparison of surgical techniques



Mentors and Team Roles

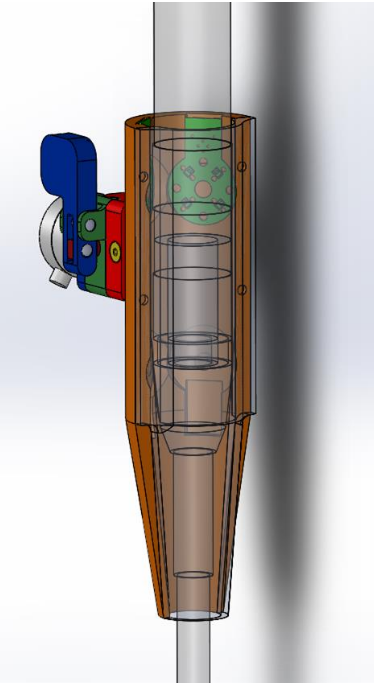
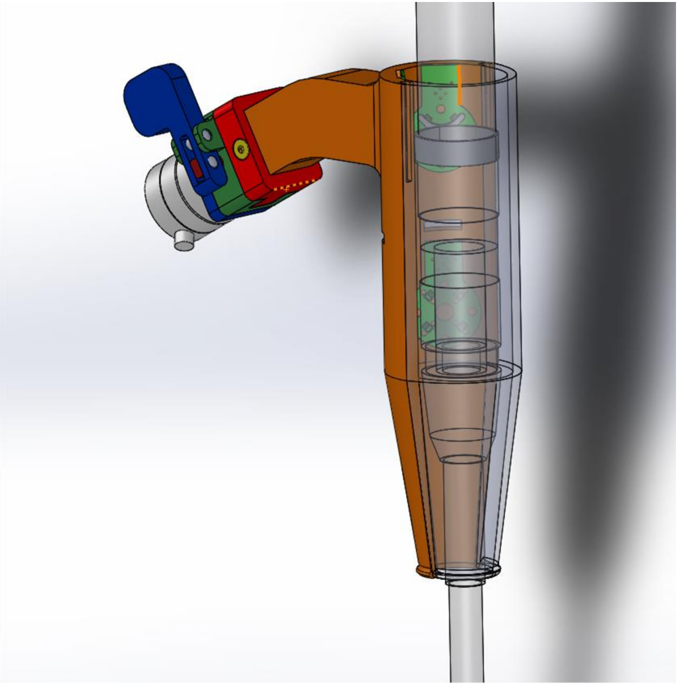
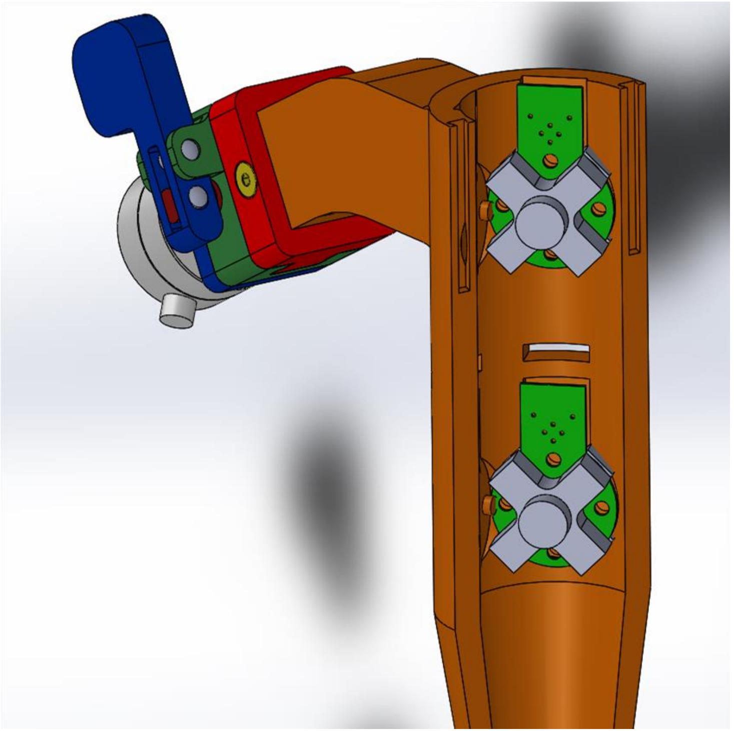
- Mentors
  - Dr. Russell Taylor
  - *Galen Surgical:* Paul Wilkening, Yunus Sevimli, David Levi
  - *Johns Hopkins Medicine:* Francis Creighton, MD and Chris Razavi, MD
- Roles
  - *Team Leader and Mechanical Design:* Prasad Vagdargi
  - *Electronic Design:* Brandon Tran & Nick Skacel
  - *Communications/Software:* Nick Skacel
  - *Controls:* Brandon Tran

Dependencies

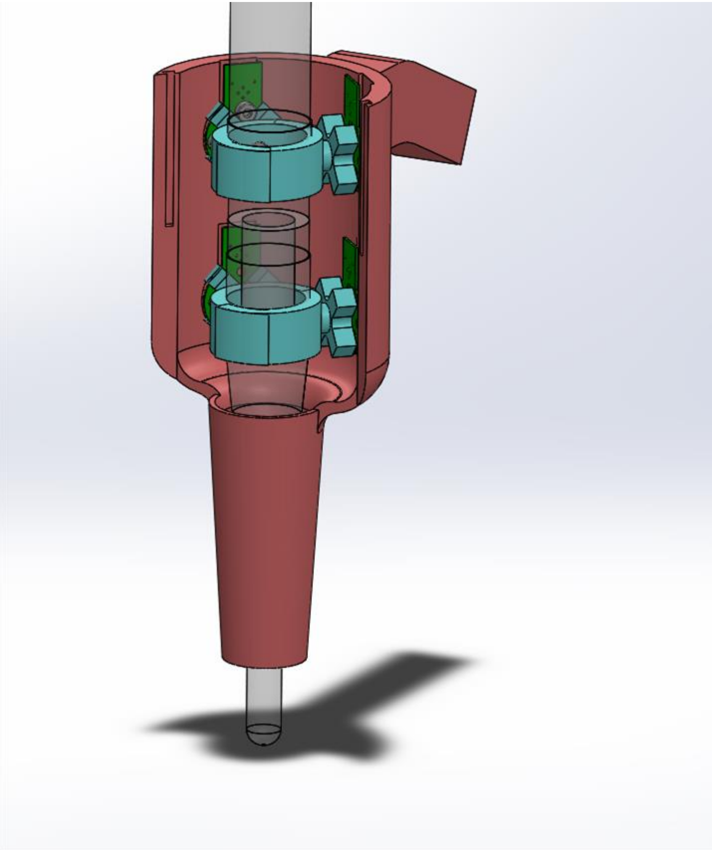
Dependency	Status	Deadlines
Order for new force sensors, DAQ board	Completed Backup: Work with ATI force sensors	Will work on ATI sensors by March 15 if needed
Access to Galen UI for DAQ to Robot communication	Completed: Discussed with Paul	None
Access to 3D printing facilities	Completed	None
Access to Mock OR	Completed	None
Drill Prototype for calibration	Completed: 11 April	None

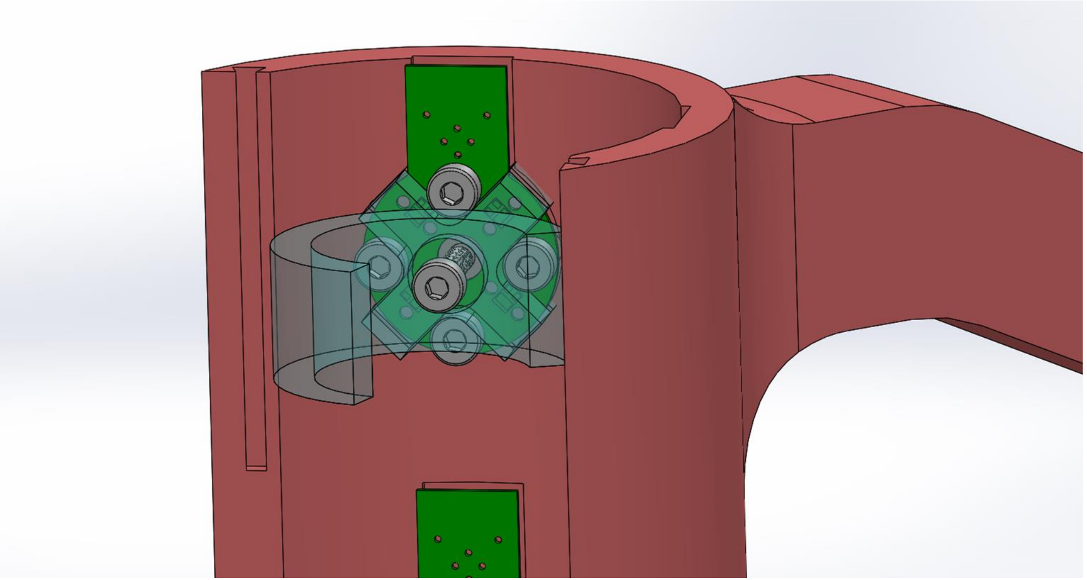
Design Iterations

- We went through multiple iterations for designs in smaller profiles

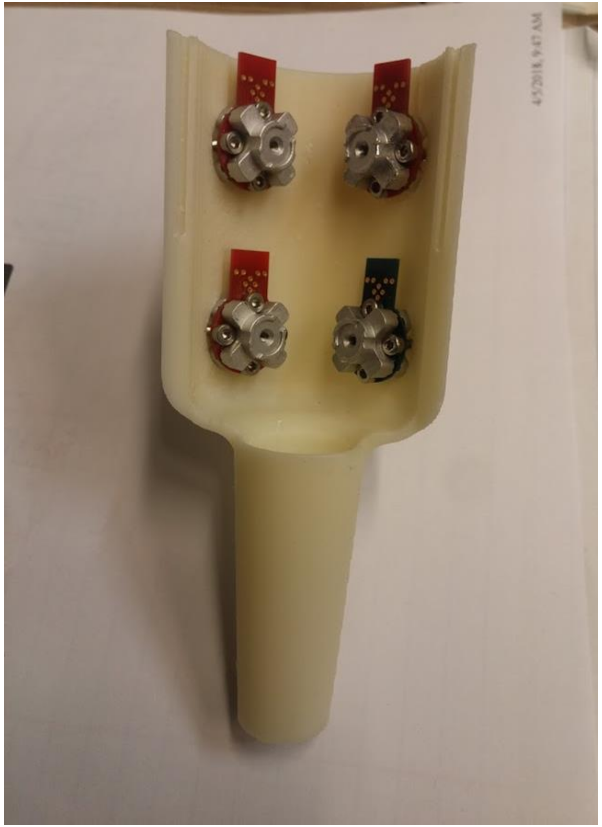




Final Design

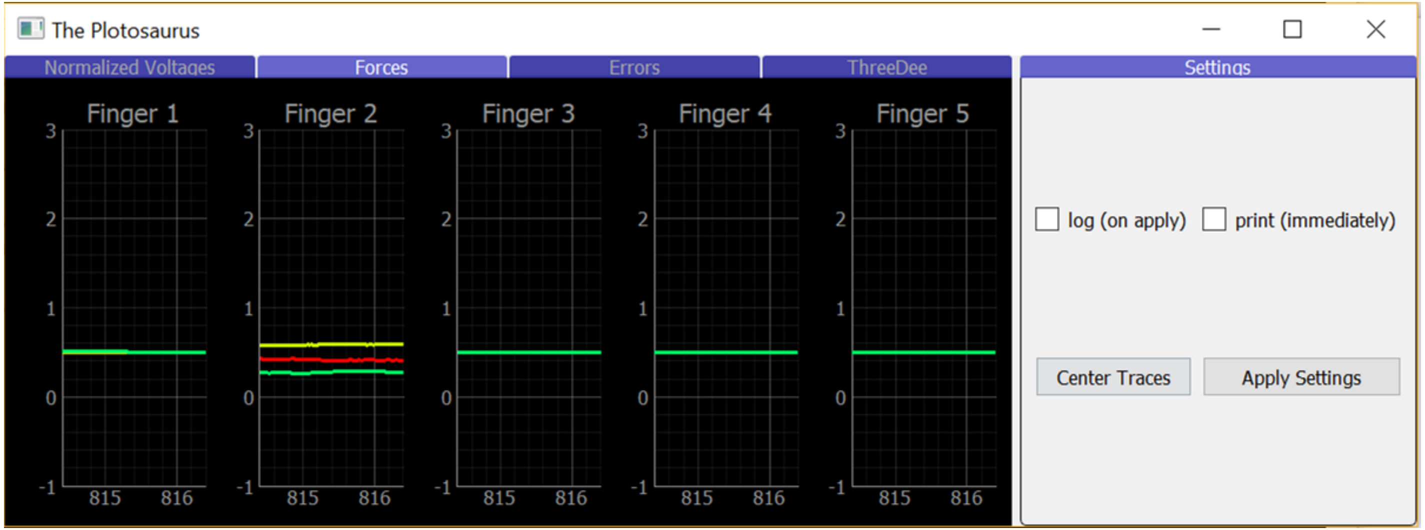




Final Design and Video



Plotosaurus for Data Collection



- Courtesy of the BLAM lab for their hand rehabilitation device
- Each “Finger” corresponds to a force sensor
- The three lines in “Finger 2” show the XYZ forces being applied to the 2nd force sensor
- The other fingers show no forces being applied to the corresponding sensors
- Y axis shows the force applied and the X axis shows the time in seconds

DAQ Sample Output

Time	Deviation from expected sample period(us)	FS 1 Fx	FS 1 Fy	FS 1 Fz	FS 2 Fx	FS 2 Fy	FS 2 Fz	FS 3 Fx	FS 3 Fy	FS 3 Fz	FS 4 Fx	FS 4 Fy	FS 4 Fz	FS 5 Fx	FS 5 Fy	FS 5 Fz
331.239	0	0.999	0.026	0.024	0.999	0.034	0.526	0.494	0.024	0.022	0.495	0.999	0.493	0.999	0.024	0.024
331.24	0	0.999	0.026	0.024	0.999	0.034	0.526	0.494	0.024	0.022	0.495	0.999	0.493	0.999	0.024	0.024
331.241	0	0.999	0.026	0.024	0.999	0.034	0.526	0.494	0.024	0.022	0.495	0.999	0.493	0.999	0.024	0.024
331.242	0	0.999	0.026	0.024	0.999	0.034	0.527	0.494	0.024	0.022	0.495	0.999	0.493	0.999	0.024	0.024
331.243	0	0.999	0.026	0.024	0.999	0.034	0.528	0.494	0.024	0.022	0.495	0.999	0.493	0.999	0.024	0.024
331.244	0	0.999	0.026	0.024	0.999	0.034	0.528	0.494	0.024	0.022	0.495	0.999	0.493	0.999	0.024	0.024
331.245	0	0.999	0.026	0.024	0.999	0.034	0.526	0.494	0.024	0.022	0.495	0.999	0.493	0.999	0.024	0.024
331.246	0	0.999	0.026	0.024	0.999	0.034	0.528	0.494	0.024	0.022	0.495	0.999	0.493	0.999	0.024	0.025
331.247	0	0.999	0.026	0.024	0.999	0.034	0.527	0.494	0.024	0.022	0.495	0.999	0.492	0.999	0.024	0.025
331.248	0	0.999	0.026	0.024	0.999	0.034	0.528	0.494	0.024	0.022	0.495	0.999	0.493	0.999	0.024	0.024
331.249	0	0.999	0.026	0.024	0.999	0.034	0.528	0.494	0.024	0.022	0.495	0.999	0.493	0.999	0.024	0.024
331.25	0	0.999	0.026	0.024	0.999	0.034	0.527	0.495	0.024	0.022	0.495	0.999	0.493	0.999	0.024	0.024
331.251	0	0.999	0.026	0.024	0.999	0.034	0.526	0.495	0.024	0.022	0.495	0.999	0.493	0.999	0.024	0.025
331.252	0	0.999	0.026	0.024	0.999	0.034	0.526	0.495	0.024	0.022	0.495	0.999	0.493	0.999	0.024	0.024
331.253	0	0.999	0.026	0.024	0.999	0.034	0.527	0.494	0.024	0.022	0.495	0.999	0.493	0.999	0.024	0.024
331.254	0	0.999	0.026	0.024	0.999	0.034	0.527	0.494	0.024	0.022	0.495	0.999	0.493	0.999	0.024	0.025
331.255	0	0.999	0.026	0.024	0.999	0.034	0.527	0.494	0.024	0.022	0.495	0.999	0.493	0.999	0.024	0.024
331.256	0	0.999	0.026	0.024	0.999	0.034	0.526	0.494	0.024	0.022	0.495	0.999	0.493	0.999	0.024	0.024
331.257	0	0.999	0.026	0.024	0.999	0.034	0.527	0.494	0.024	0.022	0.496	0.999	0.493	0.999	0.024	0.024

- The DAQ calculates the XYZ forces on the sensors
- Outputs a .txt file that contains time, deviation from sampled period, and xyz forces for each sensor

Calibration Plan

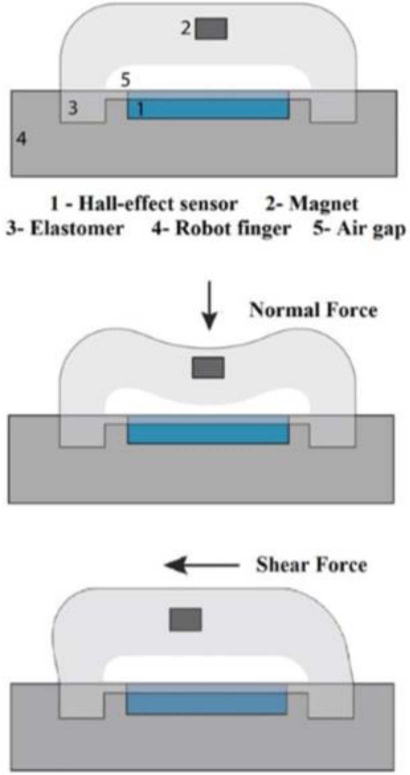
- The Galen system has a built in force sensor
- We can transform the tool-to-robot force to tip force
  - Rigid bodies and known tool lengths
  - Galen system provides tool angle measurements for the transformation
- For the drill forces we are able to produce a .txt file with the transformed uncalibrated xyz forces (12 readings in total)
- Similarly, we can produce a .txt file with “known” tooltip forces
  - Galen force sensor readings and computed transformation based on angle measurements and fixed lengths
- Solving a least squares problem (CIS 1)
  - $A\vec{x} = \vec{b}$ where A would be an n by 12 matrix of drill forces and b would be the Galen forces

Problems Faced

1. Initial prototype for calibration took longer than we expected
2. Cables that we had were too short
    a. Have to hold the DAQ during calibration
3. 3D printed parts too weak to hold drill, switched to metal interface between drill and sensor
4. Assembly was initially complicated: Redesign
5. Sensors are being calibrated by the BLAM Lab
    a. Sensors output forces, but not calibrated XYZ newton force

Hall Effect Force Sensing

- Hall Effect sensor: varies output voltage based on magnetic field
- Magnet inside elastomer
  - Elastomer: polymer having elastic qualities
- Hall voltage can be calibrated to xyz force readings
- Advantages: sensors are smaller, drill to sleeve contact with elastomer/flexure material easier to build than current design

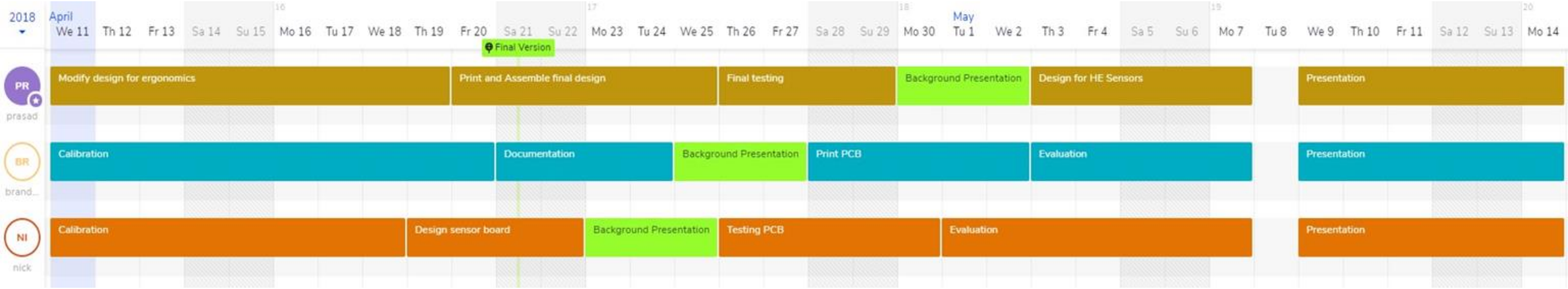


T. Paulino et al., "Low-cost 3-axis soft tactile sensors for the human-friendly robot Vizzy," 2017 IEEE International Conference on Robotics and Automation (ICRA), Singapore, 2017, pp. 966-971.

Deliverables

- Minimum
  - Design and prototype force sensing tool holder
  - Provide forces sensing at the tooltip
- Expected
  - Design iteration for ergonomics
  - Provide calibrated XYZ force sensing at the tooltip
  - Design and Print PCBs for Hall Effect sensor
- Maximum
  - ~~Create virtual fixtures using drill force measurements.~~
  - Test Hall Effect sensors, design HE sensor drill
  - Test using Galen robot on phantom skulls and measure tooltip forces

Schedule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Final Version
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Modify design for ergonomics
Print and Assemble final design
Final testing
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Design for HE Sensors
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Calibration
Documentation
Background Presentation
Print PCB
Evaluation
Presentation
NI
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Calibration
Design sensor board
Background Presentation
Testing PCB
Evaluation
Presentation

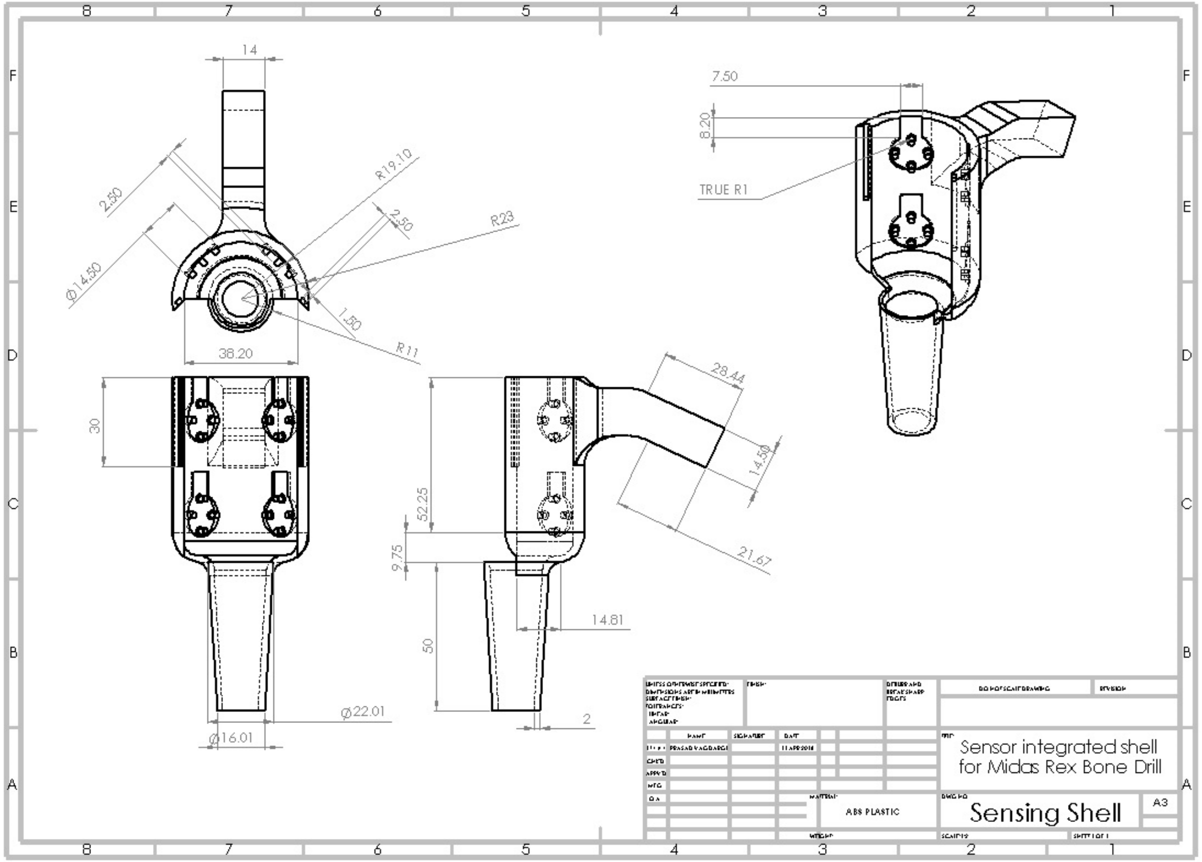
Original Milestones

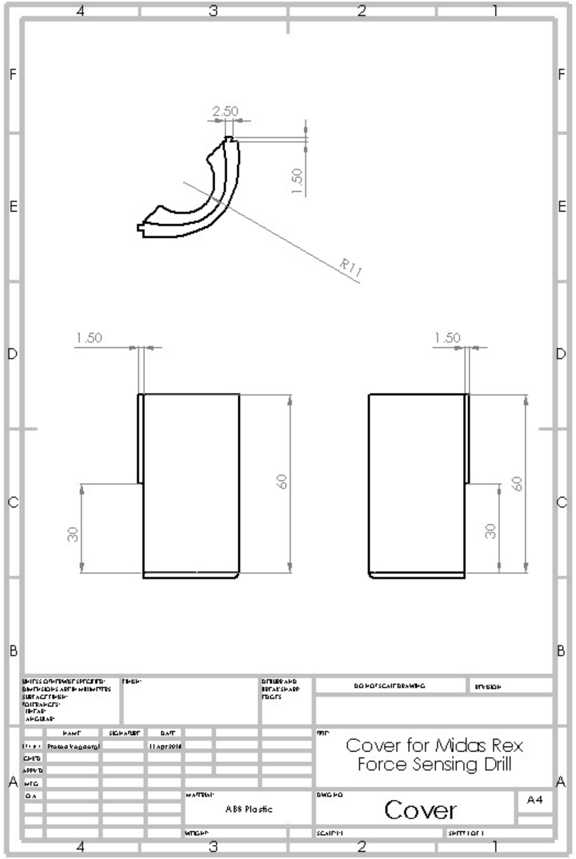
Initial Prototype Manufacture	Feb. 25
Order/Test Sensors	Mar. 1
Test fixture development	Mar. 10
Calibration and Analysis	April 1
UI design	April 12
Safety limits testing	April 28
Presentation	May 12

Updated Milestones

Initial Prototype Manufacture	Completed
Order/Test Sensors	Completed
Calibration and Analysis	19 April
Modify Design for Ergonomics	20 April
Design and Print HE PCB	23 April
Assemble HE sensor	4 May

Documentation: Design





Reading List

- Y. Hu, H. Jin, L. Zhang, P. Zhang and J. Zhang, "State Recognition of Pedicle Drilling With Force Sensing in a Robotic Spinal Surgical System," in IEEE/ASME Transactions on Mechatronics, vol. 19, no. 1, pp. 357-365, Feb. 2014.
- P. Kazanzides, J. Zuhars, B. Mittelstadt and R. H. Taylor, "Force sensing and control for a surgical robot," Proceedings 1992 IEEE International Conference on Robotics and Automation, Nice, 1992, pp. 612-617 vol.1.
- Force of Cochlear Implant Electrode Insertion Performed by a Robotic Insertion Tool: Comparison of Traditional Versus Advance Off-Stylet Techniques, Daniel Schurzig, Robert J. Webster III, Mary S. Dietrich, and Robert F. Labadie, Otology & Neurotology, 2010
- T. Paulino et al., "Low-cost 3-axis soft tactile sensors for the human-friendly robot Vizzy," 2017 IEEE International Conference on Robotics and Automation (ICRA), Singapore, 2017, pp. 966-971.

Problem: Material for interface