Force-Sensing Forceps for Cochlear Implant Surgery

Final Project Report

EN 601.656 Advanced Computer-Integrated Surgery (CIS II)

Ajay Gawade
agawade1@jhu.edu

Background:

A cochlear implant is a small electronic device that electrically stimulates the cochlear nerve (nerve for hearing). However, currently, there are no established methods for guidance, monitoring, or feedback to the surgeon and the implant insertion process is entirely dependent on surgeon dexterity. [2]. Studies show that overall 17.6% trauma rate which implies that CI (Cochlear Implantation) insertion could be improved with more accurate and consistent electrode insertion using suggested techniques and types of electrodes.[3]

The Force sensing forceps will control the minimal force required in the cochlear invasive implant surgeries which will prevent damaging the ear, cochlea, eardrums, etc. to the surgeons. The design will also make the cochlear implant process easier by "Gripping electrode".

Aim:

The goal of the project is to design a prototype for testing the force-sensing forceps that can measure force, thereby enabling successful and safe insertion procedures which will eventually reduce the trauma rates.

The goal of the semester is

1. To design and develop a fully working prototype and test.
2. Calibration and Testing of the new Force/Torque sensor
3. Experimental methods to create calibration procedures to validate the sensor data concerning ground truth.

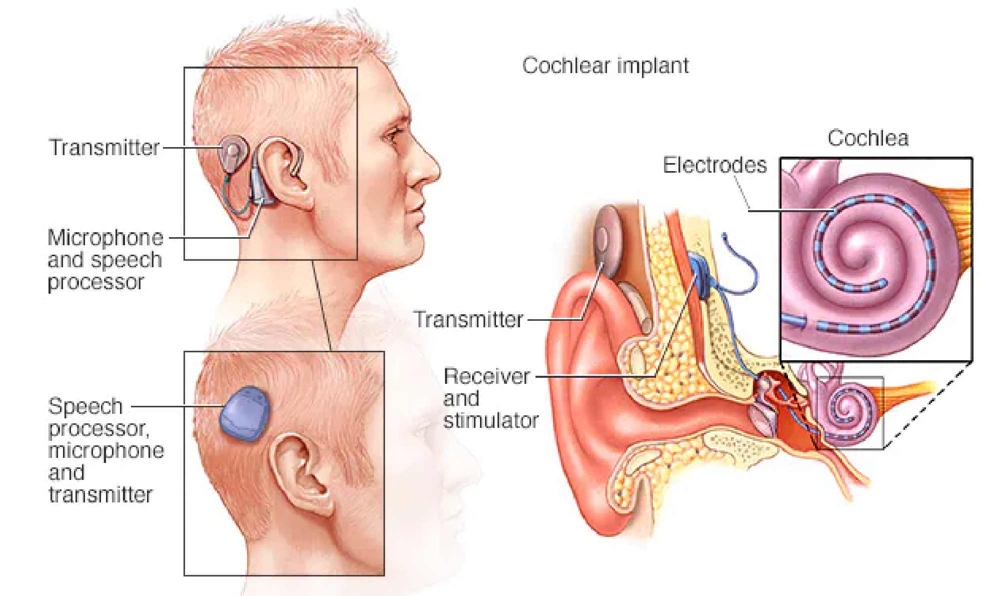


Figure 1. Cochlear implant with electrode array inside the cochlea [1]

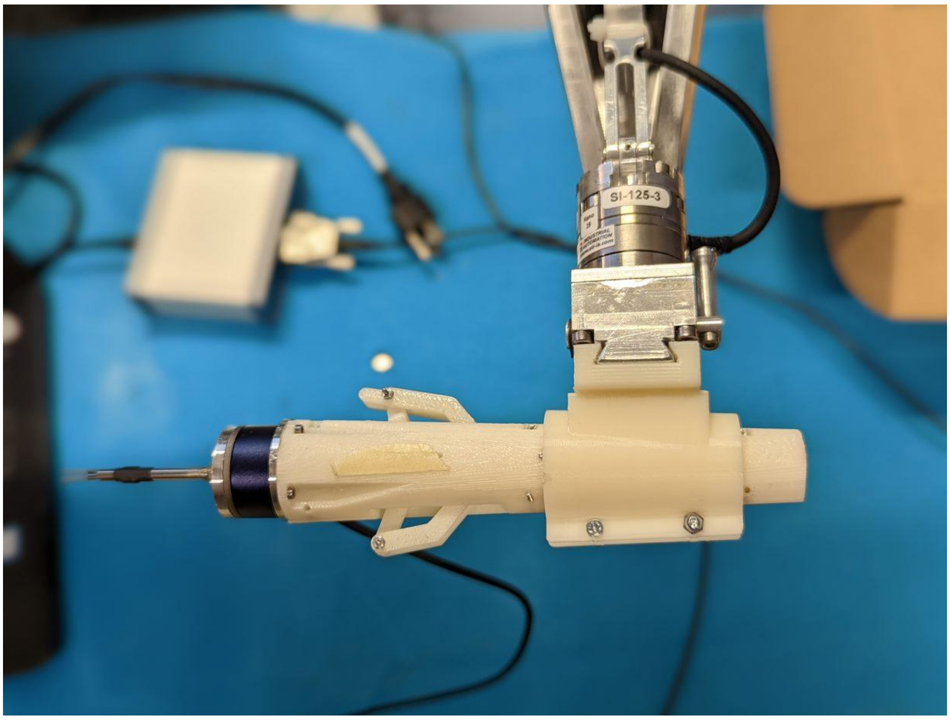


Figure 2. Force Sensing forceps embedded with the sensor

Team Members

Ajay Gawade (agawade1@jhu.edu)

Graduate Student, *Laboratory of Computational Sensing and Robotics, Johns Hopkins University*

Mentors

- Primary Mentor: Anna Goodridge (anna.goodridge@jhu.edu)

  Assistant Research Mechanical Engineer, LCSR

- Principal Investigator: Prof. Russell Taylor (rht@jhu.edu)

  John C. Malone Professor, Department of Computer Science

  Director, LCSR

- Surgeon Mentor: Dr. Deepa Galaiya (gdeepa1@jhmi.edu)

  Assistant Professor of Otolaryngology-Head and Neck Surgery

- Secondary Mentor: Justin Kim (iordachita@jhu.edu)

  Department of Mechanical Engineering, Johns Hopkins University

Technical Summary:

- The forceps are attached to a Force/Torque sensor " **WITTENSTEIN™ Hex21 6-Axis Force/Torque Sensor** " which collects data in real-time.
- Generated data is validated through many experimental methods such as calculating spring constants of Jaws and the springs using the Force equation,

F = -k. x (displacement of the spring/jaws) in Newtons

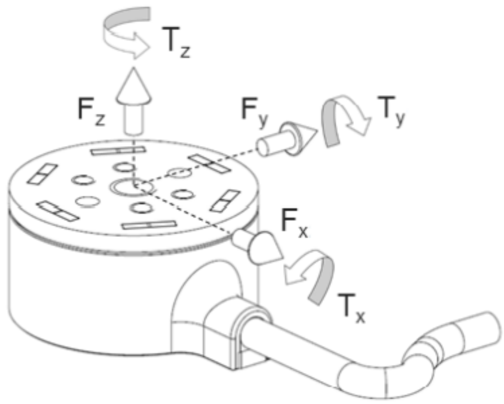


Figure 6.2: Coordinate axes definition of HEX 21 F/T sensor *[5]*

Calculating the Resultant Force:

$$\vec{F}resultant = \sqrt{F_x^2 + F_y^2 + F_z^2}$$

Where Fx, Fy, and Fz are forces in x,y, and z-direction. The resultant force is the same perception force by the surgeon as discussed in [6].

Noise Reduction using moving average filter:

$$y(n) = \frac{1}{windowSize}(x(n) + x(n-1) + \ldots + x(n - (windowSize - 1))).$$

The aim is to limit the force within 18mN [6] to reduce the damage caused by the CI.

Data collection

Dependencies and Plan:

Dependencies	Plan
Force/Torque sensor false readings	Tool calibration
Sensor isolation	Design 3-D casing to prevent it from generating false data
Sensor Calibration	Rebiasing it and removing inaccurate readings
Electrode Insertion Methods	Selection of CI method within threshold range

Deliverables:

	Deliverables	Dates
Minimum	Improved Design of the forceps	1-March
Minimum	Complete working prototype of the forceps	15-March
Expected	Sensor Data collection and Validation	29-March
Expected	Calculating actual forces using the jaws and spring load	12-April
Expected	Data collection from Nano-43ati sensor	19-April
Expected	Development of the electrode insertion procedure and data collection	27-April
Maximum	Testing Normally closed design with HEX21 and Nano-43 ati	4-May
Maximum	Calibration procedure of Wittenstein Sensor(HEX 21)	9-May
Maximum	Comparison of HEX 21 with Nano-43	11-May

Table 1. Deliverables

Planned vs Accomplished:

Planned	**Accomplished**	**Action**
Wittenstein HEX21 sensor data collection	Detected the flaw in the sensor	Asked company to replace the sensor
New Wittenstein HEX21 sensor data collection	Detected Uncertain drift in the sensor	Designed a process to take the (valid) readings from the sensor
Closed Forceps design* and assembly	Design ready for assembly	Sensor damaged during procedure
Force sensor Calibration procedure	Comparison of the Nano-43 ati sensor and HEX 21 sensor	In-process of the correlating both the sensor's data
Calculating the cochlear insertion forces	Accomplished	Using HEX21 and Nano-43 ati
Reducing the CI forces	Accomplished	Experimental methods
Filtering the sensor data (HEX21)	Accomplished	Using MATLAB
Synchronising both the sensor's data	In-progress (generated filtered .xlsx from rosbag)	Manual comparison form Max-to-Max and Min-to-Min

Experimental Setup:

1. Design of the cochlear holder with HEX 21 sensor

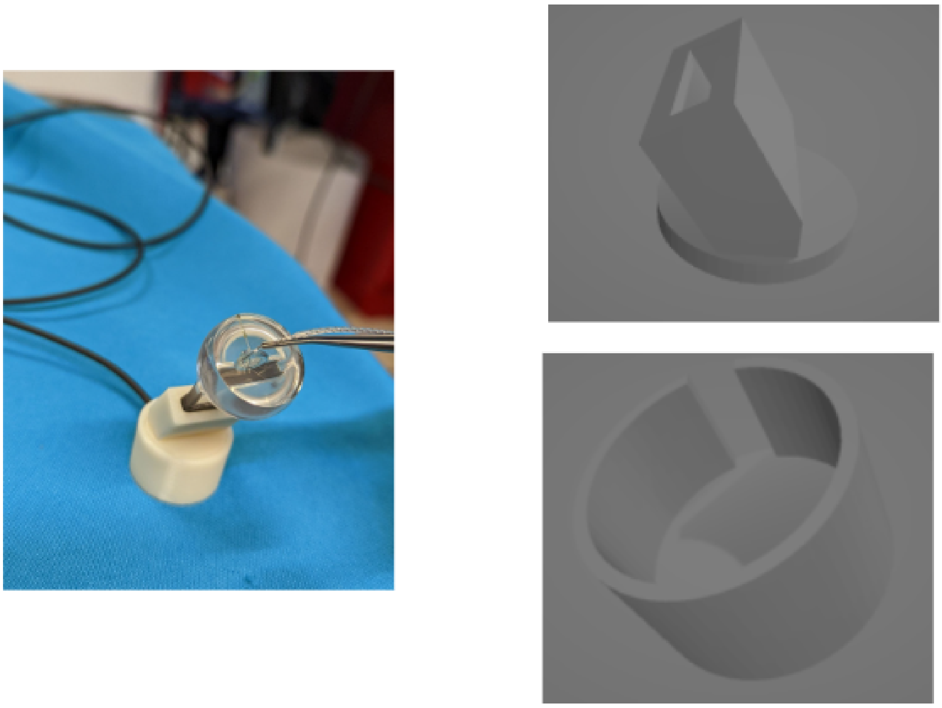


Fig: Improved casings using Solidworks software

2. Experimental Setup to reduce electrode tap

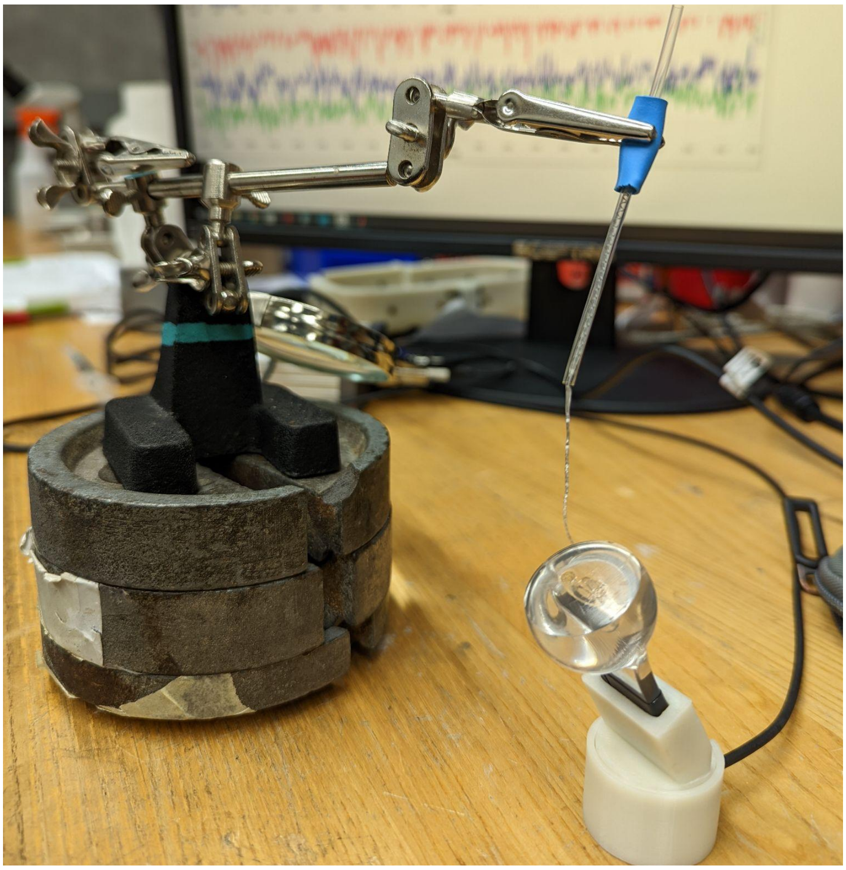


Fig: Feeding electrode from the above to remove slack and impulse

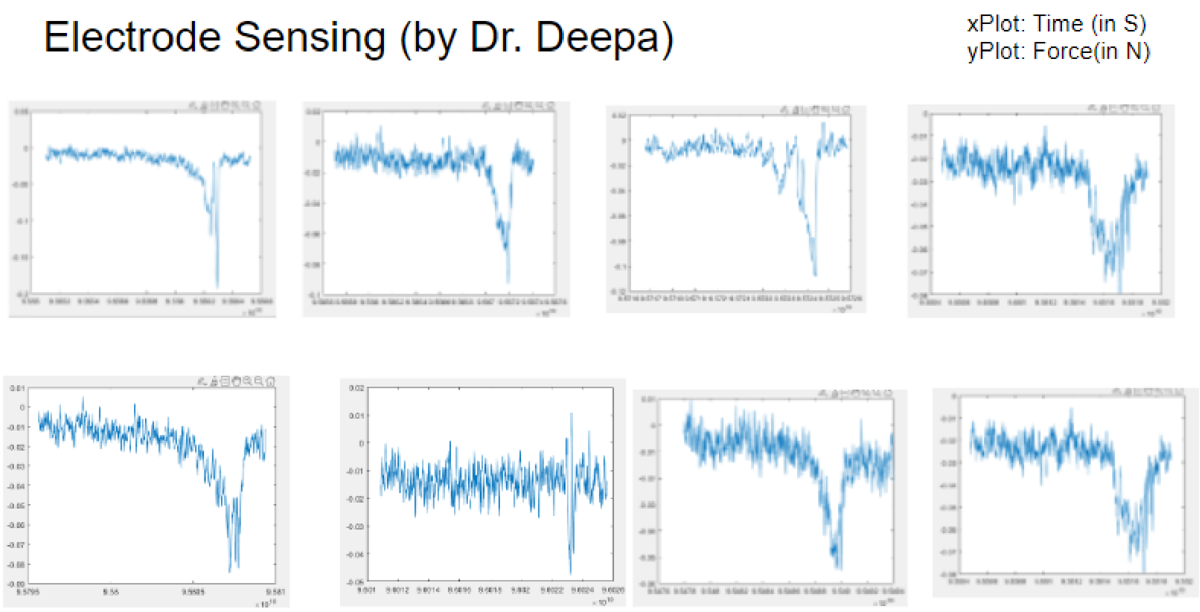
4. HEX 21 and Nano-43 ati sensor to measure the forces and compare the ground truth

Fig: CI setup using both sensors

5. Latest Experimental setup by attaching the electrode to the table and feeding it through the hole (mimic the real surgery)

Results:

1. Wittenstein Force Sensor (HEX 21)



- Mean of Max Force values = **0.085N (Fz)**
- Angle of the Force = 60 degrees
- Actual force on the Cochlea = **0.17N**
- **Problem: Electrode causes impulse breaking the threshold**

2. Rebias Procedure of Wittenstein Sensor: (to reduce drifting effect)

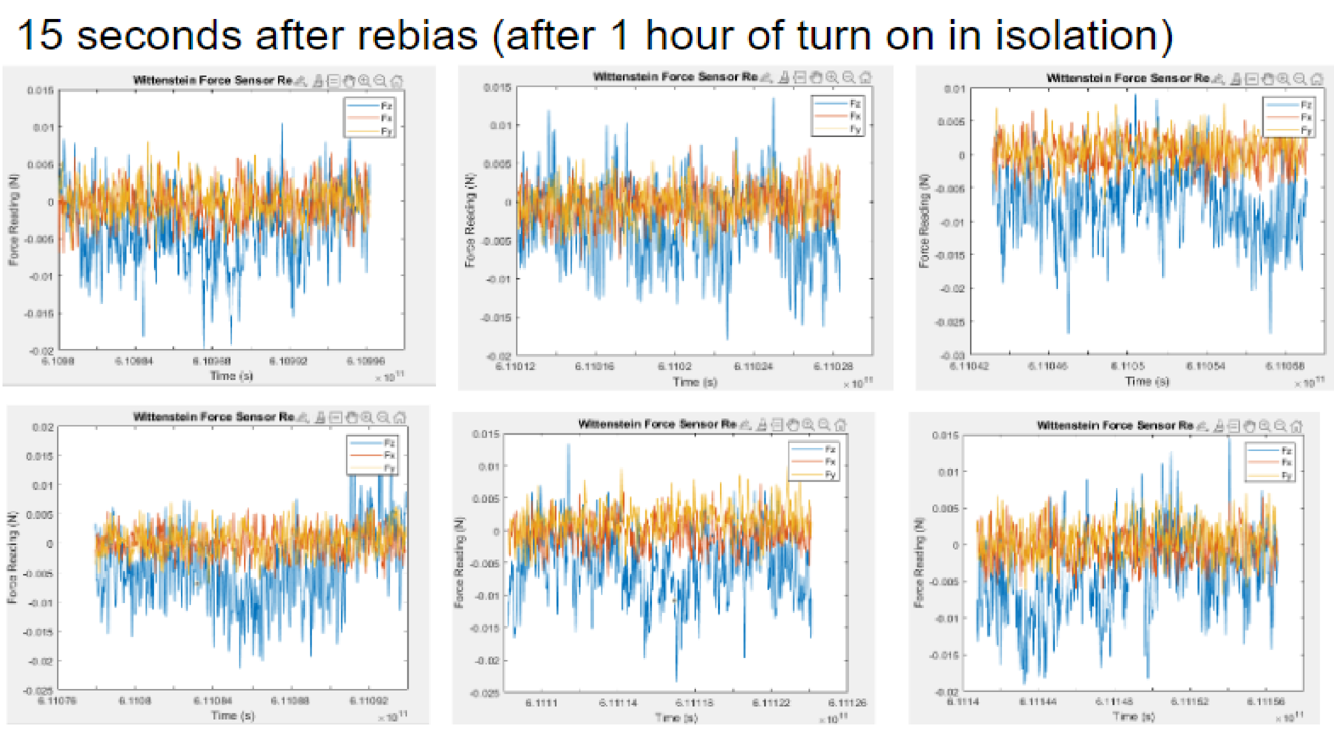


Fig: Drift assessment of the HEX 21 sensor(reduced drift)

3. Experiments by Dr. Deepa (Nano 43ati Sensor, Mounted Electrode)

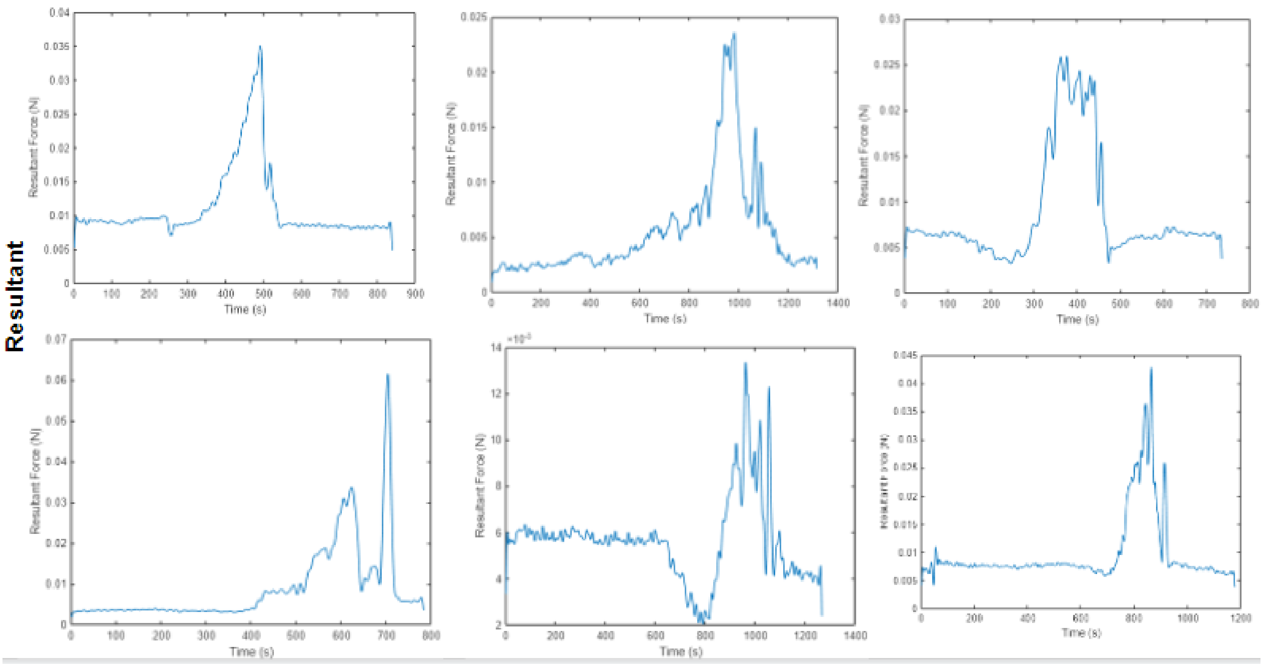


Fig: Resultant force of ***Nano-43 ati*** *using MATLAB and ROSbag*

- Mean of Max Resultant Force values = **0.028N (Fz)** **Mean calculated by averaging maximum valid readings between the experiment time range.*

4. Consistent HEX 21 force sensor reading (Fx, Fy, Fz)

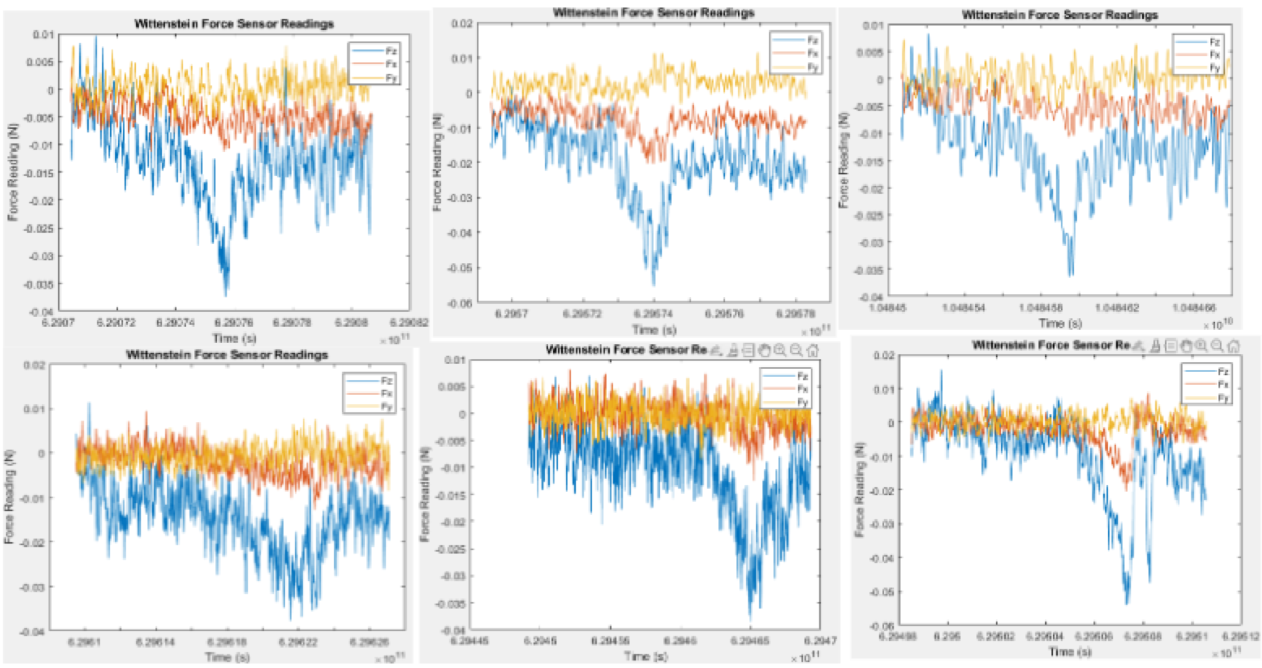


Fig: Calculating Fx, Fy, Fz of ***HEX 21*** *sensor*

- Mean of Max **Fz (downwards)** Force values = **0.050N (Fz)** **Mean calculated by averaging maximum valid readings between the experiment time range.*
- Drift is reduced by rebiasing the sensor after each reading.

5. Repetitive Resultant Forces:

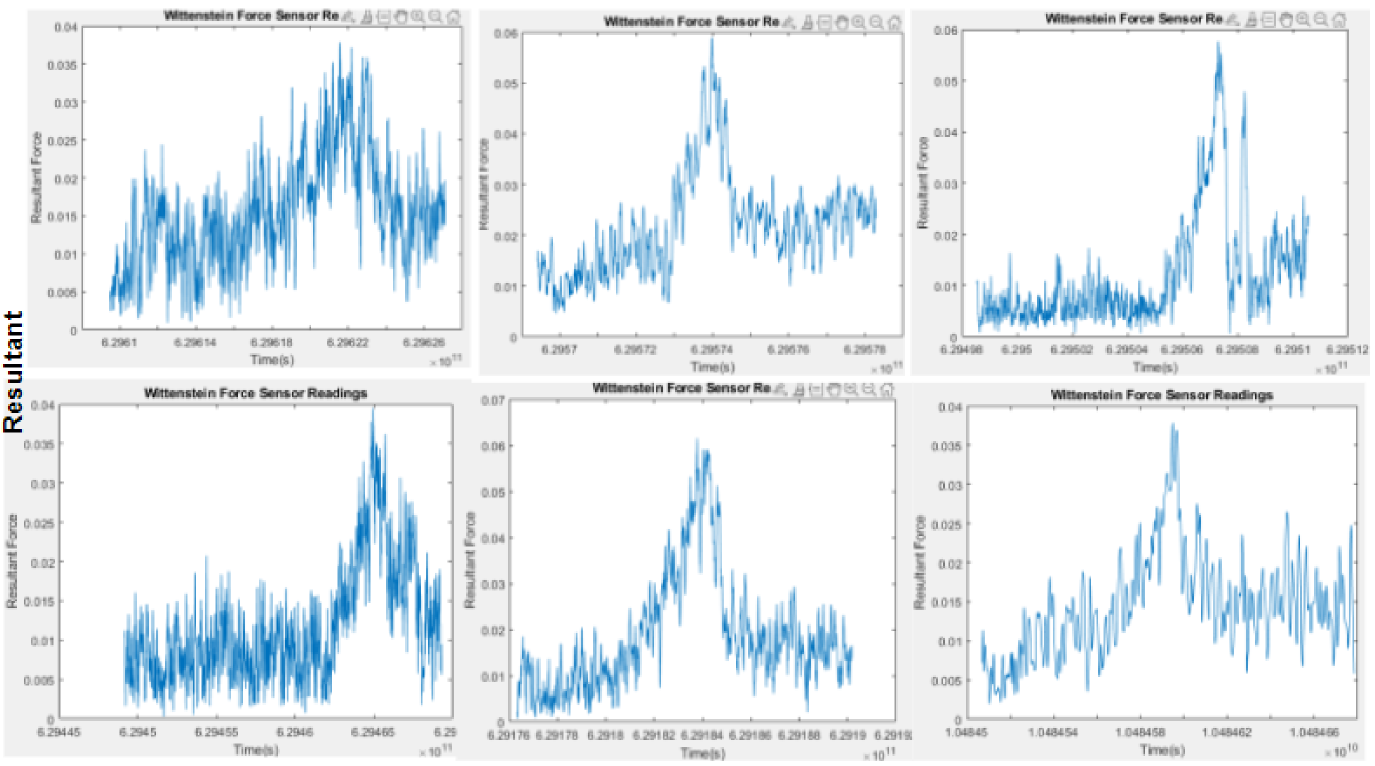
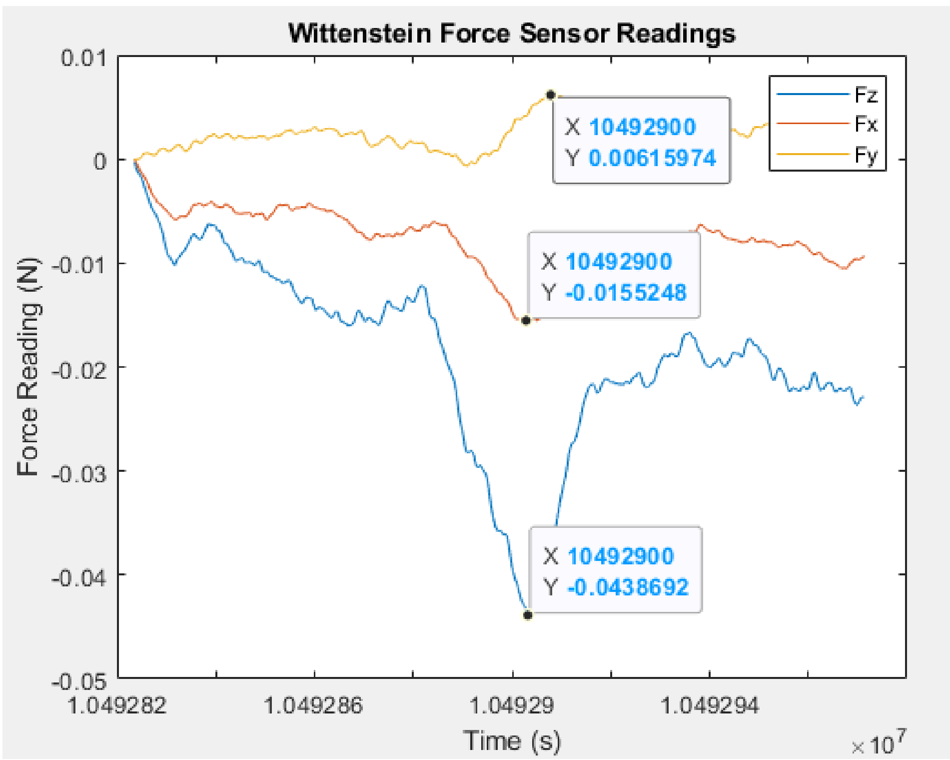


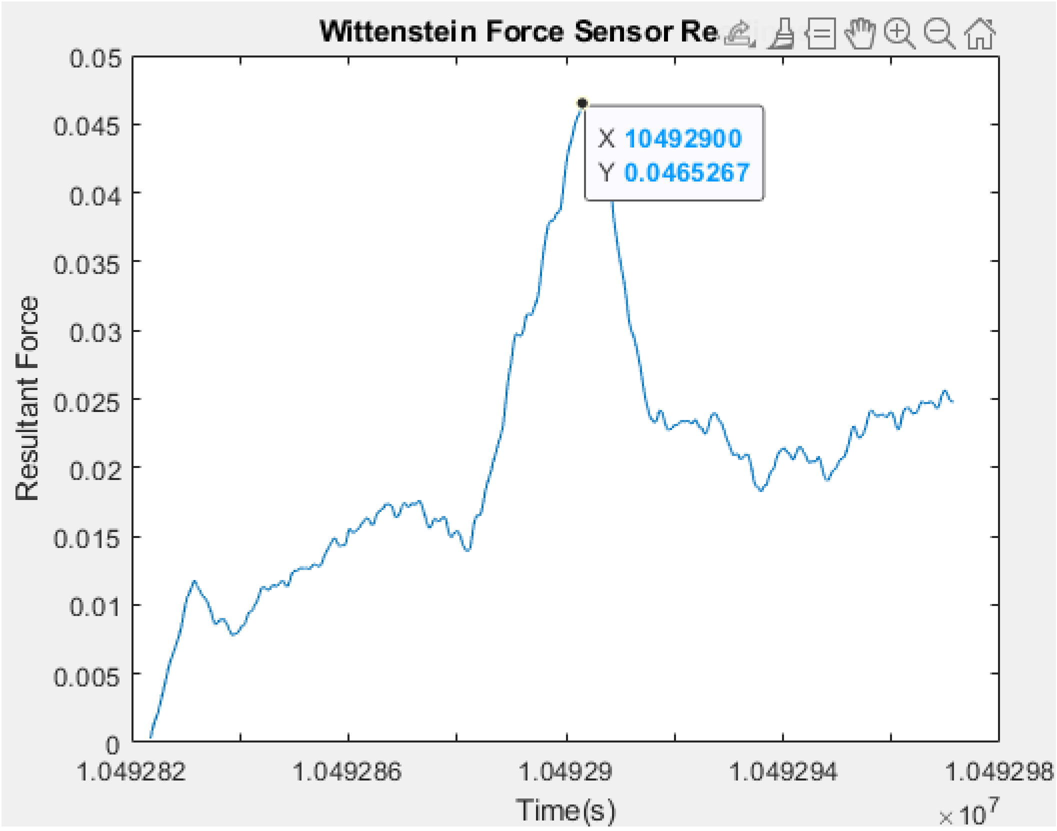
Fig: Calculation of the resultant force of ***HEX21*** *using MATLAB*

- Mean of Max **Resultant** Force values = **0.033N (Fz)** **Mean calculated by averaging maximum valid readings between the experiment time range.*

6. **6.** Final results after noise removal:



Maximum **Fz(downwards): 43mN**



Maximum Force: **46mN**

Note: The above-mentioned forces are one of the readings which are used to calculate the mean of Maximum forces (Resultant: 33mN, Fz: 50mN)

Discussion and Future Work:

1. The HEX 21 sensor can be used for calculating the perception forces by the surgeon once it is attached to the forceps and after a better calibration method and experimental procedures.
2. Once the HEX 21 sensor data is valid (using sensor validation), it can be compared to the Nano-43 ati sensor using the ROS packages (https://github.com/WSE-Resense/Resense.py). The data will be in sync and can be compared easily.
3. *The normally closed design will give better results as the pinching force will be eliminated during the CI procedure. (*Designed by: Daniel Leongomez*)
4. This procedure can be compared to the ground truth using the Nano43-ati sensor (considered to be valid).
5. Bernstein Polynomial can be used in the calibration procedure to map the real vs expected output.

Reading list [1]

- Gao, Anzhu, et al. "3-DOF Force-Sensing Micro-Forceps for Robot-Assisted Membrane Peeling: Intrinsic Actuation Force Modeling." *2016 6th IEEE International Conference on Biomedical Robotics and Biomechatronics (BioRob)*, 2016, doi:10.1109/biorob.2016.7523674.
- Handa, James, et al. "Design of 3-DOF Force Sensing Micro-Forceps for Robot-Assisted Vitreoretinal Surgery." *IEEE Engineering in Medicine and Biology Society*, 2013, doi:10.1109/EMBC.2013.6610841
- Hong, Man Bok, and Yung-Ho Jo. "Design and Evaluation of 2-DOF Compliant Forceps With Force-Sensing Capability for Minimally Invasive Robot Surgery." *IEEE Transactions on Robotics*, vol. 28, no. 4, 2012, pp. 932–941., doi:10.1109/tro.2012.2194889.
- http://wiki.ros.org/Topics
- *ROS: an open-source Robot Operating System* Morgan Quigley* , Brian Gerkey†, Ken Conley†, Josh Faust†, Tully Foote†, Jeremy Leibs‡, Eric Berger†, Rob Wheeler†, Andrew Ng* *Computer Science Department, Stanford University, Stanford, CA
- Data collection from the Wittenstein HEX21

Reference:

1. Final Project Report "Force-Sensing Forceps for Cochlear Implant Surgery" by Justin Kim, CIS-2, Spring 2021
2. https://www.hopkinsmedicine.org/health/treatment-tests-and-therapies/cochlear-implant-surgery#:~:text=A%20cochlear%20implant%20is%20a,internal%20part%20of%20the%20implant.
3. Hoskison E, Mitchell S, Coulson C. Systematic review: Radiological and histological evidence of cochlear implant insertion trauma in adult patients. Cochlear Implants Int. 2017 Jul;18(4):192-197. DOI: 10.1080/14670100.2017.1330735. Epub 2017 May 23. PMID: 28534710.
4. https://www.roswellpark.org/cancertalk/201608/advantages-robot-assisted-surgery#:~:text=Smooth%20Operations&text=With%20more%20experience%2C%20the%20surgeon,Less%20blood%20loss
5. https://www.wittenstein.de/fileadmin/Meta-Visuals/Microsites/resense/flyer/flyer-resense-hex-21.pdf [Operating Manual]
6. Kratchman, Louis B., Daniel Schuster, Mary S. Dietrich, and Robert F. Labadie. "Force perception thresholds in cochlear implantation surgery." *Audiology and Neurotology* 21, no. 4 (2016): 244-249.