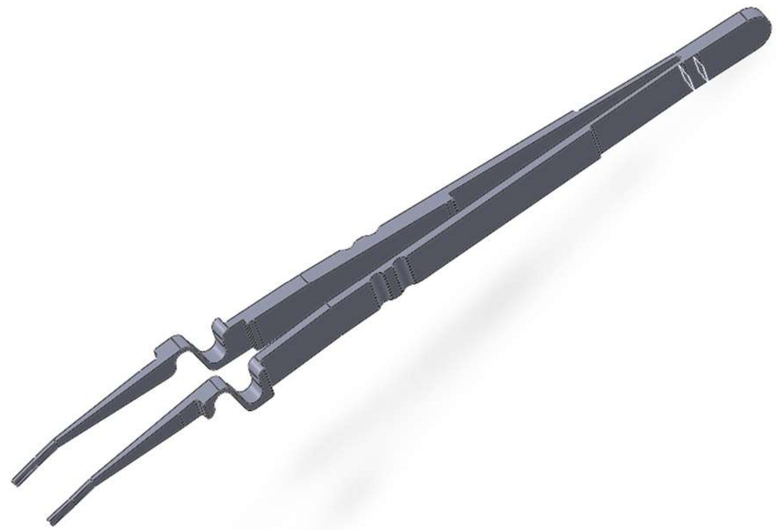
Force-Sensing Forceps for Cochlear Implant Surgery



Group 02:

Justin Kim

kkim141@jhu.edu

Principal Investigator: Prof. Russ Taylor

Primary Mentor: Anna Goodridge

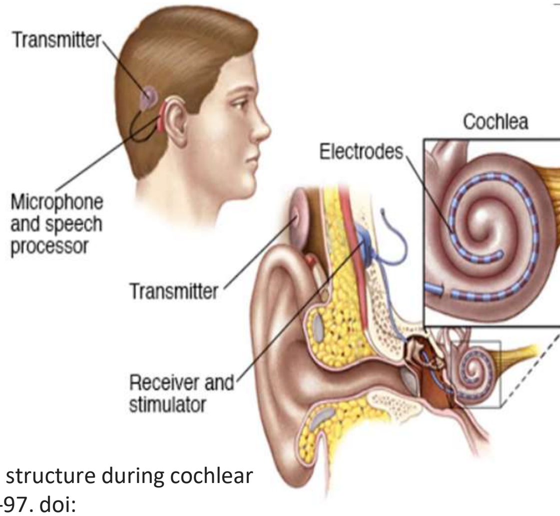
Surgeon Mentor: Dr. Deepa Galaiya

Secondary Mentor: Prof. Iulian Iordachita

Clinical Motivation – Cochlear Implant Surgery

- During cochlear implant surgery, electrode is inserted into the cochlea
- Electrode position determines performance
- No established guidance, monitor, or feedback method

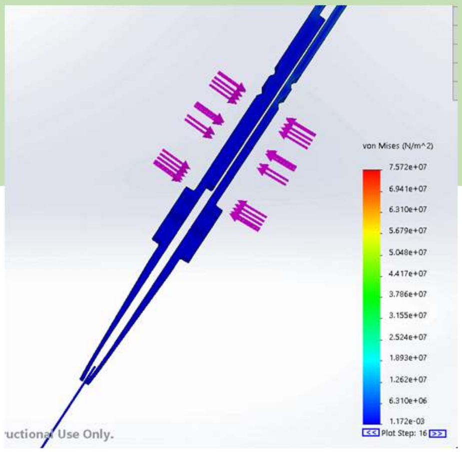
- Average Insertion force ~20 mN (Seta, 2017)
- Traumatic insertion force ~60 +/- 20 mN (Seta, 2017)
- Trauma rate: 17.6% (Hoskison, 2017)



De Seta D, Torres R, Russo FY, Ferrary E, Kazmitcheff G, Heymann D, Amiaud J, Sterkers O, Bernardeschi D, Nguyen Y. Damage to inner ear structure during cochlear implantation: Correlation between insertion force and radio-histological findings in temporal bone specimens. Hear Res. 2017 Feb;344:90-97. doi: 10.1016/j.heares.2016.11.002. Epub 2016 Nov 5. PMID: 27825860.

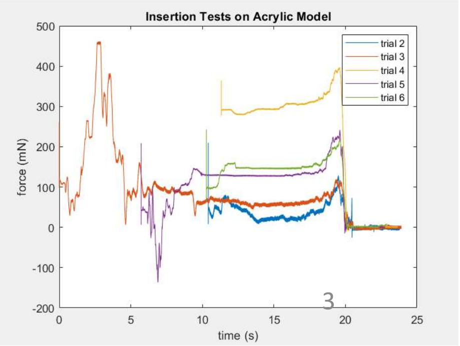
Hoskison E, Mitchell S, Coulson C. Systematic review: Radiological and histological evidence of cochlear implant insertion trauma in adult patients. Cochlear Implants Int. 2017 Jul;18(4):192-197. doi: 10.1080/14670100.2017.1330735. Epub 2017 May 23. PMID: 28534710.

Prior Work



- Work Fall 2019 – Spring 2020
  - Initial Forceps Design
  - CAD & FEA
  - Fabrication of a few prototypes
  - Calibration study
  - Test using cochlea models
  - Analysis

- Challenge:
  - Isolate insertion force from pinching force
  - 1 DOF



This semester’s goal

Laboratory for Computational Sensing + Robotics

- Design new forceps based on 3-DOF force sensing vitreoretinal forceps (Dr. Iulian Iordachita)
- Build a functional prototype with sensors ready for testing

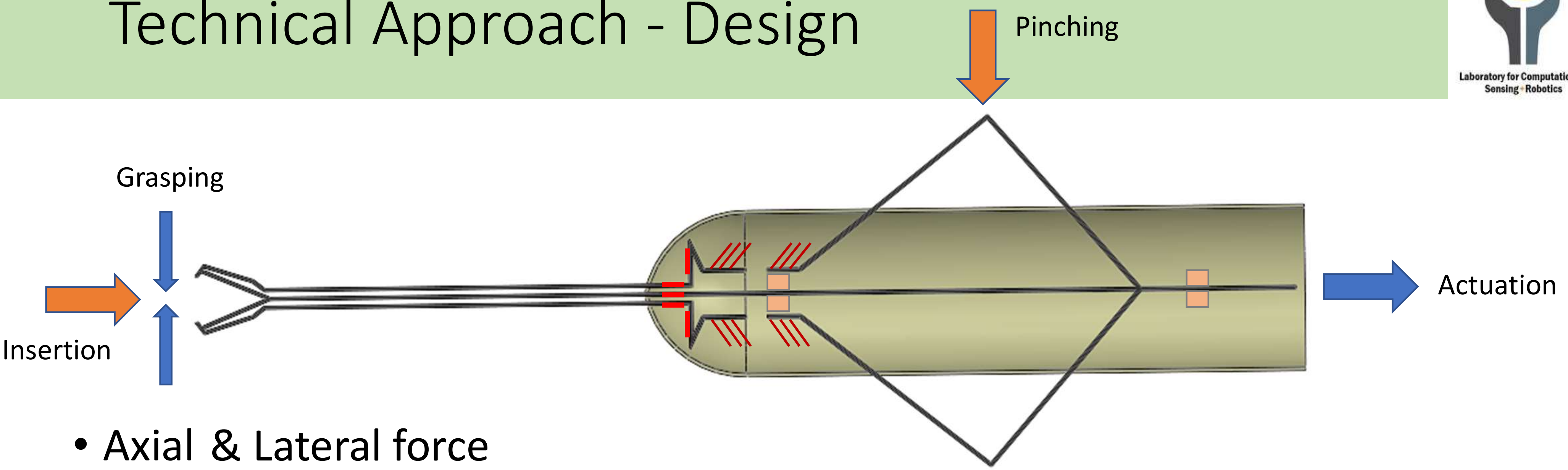
Technical Approach - Design

- Determine Forceps Geometry
  - Ergonomic frame
  - Design a feature to isolate pinching force
  - Determine sensor location
  - Material selection – mechanical property
  - Specify forceps length & width & thickness – beam deflection

- Isolate insertion force from pinching force
  - Pinching force is not constant
  - Surgeon may release pinching intermittently during insertion

Pinching	Insertion
Pinching	o
Pinching	x
Releasing	o
Releasing	x

Technical Approach - Design



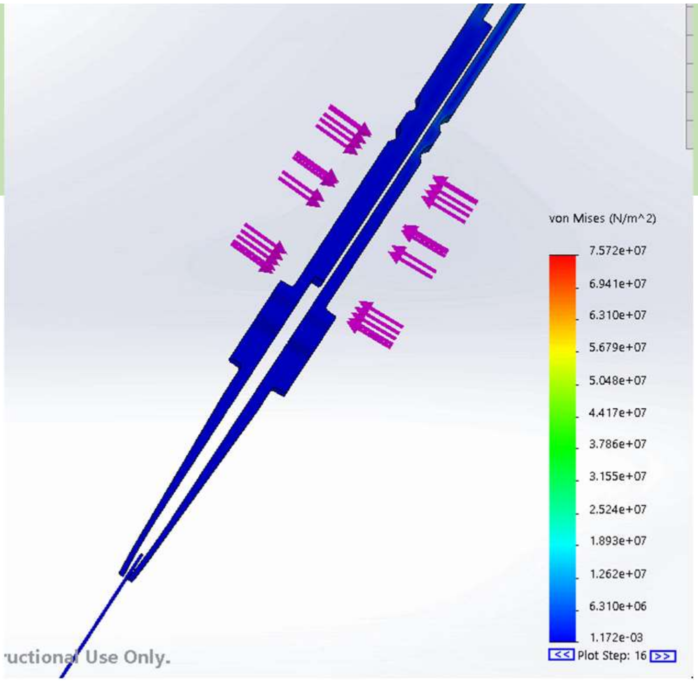
- Axial & Lateral force
  - 3 DOF force measurement
- Cruciform – bending
  - Bends only when insertion force is applied (isolate pinching force)

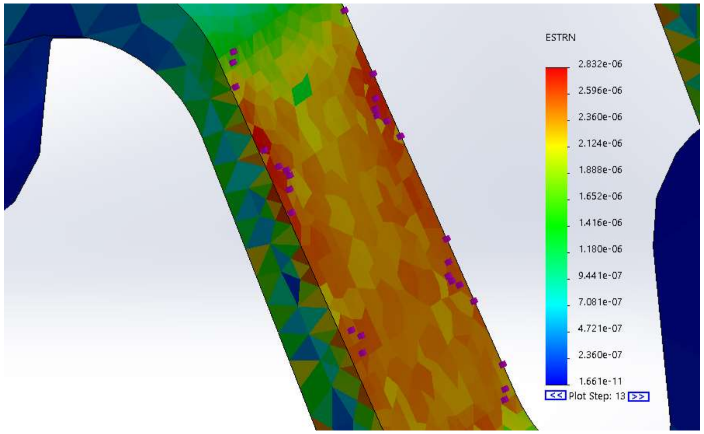
- Actuation mechanism
  - Pinching motion preserved
  - Front region is grounded

Technical Approach - Prototype

- Build CAD model of the design
- Run FEA to validate deflection calculation
  - Both static & nonlinear iterative
  - Fixed at base
  - Axial force
  - Lateral force
  - Pinching force

- Build prototype
  - In-house: EDM, laser cut, CNC
  - Rapid prototype as needed
  - Outsourcing: Protolab, injection mold (plastic case)





Technical Approach - Test

Laboratory for Computational Sensing + Robotics

- Calibration
  - Lift known weights
  - Analyze data on MATLAB
- Testing (Dr. Galaiya)
  - Insertion through cochlea models
  - Compare readings with a scale
  - Analyze data on MATLAB

Deliverable

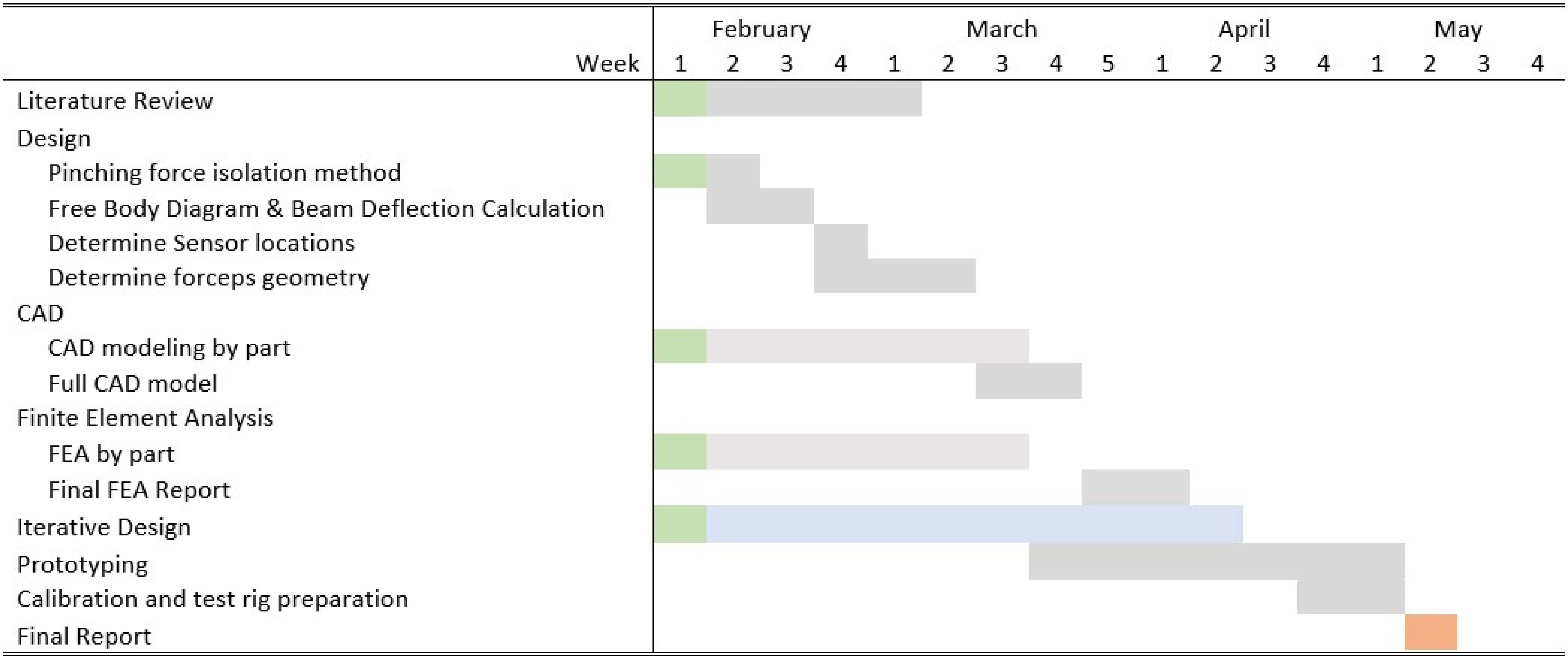
	Deliverables	Date
Minimum	Completed final design	4-Mar
	Final CAD model	16-Mar
	Report of Finite Element Analysis results	1-Apr
Expected	Fabricated prototype with sensors attached	20-Apr
	Preparation for calibration and test rig	4-May
	Plan for further tests	4-May
Maximum	Report of calibration data analysis	TBD
	More tests under different conditions	TBD
	Plan for design iteration and future work	TBD

Dependencies

- Major dependency: Prototyping
  - In-house: depending on in-campus activity situation, may ask Anna for help run the machine
    - Will provide necessary Stl or G-code
  - Outsourcing: wait for quote & build time
  - Budget: LCSR

- Testing
  - Dr. Galaiya’s schedule

Timeline


February
March
April
May
Week
1 2 3 4 1 2 3 4 5 1 2 3 4 1 2 3 4
Literature Review
Design
Pinching force isolation method
Free Body Diagram & Beam Deflection Calculation
Determine Sensor locations
Determine forceps geometry
CAD
CAD modeling by part
Full CAD model
Finite Element Analysis
FEA by part
Final FEA Report
Iterative Design
Prototyping
Calibration and test rig preparation
Final Report

Roles and Responsibilities

- Group 02:
  - Justin Kim: Sole member. Responsible for all tasks

Management Plan

Laboratory for Computational Sensing + Robotics

- Weekly LCSR lab meeting (Wednesday 4:00 p.m.)
- Meet with Anna weekly (Monday 12:30 p.m.)
- Meet with Deepa as needed
- Consult with Dr. Iordachita as needed

Reading List

- Aguirre, Milton, et al. "Technology Demonstrator for Compliant Statically Balanced Surgical Graspers." *Jounral of Medical Devices*, vol. 9, June 2015, doi:020926-1.
- 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.
- Gao, Anzhu, et al. "Fiber Bragg Grating-Based Triaxial Force Sensor With Parallel Flexure Hinges." *IEEE Transactions on Industrial Electronics*, vol. 65, no. 10, Oct. 2018, doi:10.1109/TIE.2018.2798569.
- 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.
- Turkseven, Melih, and Jun Ueda. "Analysis of an MRI Compatible Force Sensor for Sensitivity and Precision." *IEEE Sensors Journal*, vol. 13, no. 2, Feb. 2013, doi:1530–437X/$31.00.
- Zhang, Tianci, et al. "Miniature Continuum Manipulator with 3-DOF Force Sensing for Retinal Microsurgery." *Journal of Mechanisms and Robotics*, 2021, pp. 1–34., doi:10.1115/1.4049976.

References

- De Seta D, Torres R, Russo FY, Ferrary E, Kazmitcheff G, Heymann D, Amiaud J, Sterkers O, Bernardeschi D, Nguyen Y. Damage to inner ear structure during cochlear implantation: Correlation between insertion force and radio-histological findings in temporal bone specimens. Hear Res. 2017 Feb;344:90-97. doi: 10.1016/j.heares.2016.11.002. Epub 2016 Nov 5. PMID: 27825860.
- 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.
- 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.
- “Implant Programs - Mankato.” *Mayo Clinic Health System*, www.mayoclinichealthsystem.org/locations/mankato/services-and-treatments/audiology/implant-programs.

Thank you! Questions