Project Proposal:
Force Sensing Drill - Cutter Tool for Skull Base Surgery

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Topic/Goal: Force Sensing Drill/Cutter Tool for Skull Base Surgery

The Galen Surgical Robot is a hand-over-hand cooperative controlled surgical robotics system used for head and neck microsurgery. Currently, the Galen only sense tool-to-robot forces to reduce hand tremor and increase precision. For some applications, it is useful to measure and control the tool-to-tissue forces as well.

The project topic is to design a prototype and measure the forces at the tooltip of a drill used for head and neck surgical applications. This drill will be used cooperatively with the Galen Surgical Robot. Future work will include visualization of forces, safety limits, surgical skill evaluation, and comparison of surgical techniques.

Team Members and Mentors

Prasad Vagdargi is the team leader and will handle the mechanical design aspect of the project which includes drill-sleeve CAD prototyping. Brandon Tran and Nick Skacel will work collaboratively on the electronic design components. Nick will focus on implementing the communication with Galen system and developing any software to facilitate this process. Brandon will focus on implementing robotic controls to improve surgical safety.

The mentors on this project include Dr. Russell Taylor, members of the Galen surgical team (Paul Wilkening, Yunus Sevimli, and David Levi). In addition, the project has two surgeon mentors from Johns Hopkins, Dr. Francis Creighton and Dr. Chris Razavi.

Statement of Relevance

The aim of this project is to develop a force sensing drill in order to provide physicians with more feedback and control during skull base drilling, a required step in many cranial surgeries. From 2006 to 2013, the complication rate in cranial surgery decreased from 23.2% to 14.6%, a promising but still alarming rate.[1] Many complications can occur during skull base drilling due to the complex anatomical components and the severity of damaging adjacent anatomy.[2] For example, in anterior petrosectomy for tumor excision, drilling may be within 1 millimeter of the carotid artery, facial nerve, cochlea, and venous sinuses.[3]

Due to these complications, a physician's accuracy and precision are crucial in producing favorable surgical outcomes. A physician's inadvertent motions, hand tremors, and lack of feedback or safety controls from their surgical tools, however, hinder the physician's accuracy and precision during skull base drilling.[4] To solve these human limitations, we propose a drill holder that integrates multiple force sensors with a high speed surgical drill. This coupling will eventually be interfaced with the Galen robotic system, a cooperatively-controlled "steady-hand" robotic platform to display forces and implement safety controls.

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[1] Cote, David J., et al. "United States neurosurgery annual case type and complication trends between 2006 and 2013: An American College of Surgeons National Surgical Quality Improvement Program analysis." *Journal of Clinical Neuroscience* 31 (2016): 106-111.

[2] R. L. Galloway, "The process and development of image-guided procedures," *Annual Review of Biomedical Engineering*, vol. 3, pp. 83–108, Aug 2001.

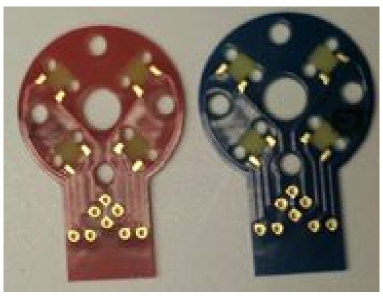
[3] K. Ikeda, K. Shoin, H. Taguchi, J. Yamano, and J. Yamashita, "Cranionavigator combining a high-speed drill and a navigation system for skull base surgery–technical note," *Neurologia Medico-Chirurgica*, vol. 39, no. 9, pp. 701–708, 1999.

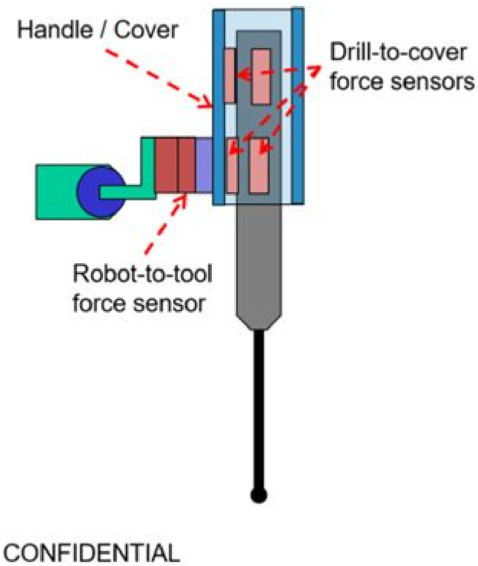
[4] Fisch, Ugo, and Douglas Mattox. "Microsurgery of the skull base," *Thieme*, 1988.

Technical Summary

The idea is to design a sleeve which encompasses the drill, and contains the required force sensors within it. This is essential for various reasons such as maintaining the original ergonomics of the drill along with reducing the moment arm of the sensors.

Force Sensors: An important part of this project is the force sensors used within the device. We intend to use a 3DOF force sensor with a small footprint. The present sensors are constructed by the use of 4 strain gauges on a printed circuit board, which provides two moment arm measurements and one axis of force measurement in the Z direction. The DAQ board for this sensor presently supports 5 sensors using multiplexing. The resolution of the sensors is yet to be quantified, along with its sensing limits.





Left: Force sensors and Right: Design sketch of sensing sleeve

The project will be divided into three stages:

1. **Initial Prototype:** This stage of the project will include literature review and analysis of existing designs of force sensing mechanisms. This is followed by an initial 3D printed prototype, used for checking the tolerance, location of sensors and testing the ergonomics of the sensing sleeve.
2. **Calibration and Testing:** Further analysis of the prototype will be then conducted to calibrate the measured forces at the tooltip. This will be done using a calibration jig/setup using ATI force sensors, which are highly accurate.
3. **Control and Review:** The final stage of the project will include the control of the Galen robot using the measured force as an input, to create virtual fixtures. The measured forces will also be displayed on the control UI of Galen robot. This stage will also include a final design review according to feedback from surgeons and better ergonomics.

Deliverables

- *Minimum*
  - Design and prototype a force sensing tool holder
  - Provide uncalibrated XYZ force sensing at the tooltip
  - Communicate sensed forces at the tooltip to the Galen System user interface

- *Expected*
    - Multiple design iterations to accommodate the surgeon's ergonomic preferences
    - Provide calibrated XYZ force sensing at the tooltip
    - Testing the calibration using the Galen system on phantom skulls.
- *Maximum:*
    - Incorporate threshold based warnings and motion control to constrain instrument within safety limits.
    - Create virtual fixtures using drill force measurements
    - Testing by Dr. Razavi

Key dates & assigned responsibilities

Milestone	Date	Assigned Responsibility
Initial Sleeve Prototype Manufacture	Feb. 25	Prasad
Order/Test Sensors	Mar. 1	Brandon
Test fixture development	Mar. 10	Prasad
First Prototype and Calibration	April 1	All
UI design	April 12	Nick
Safety limits testing	April 28	Brandon
Presentation	May 12	All

Dependencies

Dependency	Status	Deadlines/Backup
Order for new force sensors, DAQ board	Completed	March 15 Backup: Work with ATI force sensors if these sensors are not accurate enough
Access to Galen UI for DAQ to Robot communication	Completed	None
Access to 3D printing facilities	Completed	None
Access to Mock OR	Completed	None

Management Plan

We will be having weekly Galen meeting on Fridays at 11 AM. There, we will receive feedback from our mentors and ask questions about our project. We will be meeting as a team twice weekly on Thursday.

Budget

Item	Quantity	Cost per number ($)	Total ($)
Sensors	5	150	750
DAQ Board	1	500	500
3D prototyping	3	50	150
Misc. (Connectors/Screws/Wiring)	1	50	50
Total			Approx. 1450

Future Work

During various surgeries in Otorhinolaryngology, the inner ear is accessed through craniotomy for procedures like cochlear electrode implantation for hearing aids amongst others. In such procedures, the forces exerted on the inner ear bones, and the forces of insertion of implant into cochlea are an important factor for determining the likelihood of intracochlear damage. Quantifying and measuring these forces are therefore an essential task to predict the success rate of the procedure. Human operators demonstrate a high degree of variability between trials, and previous work has shown the success of automated cochlear implant insertion by reducing variability and overall forces.

The force sensing sleeve might be modified to develop a stylet for inserting such cochlear implants and measuring the forces received on it. This would help in measuring the variability and comparison of forces measured between different surgical techniques/surgeons.

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