Force-Sensing Drill for Skull Base Surgery
Group #8

Team & Mentors

Team: Harsha Mohan, Seena Vafaee

Mentors: Russell Taylor, Anna Goodridge, Deepa Galaiya, Pete Creighton

Background & Motivation

The Galen Robot is a hand-over-hand, cooperative-controlled surgical robotic system designed for use in head and neck surgery. This system combines the precision and dexterity of a robot with the cognition and intelligence of a surgeon. For surgeries around the skull base, any tremor, jerk, or overshoot could have serious consequences on the patient outcome.

Additionally, the forces applied by the surgeon to the bone during drilling operations can be extremely small and hard to control precisely, especially for less experienced surgeons. For example, certain maneuvers require the surgeon to have control over the compliance of their own fingertips which are contacting the drill.

A device which precisely measures the critical range of forces applied during microsurgery can pave the way for new methods of virtual fixtures and haptic feedback to improve the surgeon's perception of the forces they apply. This sensor can be used to help train residents, by measuring and contrasting the forces applied by residents and expert surgeons.

Technical Approach

Data Acquisition

The current literature describing the tool-tissue interaction forces during skull-base surgical procedures is very limited. To this end, we will be performing multiple drilling experiments to understand the magnitude and range of forces exerted onto the tissue.

For the first experiment, a chicken egg is placed in a fixture, which is rigidly attached to an ATI Nano 17 6-DOF Force/Torque sensor. The surgeon drills small holes in the egg shell without piercing the inner membrane of the egg. In previous literature, it has been demonstrated that egg shells display similar properties to inner-ear anatomy [9]. Thus, using eggs as a drilling specimen provides a cheap and effective outlet to refine the experimental setup in preparation for drilling experiments with a real temporal bone.

For the second experiment, the chicken egg is replaced with a temporal bone. The surgeon then performs a mock mastoidectomy.

We determined it appropriate to also consider the torques being applied to the force sensor. To account for the torques, we will be conducting drilling experiments with an Atracsys system to track the position of the drill with respect to the Force/Torque sensor. Knowing the position of the drill with respect to the sensor, we can calculate the moment arm and forces which contribute to the torque readings on the sensor. We can then combine this force vector with the force readings from the sensor to get a very accurate representation of the tool-tip interaction forces.

Design

We are currently exploring two parallel design branches. Both branches rely on deformation or displacement between an inner shell rigidly fixed to the drill and an outer shell held by the surgeon. The outer shell is connected to the inner shell either via carefully engineered flexural members (branch 1) or an off-the-shelf 6-DoF force/torque sensor (branch 2). The images below show screenshots of our CAD model for branch 1. We will begin by 3D-printing this model for an ergonomic study, then proceed with more refined design and prototyping of both branches in parallel.

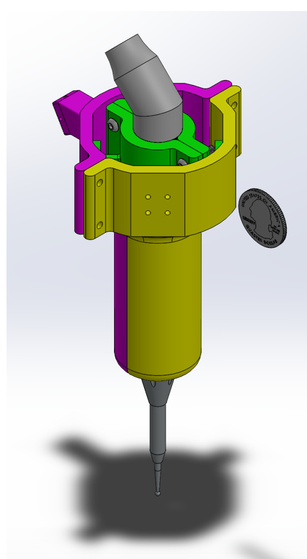

Figure 1: Isometric View

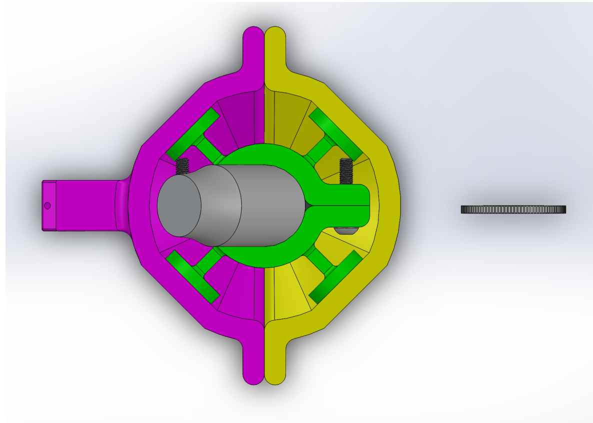

Figure 2: Top View

The design of flexural elements and the selection of strain gauges, DAQ, or off-the-shelf sensors will be based on the data analysis described above. Initial design of flexural elements will use approximations based on simplified beam theory, and we will use finite element analysis to inform the final selection of materials and geometry.

We will also be working closely with surgeons to iterate on the design of the outer shell to ensure an ergonomic design that minimizes obstruction to their view of the drilling site.

Prototyping

Initial rapid prototyping will be carried out using the 3-D printer in the Robotorium and the LCSR machine shop. If any parts need to be prototyped using a CNC machine, we will consult the professional machine shop located on campus. Depending on cost and turnaround time, we may choose to outsource prototyping or machining to an external firm such as Xometry or Protolabs.

Deliverables

Table 1: Deliverables

	Deliverables	Date
Min	Initial prototype (3-D printed) of instrument	5-Mar
	Drilling Experiment Results Documentation	13-Mar
	CAD Assembly in Zip File	21-Apr
	Final Report & Documentation	10-May
Expected	BOM describing all components	26-Mar
	Three 3-D printed iterations of designs	26-Apr
	Fully fabricated (machined) & assembled prototype	5-May
Max	White paper with force readings from instrument measured during eggshell drilling experiment	TBD

Assigned Responsibilities & Milestones

Assigned Responsibilities:

Harsha Mohan will be responsible for the majority of the drilling data analysis. Seena Vafaee will be responsible for experimental data collection and prototyping. We will share the responsibility for CAD work, conceptual design, and engineering design analysis (beam theory analysis, FEA, and sensor selection).

Milestones:

Report on drilling data analysis results (Expected: March 3)
Get surgeon feedback on first prototype(Planned: March 3, Expected: March 8)
Propose budget (Expected: March 5)
Conduct drilling experiment with Atracsys (Planned: March 17, Expected: March 26)
Report on atracsys drilling data experiment (Expected: April 9)
Select off-the-shelf components and record it in a BOM (Expected: March 26)

Dependencies

For this project, we need access to the following facilities and assets: Mock Operating Room, Temporal Bone Lab, 6 DOF Force/Torque Sensor, Atracsys System, Phantom/Temporal Bones, Surgeon’s Time, LCSR 3-D Printer, and LCSR Machine Shop. These are displayed in the chart below.

Most of these dependencies have been resolved. The outstanding dependencies include a source of temporal bones for testing, and funding. We are in discussion with Dr. Deepa Galaiya to determine the availability of temporal bones. Regarding funding, we are in the process of submitting a budget proposal.

Table 2: Dependency Chart

Dependency	Need	Status	Followup	Contingency Plan	Estimated Deadline	Hard Deadline	Resolved?
MockOR Access	For testing with Galen	Seena has access	N/A	Wait for time when Galen is not being usec	N/A	N/A	Yes
Temporal Bone Lab Access	To conduct additional drilling experiments	Can accompany surgeon	N/A	Procede with available data	N/A	N/A	Yes
Funding	For prototyping	Drafting a budget	N/A	Use low-cost on-campus resources	26-Feb	12-Mar	No
Phantom/Temporal Bones	For drilling experiments	Need to acquire more foı	Find out how to get more specimens	Use egg shells as alternative			No
6DOF F/T Sensor	For drilling experiments	Available in the lab	N/A	Proceed with available data			Yes
Atracsys System	For drilling experiments	Available in the lab	N/A	Default to experiment without Atracasys			Yes
Surgeons' Time/Schedule	For ergonomic feedback and performing drilling epx	Coordinating with surgec	Communicate with Deepa	Work around their schedule	N/A	N/A	Yes
LCSR 3-D Printer	For rapid prototyping	Seena has access	N/A	Use 3-D printer in Wyman Park Building			Yes
LCSR Machine Shop	For rapid prototyping	Seena has access	N/A	Use student shop or senior design lab			Yes

Management Plan

Weekly updates will be presented at the Galen meetings every Wednesday at 4pm ET. The team will meet weekly with Anna Goodridge to have detailed discussions every Friday at 1pm ET. The team will consult with Dr. Deepa Galaiya as needed. Seena and Harsha will meet three times per week and use this time as a working meeting.

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