Motorized Flexible Arm Attachment to Tubular Retractor in Brain Surgery
Utilizing Microscopic and Instrumental Alignment

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Mentors: Dr. Alan Cohen, Dr. Axel Krieger, Dr. Mohammed Fouda

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Introduction

Background

Figure 1: Tubular retractors used in industry. *The picture on the left shows Vycor Medical's VBAS retractors[3]. The picture on the right shows NICO Corporation's BrainPath retractors[4].*

Tubular retraction is one state-of-the-art method executed to access deep-seated lesions during brain surgery. In tubular retraction, a tube-shaped device (Fig. 1) is inserted into the brain to provide an operable corridor providing access for surgical tools. Tubular retractors are unconstrained inside the brain (Fig. 2), which can allow unintended movement and lead to excess brain trauma or inconveniences during procedure. Moreover, manual devices used to adjust retractors can be shaky and unwieldy (Fig. 3).

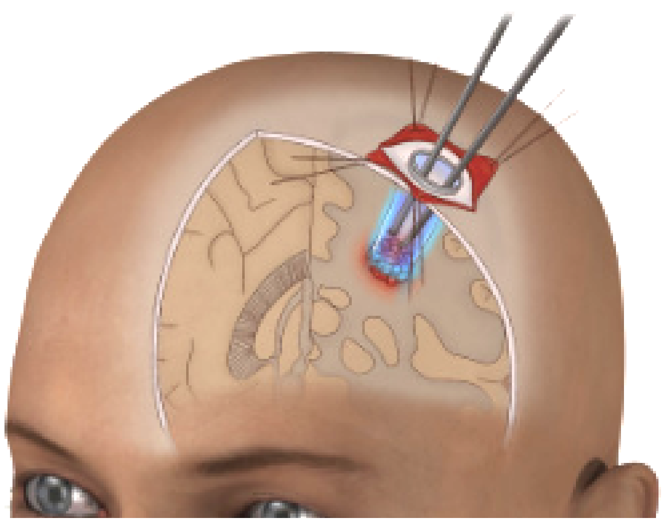


Figure 2: Tubular retractor "floats" in the brain[5].

Inserted tools may come in contact with retractor walls and cause the retractor to shift.

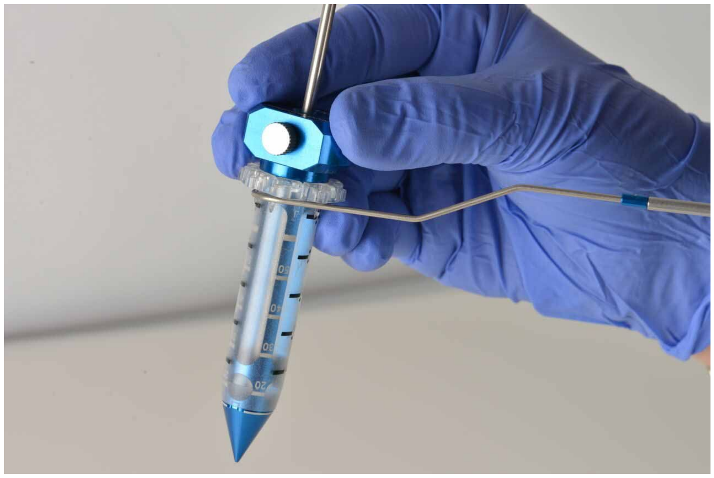


Figure 3. NICO Corporation's Shepherd's Hook technology[6].

The thin metal hook around the retractor is a manual stabilization device, but is difficult to use.

Goal

Figure 4: Flexible snake arm[7].

The base of this structure is clamped onto a patient's hospital bed or retraction system mounted around the patient's head. A tool used in the brain is clamped to the opposite end of the arm. The arm is curved in the surgeon's preferred shape. The middle knob is tightened and the arm becomes rigid.

This project aims to stabilize a custom tubular retractor by attaching it to a flexible snake arm (Fig. 4) and add the capability to electronically adjust tubular retractor orientation during use. Our second goal is to improve usability further by adjusting the distal end of the retractor (Fig. 5A) to follow the tip of the surgical tools in use. The final project goal is to allow alignment of the view through the distal end of the retractor with the surgical microscope's field of vision (Fig. 5B). This project endeavors to create the first mechatronic application of tubular retraction, and in doing so, improve surgical experience and outcome by improving device usability and safety.

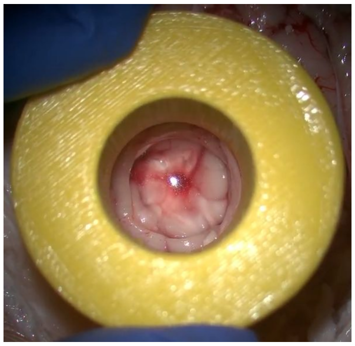


Figure 5A: View through tubular retractor.
The circular opening provides a view similar to the view through the surgical microscope.

Figure 5B: View through microscope[8].
The microscope hovers over the patient; the focused view is projected on a nearby screen.

Significance

Current methods for neurosurgical retraction are well-documented for imparting excessive focal pressure on the brain, leading to high risk of injury. Of the 700,000 neurosurgical cases each year in the US requiring brain retraction, about 9%, or 63,000 cases, exhibit acute retraction-induced injury[1]. Given that major complications cost roughly $50,000 for the patient and that each day spent in the hospital costs around $2,500[13], this amounts to a $3 billion burden on the US healthcare system due to retraction-induced injury.

A case study series where surgeons compared the NICO BrainPath retractor (Fig. 1) to conventional metal blade retractors found a 50% reduction in length of stay, and this reduced ICU time saved critical care facilities $17,000 in direct variable costs on average per retractor use[2]. Developing a safer alternative to typical manual use of tubular retractors such as the BrainPath can protect the health of patients undergoing difficult, relevant surgeries, and reduce the associated financial load on hospitals.

Many new studies have shown that tubular retractors minimize parenchymal trauma and the associated surgical complications [2, 10, 11, 12]. However, these same studies note that the limitations of tubular retractors include their reduced maneuverability, especially in greater depths in the cerebral cortex. This project will improve the safety by decreasing potential unregulated or high-noise movements that are derived from human error during manual adjustments of the retractor. Operational effectiveness will also be increased through more operable controls done through autonomous retractor adjustment to state of surgical procedure.

Technical Approach

Mechanical Design

The intermediate component (Fig. 6) will provide a secure connection between a surgical snake arm and a tubular retractor, fit into the circular cranial aperture fenestrated during the surgical craniotomy, and concurrently bypass the profile of the skull, which is high relative to the sunken brain. The snake arm will remain rigidly in a position dictated by the surgeon during the procedure, as seen in the current standard of care devices; thus, we will implement this aim with the use of market-available snake arms, such as the Leyla Retractor arm. The connecting component will take on the form of a metallic ring in order to fit inside the circular skull hole.

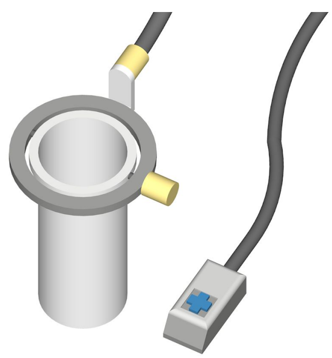


Figure 6: Mechanical. *The connecting component (dark grey) is attached to the tubular retractor and the snake arm (black). The control pad (blue) is at the base of the retractor.*

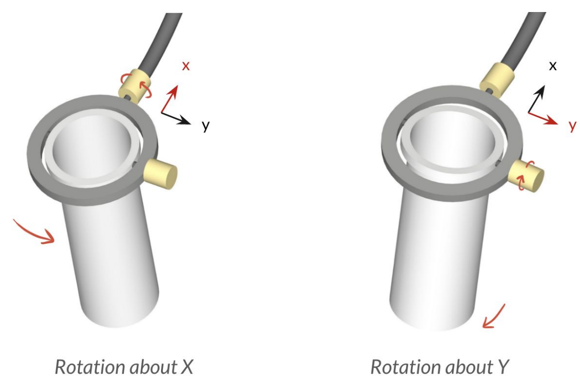


Figure 7. CIS goal. *The tubular retractor rotates for angulation. It rotates about the base motor and the axle on the connecting component (both yellow). Wires that are responsible for rotating the spindle are not shown.*

Because this ring, shown in greater detail in Fig. 8, will require actuation, the attachment will have a built-in axle (a) to which the retractor will attach. While the retractor will attach to the narrow section of the axle seen on the side of component a1, the forces causing rotation will be applied by thin strings connected to the widened section of the axle seen in component a2. The motor responsible for this rotation will be located somewhere at the base of the device (not shown). The strings will stretch from the axle shaft (a2) to this motor through the transmission housing (e). The axle (a2) will be inserted through a small hole and closed up by the spring plug (b). This is necessary so that the surgeon can press in on the axle, load the retractor, and, upon release, firmly secure the retractor in place. The rotation about the other axis will be performed by a motor or axle sitting in component f. Component c will help support this structure by providing a track along which the outer rings of the motor housing (f) will spin. The attachment will avoid obstruction by the skull due to a narrow extension that will protrude upwards from the ring attachment. This extension will interface with the snake arm through coupling this component to a local connector (d) that will screw into the tip of the snake arm in use. This system will be able to be connected in between the snake arm and retractor after the retractor has already been inserted into the brain.

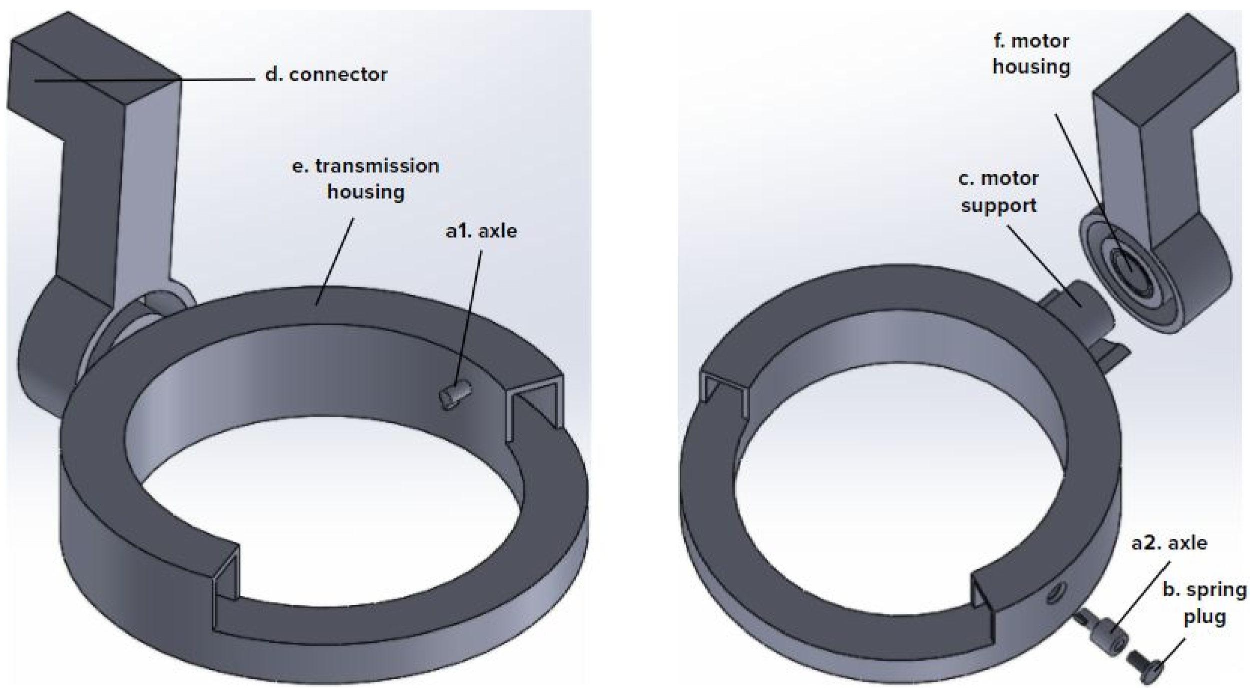


Figure 8. Mechanical Design CAD.

The retractor will be inserted into the ring, with which its circular cross-section will be concentric.

Retractor angulation will require the retractor to be capable of control by surgeon interaction in fine rotational steps about two horizontal axes (Fig. 7*)*. The surgeon will be able to press buttons on a directional pad or joystick style controller to control two sets of motors, each set responsible for rotating about one horizontal axis. This first set will consist of one micromotor that will be part of the local connector screwed into the tip of the snake arm. The second set will consist of two micromotors, enclosed at the base of the Leyla arm, that, when synchronized, will provide clockwise and counterclockwise motion, through wires that extend along the system, to the axle that will lodge into the retractor. These wires will be directed along a minimally obtrusive trajectory with the help of low-friction internal mechanical geometry.

If we discover that this design is not optimal, we may explore other designs. One possible design is a “turret rotation” mechanism which will rotate the outer ring about its central axis. The angling will be done by tilting the central axis with respect to the vertical. This will be accomplished through a motor sitting on top of the ring. This design is anticipated to be less effective because the motor may obstruct the path of surgical instruments. To fine tune the design or select another, “two-axis gimbal” structures will be researched.

Computer Integrated Functionality

The motorized alignment of the retractor will utilize the developed actuation method to realign the tubular retractor’s scope of vision, such that its angle of orientation matches that of the surgeon’s surgical forceps, upon surgeon command (i.e. a button or foot pedal). The surgical forceps will be fitted with inertial measurement units (IMUs) that will be constantly collecting gyroscope and accelerometer data. Similarly, the retractor holder will also be fitted with IMUs that will be collecting the same data. Using this data, we will then apply the methods used by Contreras-Rodriguez et al. (2017) to properly process and filter the data to collect estimates of orientation for both the forceps and the retractor. This will be done using the formula from the paper:

$$\sigma_G = \omega * \Delta t$$

Where sigma_g is our orientation, omega is our gyroscope output, and delta t is the time step at which our gyroscope outputs data.

However, drift is a common problem associated with IMUs; we hope to minimize this through the use of multiple IMUs and by combining the gyroscope and accelerometer data to estimate orientation. To filter out drift we will correct for offset compensation as was done in the Contreras-Rodriguez paper and similarly utilize the direct cosine matrix (DCM) to compensate for drift.

Then, upon the press of a button by the surgeon, the motors holding the retractor will slowly move the retractor so that its orientation matches the orientation of the forceps at the time the button was pressed. This step will require both calibration and a mathematical mapping of the retractor motors so that we programmatically know how motor steps will translate to angle/orientation changes. Furthermore, this movement may result in high levels of noise from the accelerations during movements. In that case we would implement a Proportional Integral Feedback Controller (PI) as was done in the Contreras-Rodriguez paper to remove noise and possibly filter out more drift as well.

For neurosurgery, more so than many other surgeries, precision is essential. When a surgeon moves the retractor during a procedure, the retractor may never move more than 5 degrees in any direction depending on the size and location of the brain lesion. For this reason, it is important that the orientation is able to be estimated with high precision (i.e. within a degree or so). We plan to use multiple IMUs on the forceps (this will be a major difference between our project and the Contreras-Rodriguez et al (2017) paper) and then apply some method of filtering (yet to be determined) that will allow us to determine estimates at a higher resolution. However, if trials with the device demonstrate that we cannot reach the resolution desired even with multiple IMUs, we will add a method of optical tracking.

In the case that optical tracking is required, the forceps would need to be elongated on the back end (non tool side) and optical trackers would be placed at two points along this extended end. A camera system would then need to be installed within the operating room to track the optical trackers. We would then need to determine the coordinates of the trackers in real space using methods from CIS I. It must be noted that this would be a large barrier for introduction to clinical settings and so we will work very hard to gain high enough resolution with the IMUs and only result to optical trackers should it not be attainable.

Management Plan

Deliverables

Minimum (Expected delivery April 13th)

- Hardware that allows for 2 DOF movement of the tubular retractor
- Rudimentary software to align a tubular retractor using motors, based on computer inputs such as a desired coordinate, set of angles, or a control pad/joystick
- Report analyzing the accuracy of our retractor realignment method
- Documentation of Code Base that we create

Expected (Expected delivery April 29th)

- An "orientation object" for collecting orientation/movement data using IMUs
- Finely tuned retractor angling actuation with smooth control through positive and negative x and y axis movements.
- Software that filters and analyzes data collected from the "orientation object" and determines the relative orientation of the object and moves the retractor to a matching orientation when a button or foot pedal is pressed
- Report analyzing accuracy of orientation estimation and matching

Maximum (Expected delivery TBD)

- Surgical forceps retrofitted with IMUs (without hindering their functionality)
- Software adjustments so that will it filter and analyze the data collected from the forceps and move in the same was as it did with the calibration object (New constraints in this system)
- Test report of safety features to limit velocity, maximum angle, and prevent shaky movements from surgeons
- Software that allows for retractor to change realign based on the view of a surgical microscope

Dependencies

If dependency deadlines are not met, alternative solutions will be implemented or critical checkpoints will be delayed.

Prototyping/Fabrication

- 3D printer

  The project host's available ***SLA printer*** *will be used for the mechanical retractor and attachment due to the high accuracy needed for small detailed parts. Deadline not applicable.*
- Surgical equipment

  A ***surgical snake arm*** *(Leyla retractor) is available in a non fully functional state. A fully functional version of this technology will be requested from Dr. Cohen. Spare* ***surgical instruments*** *are available in used form from Dr. Cohen's lab. This is necessary only for modelling instrumental shape, so a fully functional form is not necessary. Deadline to obtain: April 19th.*
- Hardware

  Available: *Arduino Leonardo microcontroller, breadboards, wires, soldering station.*

  Electronic equipment *such as motors, circuit elements/chips, etc, and* ***mechanical hardware*** *such as wires, pins, and fasteners, will be ordered when the specific models of each are determined.* ***Tracking equipment*** *will be requested from Dr. Cohen's lab or ordered online. Deadline to obtain: March 31st.*

Software

- Computing power

  Personal laptops owned by team members offer adequate computing power and support necessary technology such as the arduino microcontroller. Deadline not applicable.

- IMU sensors

  Low cost, accurate accelerometer and gyroscope units are commercially available and ready to be purchased using the project host budget. These sensors are necessary for functioning prototypes. Deadline to obtain: March 31st.

Testing

- Lab space

  Dr. Cohen has a lab allocated to the project host at the medical campus that can be used for testing. If Covid prevents on-campus testing, group member apartment space will suffice. Deadline to obtain: April 19th.

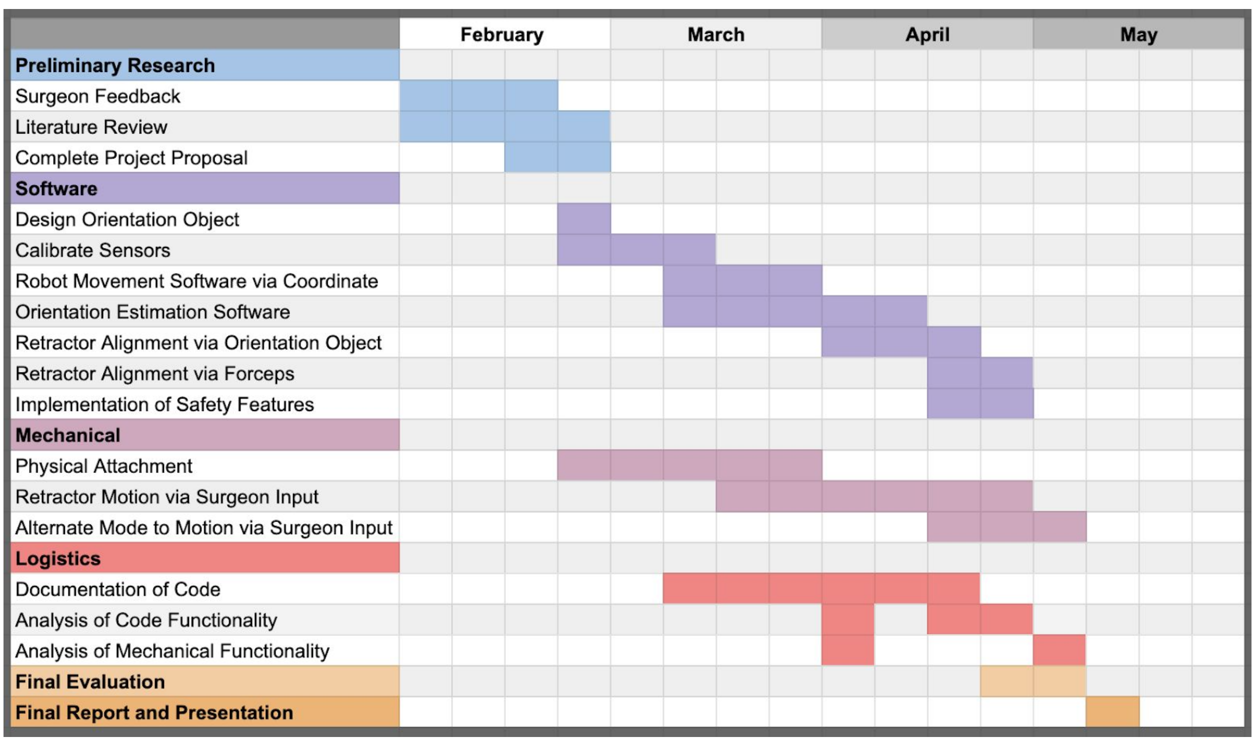
- Testing equipment

  ***Pigs, goats, or cadavers** can be purchased from a vendor in contact with the project host. The project host also has access to **benchtop models** such as polymer brains and gel, which have already been acquired. Deadline to obtain: April 19th.*

<u>Mentors</u>

- Team meeting 1-2 times a week over Zoom
- Weekly meetings with Dr. Axel Krieger at 4 PM on Fridays
- Optional weekly meetings with full CortiTech Team at 9:30 PM on Thursdays
- Biweekly meeting with Dr. Mohammed Fouda, MD
  - Time will vary each meeting based on Dr. Fouda's schedule
- Meetings with Dr. Alan Cohen as and when required

<u>Timeline</u>



Responsibilities

Mark

- Mainly responsible for the mechanical design of our project, including:
  - Design, construction, and actuation of motorized fixation device
  - Design and construction of “orientation object”
  - Time permitting: Retrofitting of sensors onto surgical forceps, joystick control

Caroline and Robby

- Mainly responsible for the design and development of software, including:
  - Initial coordinate based movement software
  - Sensor calibration
  - Filtering and analysis of sensor data
  - Orientation based motor movement
- Will also assist Mark with mechanical development and prototyping as needed

Reading List

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