

Team 9 Proposal

Electromagnetic Tracking of Endovascular Catheters

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1 Introduction

This project focuses on developing a novel approach to replace the commonly used fluoroscopy during endovascular neurosurgical procedures with electromagnetic tracking to minimize radiation exposure. Specifically, we look at using electromagnetic tracking to guide surgeons in navigating their catheters during the endovascular treatment for brain aneurysm.

This project is led by Shanelle Cao, Fangjie (FJ) Li, and Huilin (Lin) Xu, who are all senior undergraduates spanning fields of Biomedical Engineering, Electrical Engineering, Chemical and Biomolecular Engineering, and Computer Science. This project is advised by Dr. Ali Uneri of the I-STAR Labs of the Department of Biomedical Engineering, and Dr. Fernando Gonzalez, an experienced neurosurgeon in the Johns Hopkins Hospital.

2 Background

2.1 Brain Aneurysms

Brain aneurysms are bulges in blood vessels in the brain primarily due to thinning artery walls. They often occur where blood vessels branch, as vessel walls are usually thinner at these locations. Brain aneurysms can either leak or rupture, which will then quickly develop into life-threatening conditions. Leaking or ruptured brain aneurysms may cause severe headaches, stroke, permanent neurological deficits, or death [1]. In the US, around 6.7 million people live with brain aneurysms [2]. Out of the 6.7 million, around 30,000 patients experience ruptured aneurysms annually, with a fatality rate of up to 50% [2].

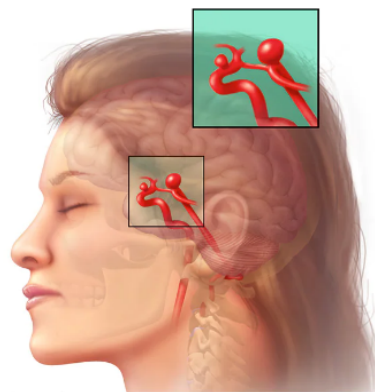


Figure 2.1.1: Brain Aneurysms (taken from [1])

2.2 Current Treatments

With such a high fatality rate, treatments are mainly concerned with stopping further blood flow into the aneurysm to prevent or stop an ongoing rupture. Two different procedures are available for embolizing aneurysms. Microsurgical clipping, as shown in Fig.2.2.1, is where a small opening is made on the skull near the site of the aneurysm, and a clip is inserted to pinch off further blood flow into the aneurysm [3]. This method is highly invasive,

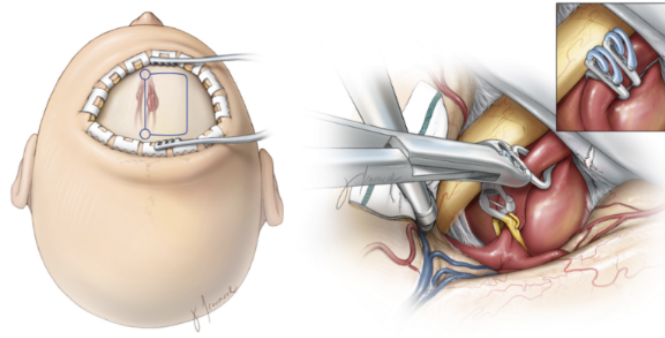


Fig.2.2.1 Microsurgical Clipping (taken from [3])

taking patients long periods of time to heal after the operation. More recently, the endovascular neurosurgical method has been developed, where a catheter is inserted from the femoral artery near the thigh of the patient and navigated to the site of the aneurysm in the brain. Once the catheter reaches the aneurysm, there are two different methods to embolize the aneurysm. One such method is coiling, where a coil of wire is inserted into the aneurysm through the catheter, causing blood clots. The other method is flow diversion, where a mesh

Endovascular coiling

- Aneurysm is accessed by a catheter, inserted in an artery at the groin and guided to the brain.
- Soft platinum wire is fed through the catheter, coiling up inside the aneurysm.
- Causes blood to clot within the aneurysm, sealing it from the artery.



Source: MayoClinic.org.

Flow diversion

- Aneurysm accessed by a catheter, inserted in an artery at the groin and guided to the brain.
- Metal mesh tube is placed in the artery, across the aneurysm.
- Blood flow is channeled through the mesh tube, away from the aneurysm.
- Clot forms within the aneurysm.



Fig.2.2.2 Endovascular Catheter-Based Surgeries (taken from [4])

tube, acting like a stent, diverts the blood flow away from the aneurysm and along the vessel. With no new blood flow into the aneurysm, existing blood inside the aneurysm will clot. Blood clotting will block further blood flow into the aneurysm, preventing or stopping an ongoing rupture. Compared to microsurgical clipping, the endovascular neurosurgical method is minimally invasive.

2.3 Catheter Pathing

Although the endovascular procedure is minimally invasive, it is hard for the surgeons to navigate the catheter to the site of the aneurysm smoothly. Once the catheter enters the patient's body through the femoral artery, it first travels through the aorta to the heart. Along this path, one common mistake is that the catheter will enter the renal artery, which leads to the kidney. To ensure that the catheter is on the right track, fluoroscopy is used during this step. Fluoroscopy uses X-ray to obtain the real-time position of the catheter inside the patient's body. Because the aorta is relatively straight, with artery diameters in the cm range, the poor soft tissue contrast of X-ray is not a concern. Sufficient information is given to the surgeon through the relative position of the catheter to the bone structures.

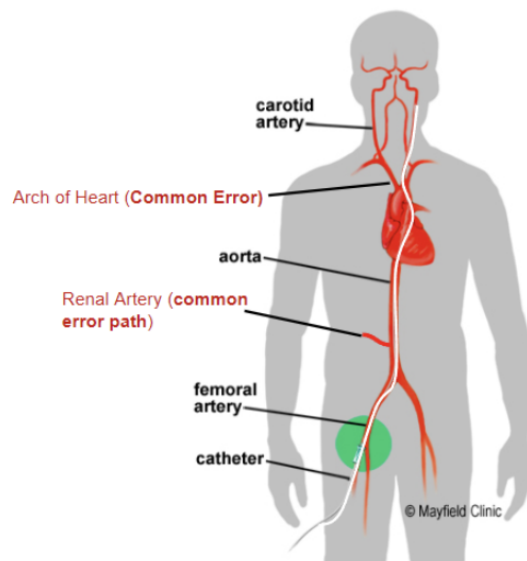


Fig.2.3.1 The arterial path taken by catheter, with common errors highlighted in red (modified from [5])

Once the catheter reaches the heart, the surgeon has to precisely determine the correct carotid artery out of the multiple branches on the aortic arch that leads to the site of the aneurysm. Additionally, the diameter of the arteries from this point on decreases to the order of mm. Due to the intricate structure of vessels in the heart and brain, a more precise imaging technique is needed. Thus, pre-operative CT angiography combined with fluoroscopy with the addition of contrast is used to increase the visualization of blood vessels and tissues.

3 Significance

As described in the background section, for endovascular techniques, fluoroscopy, and CT angiograms are used to help surgeons visualize the position of their catheter in order to navigate the catheter to the site of the aneurysm. However, this process exposes both the patient and surgeon to hundreds of mGy of X-ray radiation. At this level of radiation exposure, there are increased health risks of diseases such as cancer, cataract, non-malignant skin damage, and impaired fertility [6]. In addition, surgeons are especially at increased risk

since throughout their careers, they have to repeat this procedure multiple times. Thus, there is currently a need for methods of detecting catheter position inside the patient without relying on X-ray imaging techniques, which will greatly reduce the amount of radiation that patients and surgeons are exposed to.

4 Goals

To solve the problem as mentioned above, we propose to use electromagnetic tracking to replace X-ray imaging of catheters. There are two main aspects to this project. First, we need to engineer a catheter prototype that is compatible with the electromagnetic tracking system while not impairing its surgical performance. Second, we need to develop a software that is able to track the path of the catheter inside the patient's body, and present it visually to the surgeon for image-guided surgery.

4.1 Minimum Deliverables

At minimum, the project is expected to produce a hardware catheter prototype with an embedded EM sensor at the tip. We expect the prototype to have the following abilities:

1. 5DOF Tracking with the existing Aurora EM system, with sufficient accuracy and robustness.
2. Suitable exterior diameter and rigidity for navigation in middle cerebral arteries.
3. Sufficient Interior catheter diameter for the delivery of tools necessary for aneurysm surgery.

The prototype performance will be determined via evaluation performance.

4.2 Expected Deliverables

The expected deliverable includes the delivery of 3D slicer modules that constitutes a software with the following abilities:

1. Real-time catheter path modeling based on the EM tracker data.
2. Registration of path data onto a coarse, non-patient specific, X-ray coronal image.
3. Visualization of the generated path with the X-ray coronal image.

4.3 Maximum Deliverables

The maximum deliverable builds upon the software work from the expected deliverables. The deliverable will come in the form of extra software modules added to the software framework built for the expected deliverables. It will have the following abilities:

1. Registration of path data onto a pre-operative CT angiography (CTA) scan.
2. 3D Visualization of the path with CTA.

5 Prior Work

Prior work done by the I-STAR Labs has focused on path visualization of EM sensor data in 3D Slicer. The software developed is able to do real-time tracking of the sensor and overlay the path of the sensor on corresponding CT images.

However, after we reproduced the algorithm, we found the reliability of the registration algorithm between the sensor frame and CT frame is not ensured. Besides that, the catheter prototype is easily damaged, and the catheter is not flexible enough to ensure smooth passage in the blood vessel.

6 Technical Approach

6.1 Overview

For the hardware, we will redesign the catheter to have extra protection outside without losing its flexibility at the same time. Detailed design information can be found in section 6.3.

For the software, the main task is the registration problem between the catheter (i.e., the sensor frame) and the patient model (i.e., the CT frame). As discussed in section 2.3, for the part below the chest, only a rough model showing the relative position between the catheter and the patient's organ is needed. Our approach uses a non-patient-specific model, such as coronal X-ray imagery, to represent the body's anatomy. Since high accuracy is unnecessary in this case, the registration algorithm can be relatively simple. The detailed algorithm can be found in section 6.4. However, after the catheter enters the aorta arch and carotid artery, precision will become essential. Thus, a more advanced registration algorithm is needed in this case. We suggest using a 3D vascular model from CT angiography to represent the anatomy of this part, and non-rigid registration methods can be used. Details can be found in section 6.5.

6.2 Experiment Setup

Aurora Field Generator generates an electromagnetic field around the phantom. The field will cause current to run through the coil in front of the Aurora 5-DOF sensor. By measuring the voltage across the sensor, the position and orientation of the catheter can be determined.

We will use a torso arterial phantom for data collection, testing, and evaluation purposes. The Aurora Field Generator will be placed above the phantom. The Aurora 5-DOF sensor is attached to the catheter.

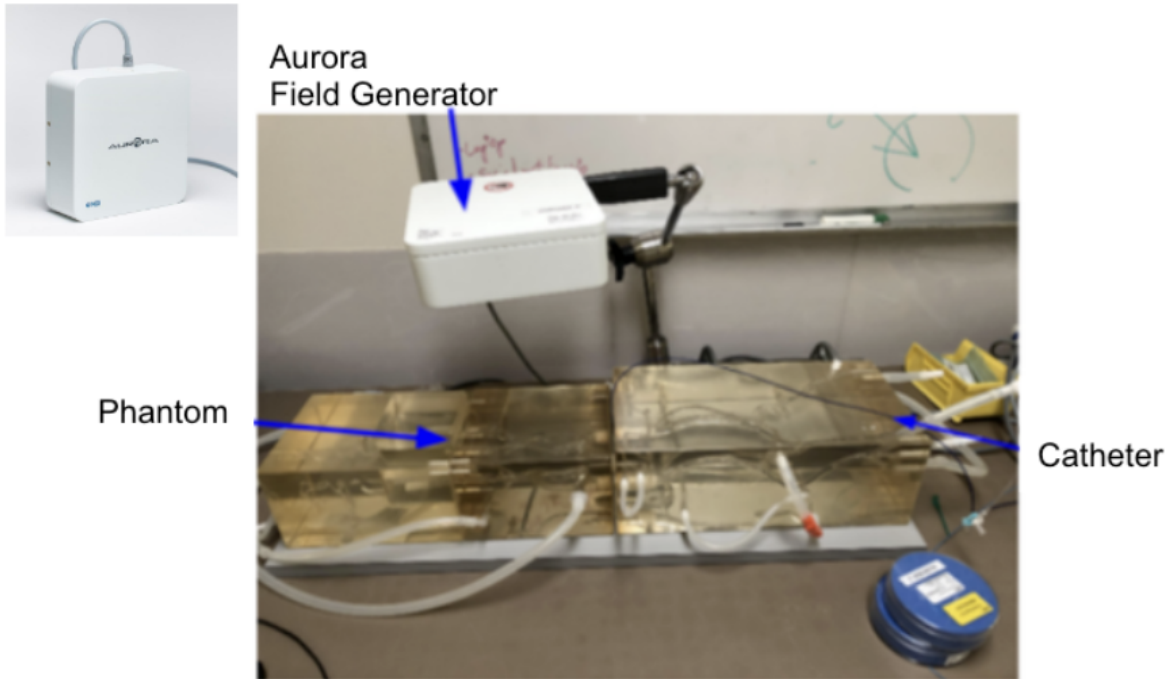


Fig. 6.2.1 The setup of the Aurora Field Generator above the arterial phantom

6.3 Catheter Design

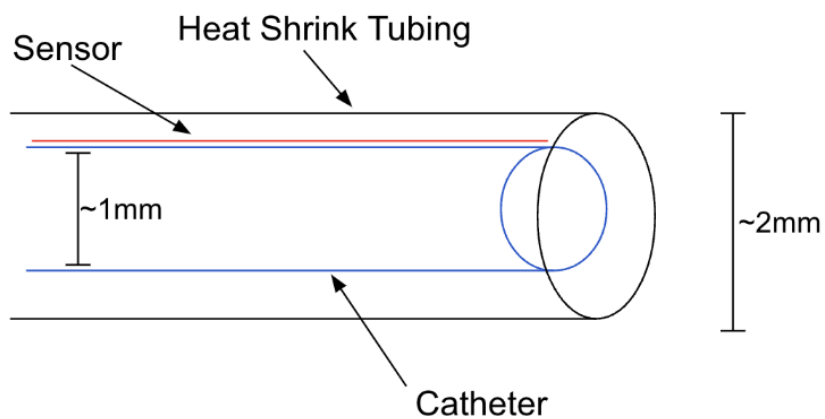


Fig.6.3.1 The general schematics of the catheter prototype with integrated EM sensor

The sensor wire will be enameled with insulation varnish to provide electrical insulation and prevent the windings from short-circuiting. This also gives sensor wire good chemical and thermal resistance. To avoid direct exposure of the sensor to blood, heat shrink tubing will be applied as the housing of the catheter, adding extra protection to the sensor.

Another advantage of this design is that it places the sensor outside the catheter, leaving enough space for medical tools or instruments inside.

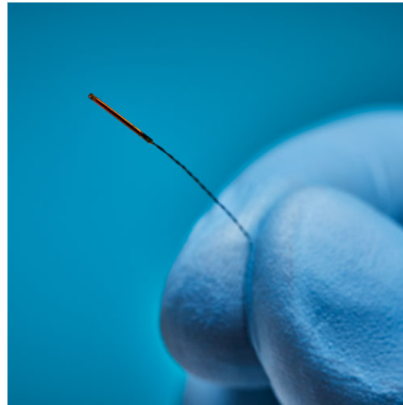


Fig.6.3.2 The EM Sensor of the Aurora system from NDI

The size and diameters of the catheter are the other factors needed to be carefully considered here. Catheters with an inner diameter of >0.040 inches for supporting surgery operations. However, they must be smaller than 2.5 mm to fit in the middle cerebral artery in an average patient [8]. The diameter of the 5-DOF sensor is 0.45mm. The diameter of the catheter to be used is around 1mm (varies based on surgeons' needs). The wall thickness of the heat shrink tubing is 0.5mm. So in total, the diameter of the integrated catheter is controlled within 2mm. Therefore, the prototype will satisfy both the internal and external diameter constraints.

6.4 Rough Model Registration

As discussed in section 2.3, for the part below the chest, coronal X-ray imagery will be used as a rough model of the patient to guide the catheter insertion. The registration between X-ray imagery and the patient's body is needed.

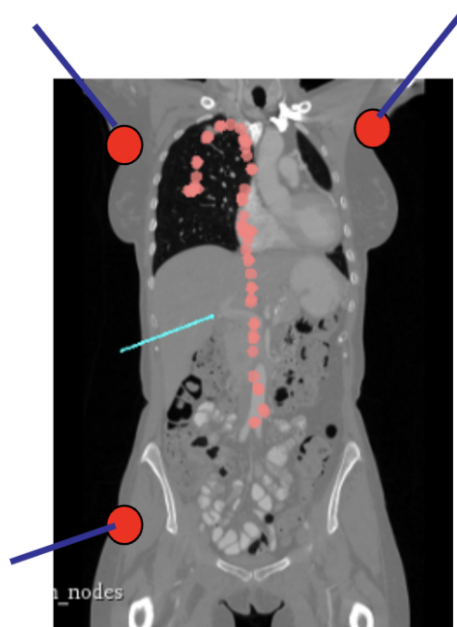


Fig. 6.4.1 The planned fiducial points registration for rough model

Here is our suggested approach:

1. Manually select several fiducial points on the model. The software will be able to calculate the position of selected fiducial points with respect to the rough model frame. Those fiducial points can be easily accessible positions on the body, such as the armpits or entrance point of the femoral artery.
2. Place the tip of the catheter on the corresponding places of the fiducial points on the patient's body.
3. Points cloud registration is performed to find the transformation between the patient's body and the rough model.

6.5 CT Registration

For above-aortic-arch navigation, the catheter needs to travel through narrow and tortuous arteries with many junctions. Therefore, there is a need to use detailed and accurate registration and visualization methods, in order to supplant fluoroscopy.

We plan to use a pre-operative CT angiography (CTA) scan to accurately register the catheter path. The planned approach is as follows:

1. From the segmented artery model of CTA, we will generate a skeletal model of the arteries by computing artery centerlines [8].
2. Using the same path tracking model as before, the path curvature will be recorded.
3. Non-rigid curvature mapping will be applied to register the path on the artery model, using coherent point drift [9].

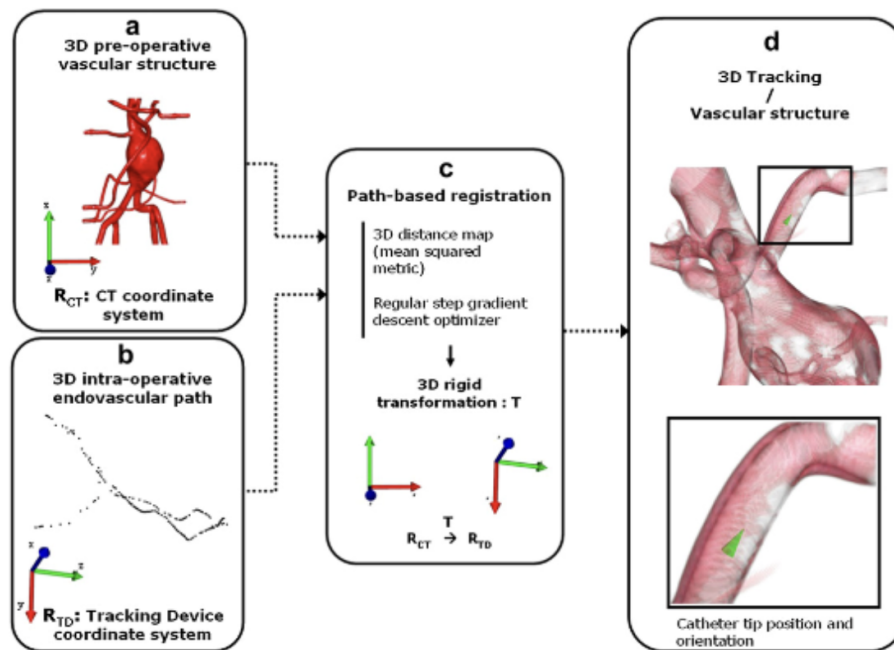


Fig. 6.5.1 The General Schematics of the Non-Rigid Path Registration with CTA

7 Dependencies

A list of hardware and software required for the project can be seen in table 7.1. Three components are still unresolved.

The prototyping materials for the catheter have not been acquired. A bill of materials has been determined for the prototype, and we need to discuss it with our mentor to secure the materials. As the materials are common electronic components (insulation varnish, heat shrink tube, etc.), we believe that most will be available in the lab workspace, and the rest can be acquired through common vendors such as Digikey. If the materials are unavailable, we will continue with other aspects of the project using an existing prototype from prior work.

The brain artery phantom will be used for data collection and evaluation of the maximum deliverable. We believe that our mentor may have access to such a phantom. If not, we will build a simple phantom using rubber tubings and 3D-printed materials.

Dependencies	Status	Follow-Up	Contingency Plan	Deadline
Aurora EM Field Generator	Acquired	—		—
Aurora 5-DOF Sensor	Acquired	—	Purchase multiple	—
Preliminary Catheter Prototype (for early stage data collection)	Acquired	—		—
Prototyping Materials (wires insulation varnish and heat shrink tubing)	Unacquired	Will be ordered/acquired after discussing design with mentors	Existing prototype may be used to support the project	March 1st
Prototyping Tools & Workstation (soldering station, heat gun, etc.)	Acquired	—		—
Main Body Artery Phantom	Acquired	—	Use backup phantom or DIY	—
Main Body Coarse Model	Acquired	Currently using phantom CT data; may switch to open X-ray dataset if available		
Brain Artery Phantom	Unacquired	Will discuss with mentors on availability	DIY w/ tubing & 3D printing	April 1st
Cerebral CTA Data	Unacquired	Will acquire through open source database		April 1st
Softwares (Computer with 3D Slicer, Plus server, Aurora driver, and path visualization module installed)	Acquired	—		—
Access to lab space and workshop	Acquired	—		—

8 Timeline

Our project timeline is listed in figure 8.1. We will focus on the minimal and expected deliverables before April. If both deliverables are on track to be accomplished by early April, we will start working on the maximum project for the remainder of the term. Many tasks are planned for a given time, due to the fact that there are three members in our group.

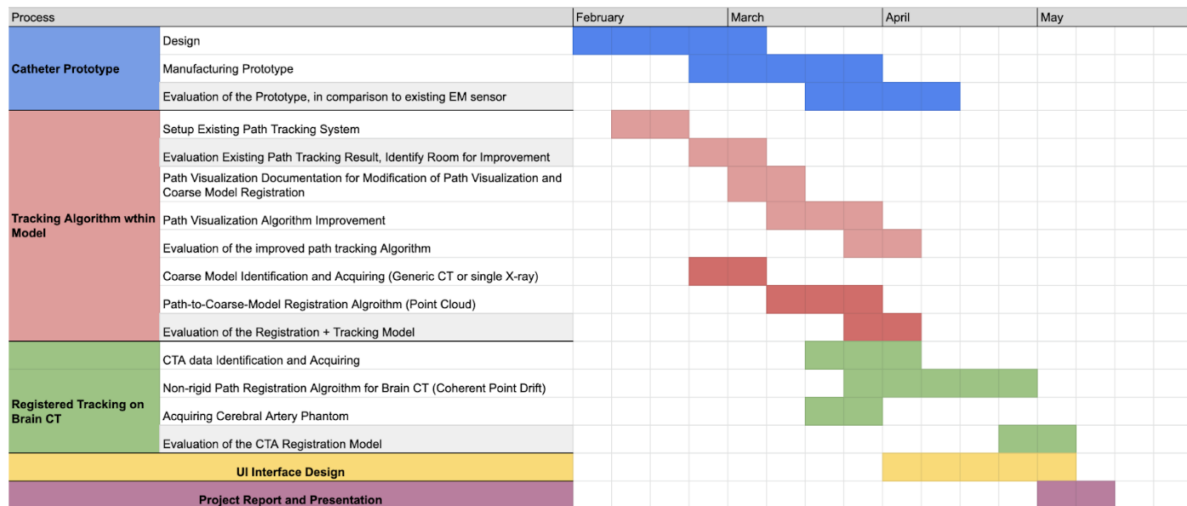


Fig.8.1 Project Timeline

9 Management

9.1 Role Distribution

At the start of the term, Huilin Xu will be responsible for manufacturing the prototype catheter and evaluating it. For the second half of the term, if the catheter prototype passes our evaluation, she will work on the maximal deliverable. She will be responsible for preparing the CTA data and implementing non-rigid registration.

At the start of the term, Shanelle Cao will work on the rough model registration along with Fangjie Li. After its completion, she will also move on to the maximal deliverable with the implementation of the non-rigid registration.

Fangjie Li will be responsible for drafting the evaluation test protocols for both the rough and CTA model registration algorithms. He will also be working on the path modeling and rough model registration deliverables.

9.2 Weekly Meeting

The team will be meeting with the mentors every Thursday at 3:30 pm, in the lab space to discuss progress and plans. Additionally, the students will meet every Tuesday at 3:30 pm to discuss logistics.

10 Reading List

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