COMPUTER INTEGRATED SURGERY II
EN.601.456.01.SP23

DaVinci-Assisted Continuum Robot Navigation and Manipulation System
Project Proposal

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Date: February 24, 2023

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1 Introduction

(a) (b)

Figure 1: Commercial surgical robots: (a) 6-DOF DaVinci surgical robots[1]. (b) Ion Inc.'s Endoluminal System which has a continuum robot end[2].

The DaVinci robot arm is a state-of-art surgical robot that offers 6-DOF translational and rotational joint control. Tendon-driven continuum robots, on the other hand, use flexible, curving structures to navigate tight spaces and perform delicate tasks (shown in Fig. 1). They have several advantages over traditional rigid robots, including improved accuracy, flexibility and reachability.

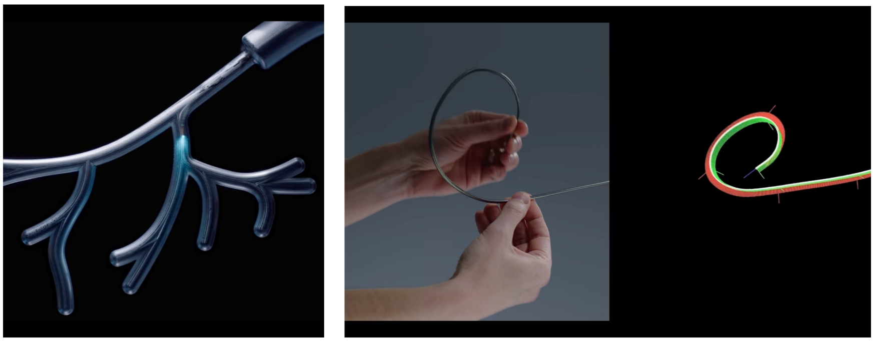
This project has wide application in surgical domains. Taking the lung biopsy as an example which previously need manual insertion of catheter by surgeons. After a continuum robot catheter was introduced to the lung biopsy field, "the pulmonary nodule biopsy resulted in an 83% diagnostic yield, which represents the likelihood that tissue samples obtained during the procedure will provide physicians with information needed to establish a diagnosis."[3]

Furthermore, our proposed robot system builds on these technologies by combining the accuracy, flexibility and reachability of the dVRK robot arm with the unique capabilities of a tendon-driven continuum robot end. By doing so, we aim to build a new design of dVRK and a corresponding navigation system that overcomes the limitations of traditional rigid robots and offers improved reachability in surgical robotics systems.

1.1 Background

As shown in Fig. 2, the inspiration for this project was drawn from the ION surgical robot, which has demonstrated the potential of flexible and accurate robotic catheter ends for minimally invasive solutions in lung biopsy[3]. With continuum robotic end such as ION, surgeons can access small lesions located deep within the lungs, which is made possible through distal tip articulation which helps target catheters to small areas outside of the airway. Preliminary studies have also shown a relatively low incidence of pneumothorax that requires medical intervention.[3]

As for the development of dVRK system, We aim to leverage the available resources of the DaVinci platform and dVRK resources at Johns Hopkins University[4], and will receive technical training from Anton Deguet in the Laboratory for Computational Sensing and Robotics (LCSR) to develop our



(a) (b)

Figure 2: Ion Inc.'s Endoluminal System[3].

navigation and manipulation algorithm.

Although there exists a good dynamic model of the tendon-driven catheter, the limited practical application of flexible catheters on the dVRK system has created a compelling opportunity for us to fully develop our project and expand the scope of flexible catheter applications in surgical robotics.

1.2 Goal

The primary goal of this project is to develop a continuum robot navigation and manipulation system that combines the advantages of accuracy and reachability of the dVRK robot arm and the unique flexibility of a tendon-driven continuum robot end. To achieve this goal, we will first generate a new design of dVRK with flexible endoscope, and then build a corresponding system of navigation and remote actuation, where we will re-identify the workflow of the continuum dVRK starting from `IO` and `PID`. Throughout the whole design and development procedures, we will especially focus on adapting various surgical catheters[5] to our continuum dVRK. The teleoperation between `ARM` and `MTM` is our highest expectation in the end.

1.3 Significance

As a comprehensive project with novel design, where we make our own continuum dVRK and build corresponding navigation system from the bottom. The project could lead further enhancement to dVRK platform.

The significance of our proposed system also lies in its potential impact on the field of surgical robotics. By offering better reachability and dexterity in delicate surgical procedures, our proposed DaVinci-assisted continuum robot navigation and manipulation system has the potential to improve surgical robotics and patient outcomes.

2 Technical Approach

2.1 Workflow

In this section, the technical approach for developing a new continuum robot end effector for surgical applications will be presented. The proposed workflow consists of mechanical design, experimentation, computer integration, and potential applications, as shown in Figure 3.

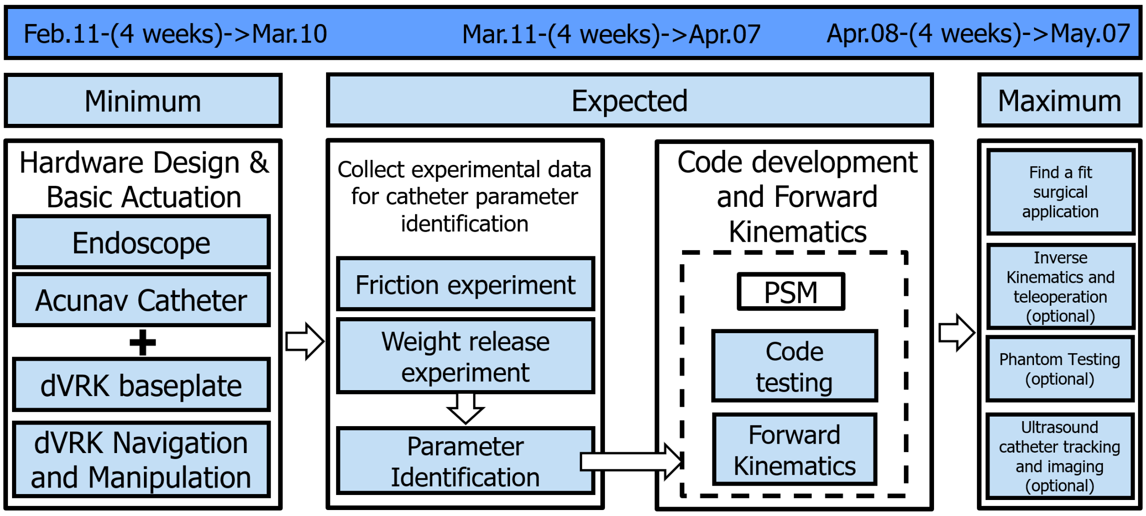


Figure 3: Basic workflow.

The first phase of the approach involves designing a new continuum robot end effector that incorporates the desirable characteristics of the available endoscope catheter and Acunav catheter. The team will compare the available actuators, mechanisms, and materials, and identify suitable components for the new end effector. Once the design is complete, the Acunav catheter will be assembled into the dvrk baseplate based on the endoscope mechanism. Basic actuation on dvrk will then be achieved to ensure that the hardware design is functional.

The second phase of the approach involves conducting experiments to obtain the necessary results for identifying catheter parameters using the DaVinci platform actuation. The team will conduct the friction experiment and weight release experiment for catheter parameter identification. These experiments will provide the necessary data for the identification of the basic parameters of the catheter, such as Young's module, Poisson's ratio, viscous damping ratio, and friction coefficient. The team will use these parameters to develop the code for forward kinematic actuation on PSM.

The third phase of the approach involves computer integration. At the beginning of this phase, the team will learn how to actuate the robot arm and catheter using simple Python and ROS commands, and detect the actuation via the GUI of dvrk. In order to manipulate and navigate the continuum robot catheter on the patient side manipulator, a dynamic model will be developed. The team will calculate the d-H parameters based on the parameters identified in the experimentation phase and use the dynamic model to control the movement of the catheter.

The fourth and final phase of the approach involves identifying a suitable surgical application for the new continuum robot end effector. The team will evaluate different surgical procedures and select one that requires the use of a continuum robot catheter. They will then test the new end effector and the algorithms on a phantom or a simulated environment to ensure that the design is functional and efficient.

2.2 Mechanical Design and Motion control principles

In this section, the focus is on designing a new continuum robot end effector that incorporates the desirable characteristics of the available endoscope catheter and Acunav catheter. The team will compare the available actuators, mechanisms, and materials, and identify suitable components for the new end effector. Once the design is complete, the Acunav catheter will be assembled into the dvrk baseplate based on the endoscope mechanism. Basic actuation on dvrk will then be achieved to ensure that the hardware design is functional.

As shown below, it illustrates the difference in mechanism between our endoscope catheter and the Acunav catheter. For the endoscope, each pulley on the dVRK baseplate controls 1 DOF(Degree of Freedom) motion. So we can control the bending in pitch(1 DOF) and yaw(1 DOF), and rolling(1 DOF) via rotary joints on the baseplate. For the Acunav catheter, each pulley on the dVRK baseplate controls 0.5 DOF motion. So we can control the bending in pitch(0.5 DOF+ 0.5 DOF), and yaw(0.5 DOF+ 0.5 DOF) via rotary joints on the baseplate. To achieve rolling, we need to design a new motion control principle and mechanism, or replace it with dVRK robot joint motion.

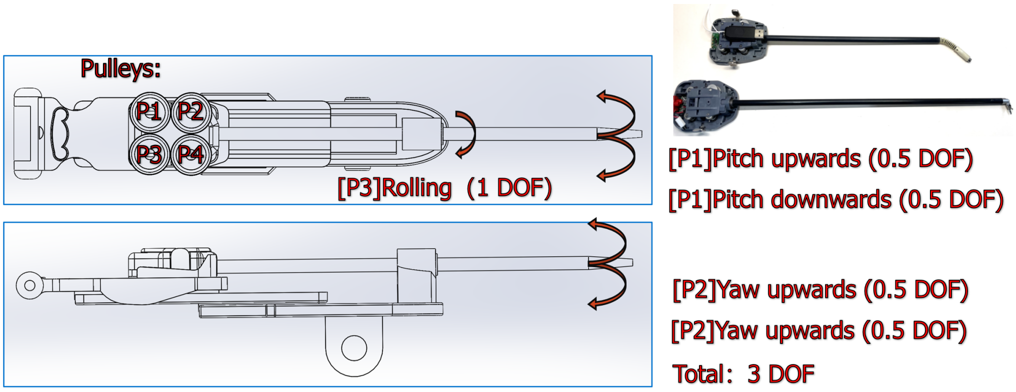


Figure 4: Motion control principle of the Endoscope catheter.

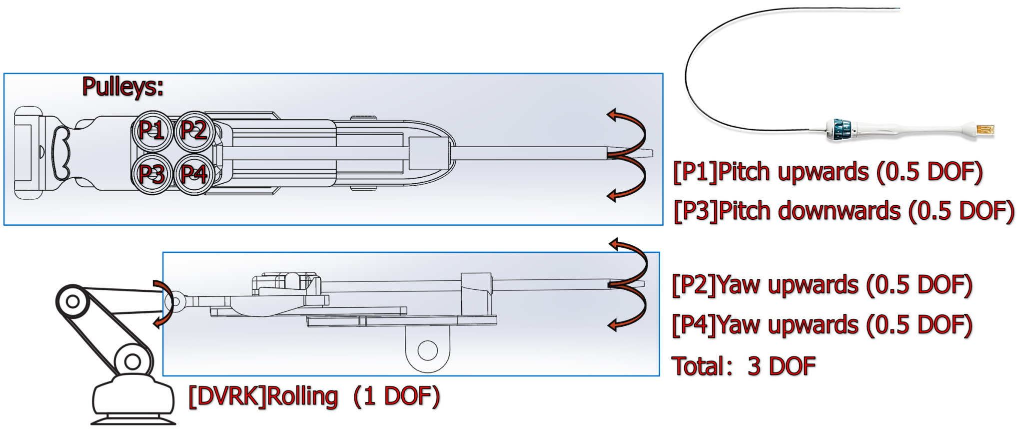
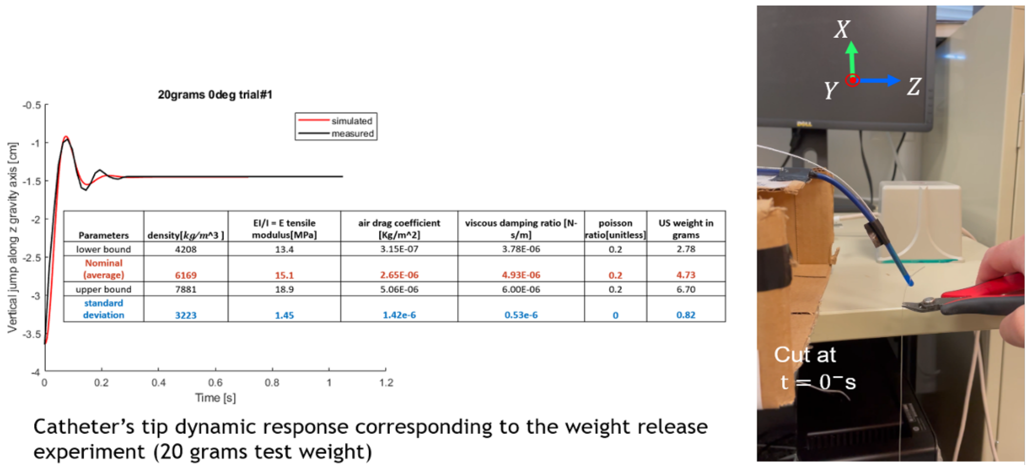


Figure 5: Motion control principle of the Acunav catheter.

2.3 Experiments and parameter identification

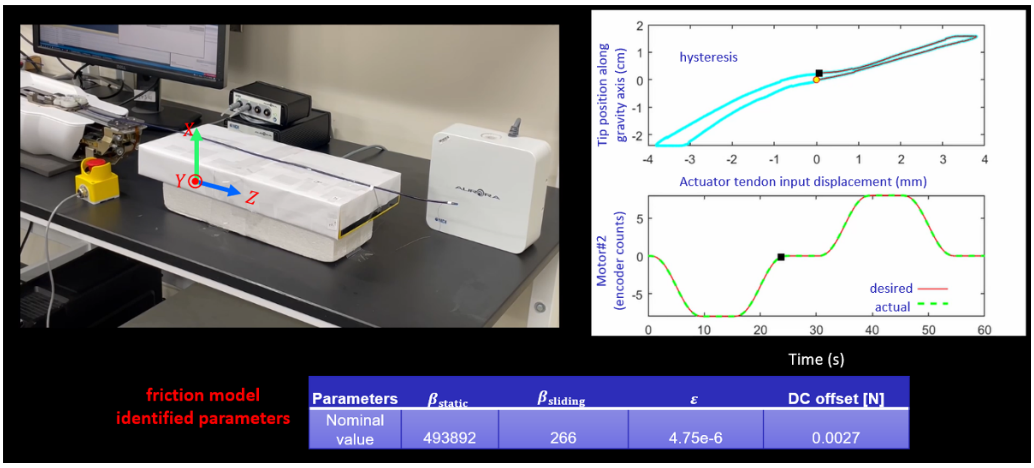
After that, we are going to take two experiments based on previous work from our mentor Mohammad. He has already developed the experimental environment and a complex model for parameter identification. We will first take the weight release experiment and then the friction model experiment. And then build an easier model with his instruction. So that we can identify the basic parameter of our catheter by the model and experimental data.



Parameters	density[kg/m^3]	EI/I = E tensile modulus[MPa]	air drag coefficient [Kg/m^2]	viscous damping ratio [N-s/m]	poisson ratio[unitless]	US weight in grams
lower bound	4208	13.4	3.15E-07	3.78E-06	0.2	2.78
Nominal (average)	6169	15.1	2.65E-06	4.93E-06	0.2	4.73
upper bound	7881	18.9	5.06E-06	6.00E-06	0.2	6.70
standard deviation	3223	1.45	1.42e-6	0.53e-6	0	0.82

Catheter's tip dynamic response corresponding to the weight release experiment (20 grams test weight)

Figure 6: Experiments to identify catheter parameter.



Parameters	β_{static}	$\beta_{sliding}$	ε	DC offset [N]
Nominal value	493892	266	4.75e-6	0.0027

Figure 7: Experiments to identify catheter friction model.

2.4 Computer Integrated Functionality

The third phase of the approach involves computer integration. At the beginning of this phase, the team will learn how to actuate the robot arm and catheter using simple Python and ROS commands, and detect the actuation via the GUI of dvrk. In order to manipulate and navigate the continuum robot catheter on the patient side manipulator, a dynamic model will be developed. The team will calculate the DH parameters based on the parameters identified in the experimentation phase and use the dynamic model to control the movement of the catheter. Following the dVRK architecture shown in Fig. 8, we will build the whole robot system in **Python** and **ROS**.

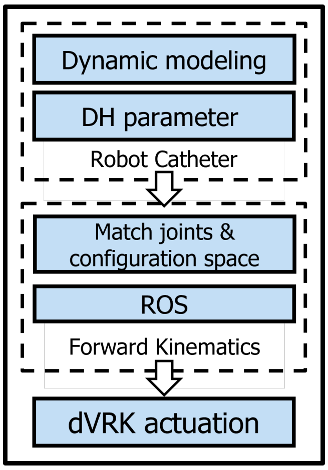


Figure 8: Overall architecture of dVRK[4].

2.5 Application

In this section, the focus is on identifying a suitable surgical application for the new continuum robot end effector. The team will evaluate different surgical procedures and select one that requires the use of a continuum robot catheter. They will then test the new end effector and the algorithms on a phantom or a simulated environment to ensure that the design is functional and efficient. The team will also assess the safety and efficacy of the new device and make any necessary modifications before proceeding to clinical trials. The goal is to develop a new surgical tool that will improve patient outcomes and advance the field of minimally invasive surgery.

3 Management

3.1 Deliverable

a. **Minimum: (Expected by 3.10, 4weeks)**

- **Mechanical design enhancement and designs innovation**
  Connection mechanism design
  Prototyping & testing
- **Verify the basic actuation function of dVRK with continuum end-effector through ROS and GUI**
  Training and getting access to DaVinci operation
  Learning dVRK navigation through GUI and ROS
  Actuating the dVRK with continuum end-effector

b. **Expected: (Expected by 4.07, 4weeks)**

- **Obtain experimental results needed for identifying catheter parameters**
  Setup experiments of the Acunav catheter
  Applying the experiment data to pre-defined model to get catheter parameters
- **Code development and forward kinematics actuation based on catheter parameters**
  Constructing the initial state of forward kinematics
  Integrate algorithms enable precise actuation of continuum effector

c. **Maximum: (Expected by 5.07, 4weeks)**

- **Find a fit surgical application**
  Find a fit surgical application to our DaVinci-assisted continuum robot navigation
  Teleoperation of the catheter using DaVinci dVRK
  Control tip of Acunav catheter to do ultrasound imaging of a phantom

3.2 Timeline

Our project follows the timeline shown in Fig. 9. In terms of timeline, we plan to spend three weeks on the minimum part of the project, during which we will work on mechanical design and test the catheter with the dVRK. The expected part will take four weeks, during which we will design experiments to obtain performance data for the catheter and build a complete forward kinematic for precise control of the catheter's tip with the dVRK. The maximum part of the project involves finding a suitable surgical application for our system and completing as much work as possible before the exam date.

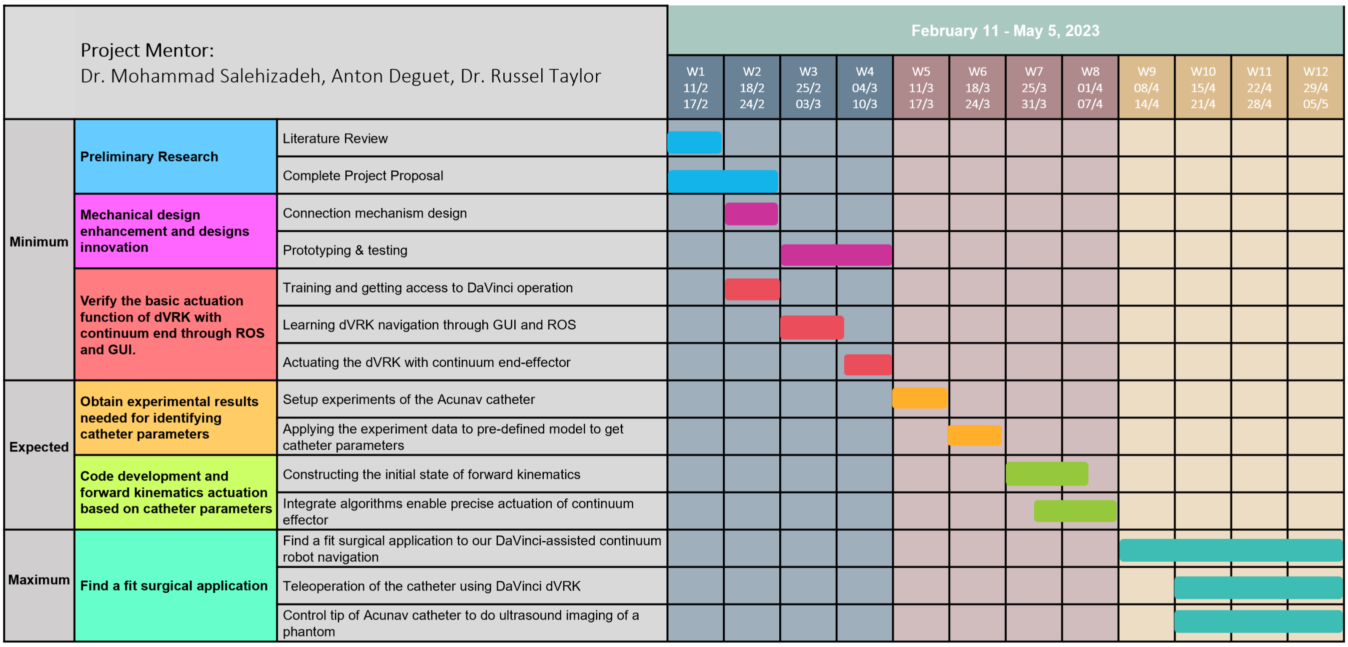


Figure 9: Gantt Chart for project timeline.

3.3 Key Dates

There are several important key dates: on Feb 23rd we will finish project presentation as well as the proposal, after which we can start our mechatronics(till Mar 10th) and computer-integrated functionalities(till Apr 7th). All the documentation will be well organized by May 7th. The detailed key dates are extracted in Fig. 10.
Our milestones and output include obtaining an Acunav catheter that can be mechanically controlled by the DaVinci system, and demonstrating the ability to actuate the catheter with the dVRK. We will also obtain performance data for the catheter through experiments, and by April 7th, we aim to have developed accurate code for actuating the catheter.

	Milestones	Output (submit in the team's chat)	Deadline	Status
Minimum	Complete project proposal	5-8 pages summary	Feb.23	Done on Feb.22
	Prototyping & testing	An Acunav Catheter that can be controlled mechanically by DaVinci	Mar.10	In progress
	Actuating the dVRK with continuum end	Video about actuating the continuum end by dVRK	Mar.10	In progress
Expected	Obtain experimental results for parameter identification	PDF document and data visualizations	Mar.24	Waiting
	Integrate algorithms enable precise actuation of continuum ends	PDF document and code with comments	Apr.07	Waiting
Maximum	Find a fit surgical application	PDF document	May.07	Waiting

Figure 10: Key dates for documentation, mechatronics and computer-integrated functionality.

3.4 Responsibilities

This is a comprehensive project where all team members should try their best to engage in both literature research, design, coding as well as documentation. Several major work and responsibilities are listed based on the team member's skill set.

Member	**Major work**
Jaspor Jiang	ROS, dVRK platform, dynamic modeling, documentation
Heyun Wang	Forward kinematics, parameter identification, experiment
Chenhan Zhang	Mechanical design, prototyping, literature review

3.5 Dependencies

- **End effectors for testing**
  Need: Rigid endoscope and Acunav Catheter
  Contingency plan: N/A
  Planned date: Feb.27
  Hard date: Feb.29
  Status: Acquiring
- **Access to hardware Models**
  Need: CAD Model of Acunav catheter and DaVinci baseplate
  Contingency plan: Manually measurement and modeling
  Planned date: Feb.27
  Hard date: Feb.29
  Status: Acquiring files
- **Software installation: ROS, MATLAB, CISST library**
  Need: License
  Contingency plan: Use Lab Computer with preinstalled software
  Planned date: Feb.24
  Hard date: Feb.27
  Status: Acquired
- **Access to dVRK**
  Need: Access and training from Anton Deguet

Contingency plan: N/A
Planned date: Feb.25
Hard date: Mar.02
Status: Acquiring

- **Weight release experiment**
  Need: EM tracker sensors
  Contingency plan: N/A
  Planned date: Apr.07
  Hard date: Apr.17
  Status: Acquired

- **Phantom**
  Need: Testing
  Contingency plan: Go without phantom testing.
  Planned date: Apr.22
  Hard date: Apr.27
  Status: waiting

3.6 Management Plan

Weekly meetings

a. Student team meeting: brainstorming, third times a week

b. Lab meeting: dVRK training

c. Mentor meeting: progress report, 3:30 PM-5:30 PM each Friday

Platforms

a. Zoom, Email: communication

b. Github: codes, documentation

c. Microsoft Teams: communication, documentation

4 Acknowledgements

We would like to thank Professor Emad Boctor for generously providing us with the Acunav ultrasound catheter.

5 Reading List

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6 Reference

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