Design and Control of a Continuum Wire Manipulator (CWM) for Minimally-Invasive Surgery

EN 601.656 CIS II PROJECT 2

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Introduction

The retina is a "layer of nervous tissue that covers the inside of the back two-thirds of the eyeball, in which stimulation by light occurs, initiating the sensation of vision" and "is actually an extension of the brain, formed embryonically from neural tissue and connected to the brain proper by the optic nerve". [3] Any damage to the retina may cause irreversible and permanent visual field defect or even blindness.

Retinal surgery has long drawn the attention of engineers and clinicians who identified a clear use case for robotics and assistive technology. [3] This technology is challenging to make, however, because of the requirement to be extremely small, delicate, and precise. In retinal surgery, skilled practitioners operate on the boundaries of human capability, dealing with minuscule anatomic structures that are both fragile and hard to discern. Surgical operations on the retina, a hair-thick multilayered structure that is an integral part of the central nervous system responsible for vision, spurred the development of robotic systems that enhance perception, precision, and dexterity.

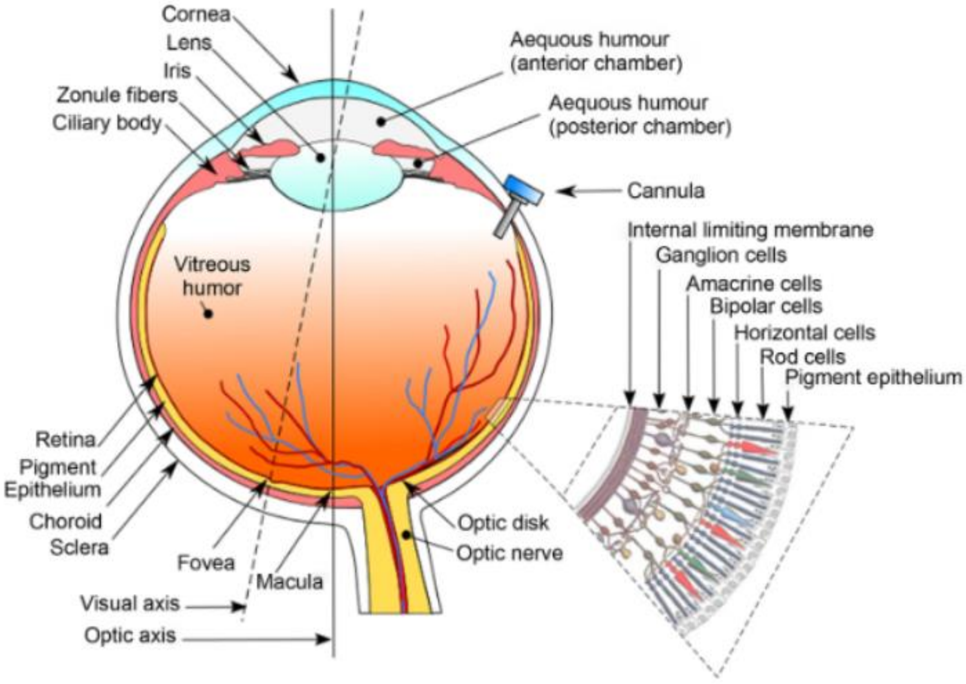


Fig1. Anatomy of the eye with retinal cell layers enlarged.

Continuum robots are more recent developments in the robotics world with non-rigid bodies shown to be able to be designed in very miniscule manners. [1,2] Continuum robots have been shown to be particularly effective at navigating through tortuous anatomical pathways in the human body. [2] Some have shown promise of steering along 3D curves in confined spaces and dexterously handle tissues.

The two most popular and used continuum robots in the medical world are tendon-driven robots and continuum tube robots (CTCRs). CTCRs comprise a series of pre-curved elastic tubes that can be translated and rotated with respect to each other to control the tube manipulator shape and tip pose. It is a rapidly maturing technology that has seen extensive research over the past decade. [1] Today, they are being evaluated as tools for a variety of surgical applications, as they can offer precision and manipulability in tight workspaces.

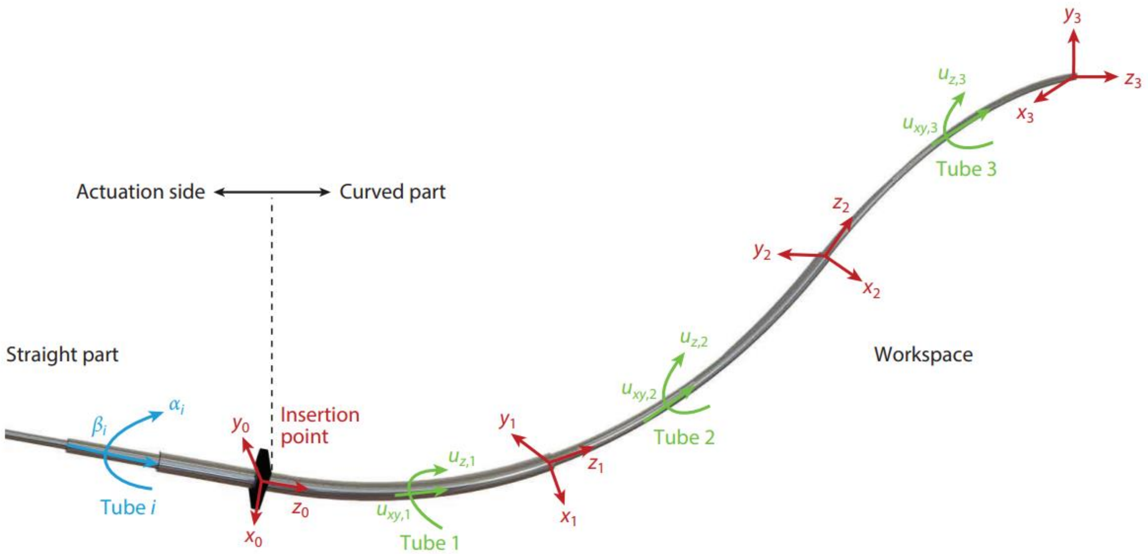


Fig2. An example of a concentric tube robot (CTCR). The CTCR is a popular and effective continuum robot introduced in 2006, and has been developed for a wide variety of minimally-invasive surgical tasks. It is the closest relative to the CWM manipulator developed here.

This proposal presents work at the intersection of continuum robot development and retinal surgery to create a device for safe subretinal injection by developing a robot and controller for a novel tendon-only manipulator, the continuum wire manipulator (CWM). The proposed technology utilizes flexible continuum structures and precise control of state-of-the-art continuum methodologies. The research in this work will need to meet navigation, size, and force constraints of our novel subretinal surgery approach which includes navigation between scleral and choroidal layers to arrive at the subretinal space. The device must also avoid puncturing the eyeball inappropriately and make both simple S-curve and C-curve shapes.

Significance & Clinical Motivation

Over 200 million people worldwide suffer from some form of retinal degenerative diseases (RDDs) (primarily the aging population over 55). [3] These RDDs include wet and dry age-related macular degeneration (AMD) and Stargardt's disease among others, and cause debilitating blindness (see figure 3). Current pharmaceutical drugs made by large pharma companies claim their drugs can heal these disease, however Phase I/II trials have all been unsuccessful causing serious adverse effects (SAEs). These trials and research today use trans-vitreal approaches to access the retina. To inject biologics to the subretinal space, this access method requires a hole to be made through the retina so drugs can be injected. Unlike the sclera, piercing through the retina is traumatic and does not readily heal.

Fig 3. Example of a view from the perspective of someone with an RDD (Stargardt's disease).

Alternatively, trans-scleral approaches (see figure 4) have been proposed and validated previously to access the subretinal space. Access via this route would avoid causing SAEs which come from trans-vitreal methods. Access this way, however, requires very thin, delicate tools, which can be steerable and easily deformable as opposed to the motion of traditional trans-vitreal needles commonly used for surgery, which are rigid. Here we propose a flexible continuum robot to safely access the subretinal space so a future minimally-invasive injection can be performed. This requires that the tool avoids puncturing key visual structures. Successful completion of this project will allow for safer injection for robot-assisted subretinal surgery. It also has the potential to carry tools attached to the end effector (such as cannulas for drug delivery, or cameras) for a variety of other surgeries and surgical tasks.

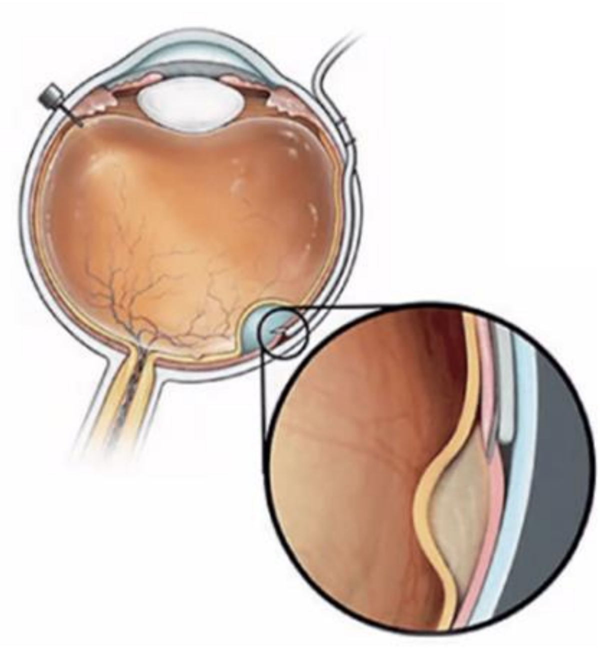


Fig 4. Example route of the CWM for subretinal injection.

Technical Approach

Overview

The design of a surgical robot is a complex task that involves the integration of different components and technologies. In particular, mechanical design plays a crucial role in ensuring the accuracy and precision of the robot's movements.

One of the key components of this project is the continuum end effector, which provides the necessary dexterity and flexibility to perform complex surgical tasks. The continuum end effector is designed to be easy to curve and slide, which allows it to navigate through narrow and complex anatomical structures. It has four degrees of freedom, which are controlled by servo motors.

To achieve precise and reliable control of the rotation motors, we are using Maxon DCX 8 M motors, which are known for their high performance and reliability. These motors are equipped with Maxon GPX 8 gearboxes and Maxon ENX 8 MAG encoders, which provide accurate and precise feedback on the motor's position and speed. The linear motor Maxon RE 8 is used to provide linear motion to the robot's end effector. This motor is designed to be compact and lightweight, while still providing high performance and accuracy.

To control the motion of the motors, we are using Maxon EPOS2 24/2 motion controller, which provides advanced features such as basic trajectory planning, position and velocity control, and real-time feedback. The motion controller will be a key component of the robot's control system, and it allows us to achieve precise and reliable motion control. Through careful design and integration, we will be able to achieve the necessary accuracy and precision to perform complex surgical tasks with the robot.

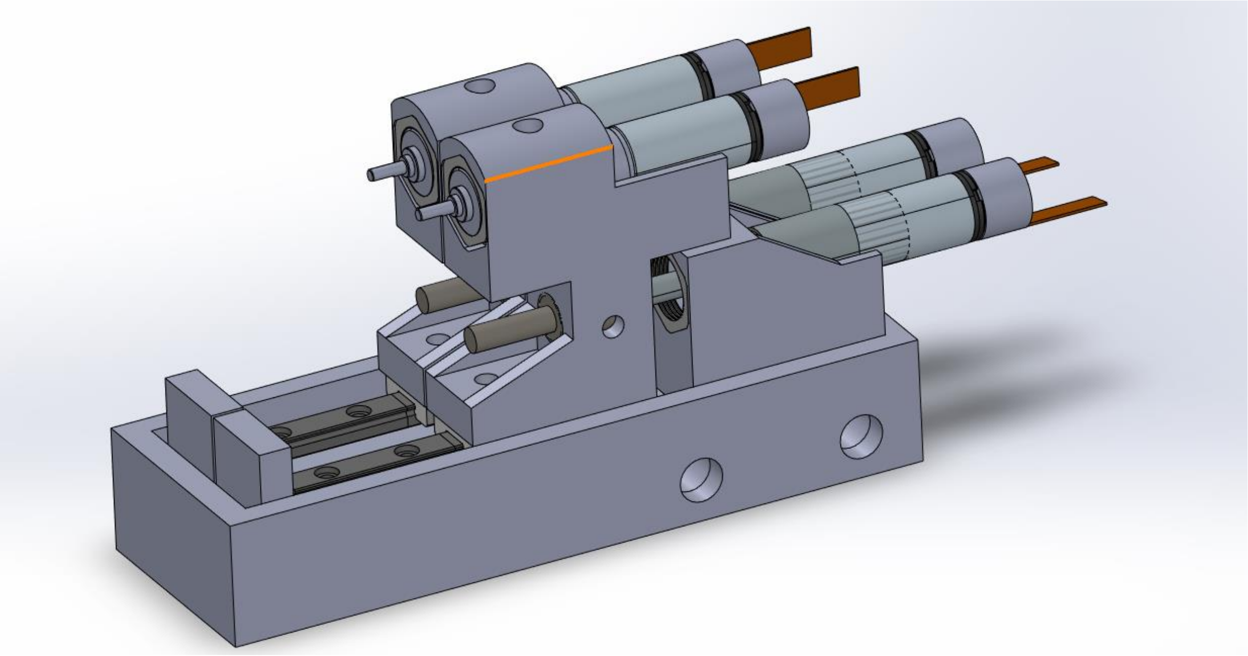


Fig5. Overview of the robotic platform. The overall length, width, and height are 86, 28.5, and 49.5 mm respectively. Four motors give four DoF (two rotation and two translation). The upper motors are responsible for the rotation, which are linked to the continuum wires. The spacing between the two wire is 11.50 mm. The lower motors generate linear motion by the leading screw structure. All motors are connected with the Maxon EPOS2 24/2 controllers by the ENX MAG encoder wires in the back.

Robotic Platform Design

The robotic platform can be divided into three parts, the container for the rotation motors, the linear base for the translation motors, and the housing to fix the robot.

The overall length, width, and height of the container are 30, 11, and 34.5 mm respectively. The primary objective of the container is to accommodate the M8 rotation motors by means of an upper hole with a radius of 4.25 mm. A hexagonal nut of M8 size is fixed in the front with the help of a soldering iron to secure the motor. A small wire holder is introduced to link the end of the rotation motor with the continuum wire. The lower part of the container is designed with a hole of outer and inner radii of 3.5 mm and 2.65 mm, respectively, to accommodate the leading screw and hence transmit linear motion. The connecting section of the screw is M5.5, and accordingly, a thread tap of the same size is employed in the inner ring to retain the screw. Additionally, a small hole with a radius of 1.35 mm is utilized to hold set screws that keep the leading screw stable. On the base, there exist two holes with a radius of 1.35 mm and a spacing of 6.5 mm. These holes are intended to hold M2 thread inserts and align with the slide units of the IKO LWLF standard linear path. There is a hole of the same size going through the container from the upper side to the base, which gives access to help installing the screw in the M2 inserts. A triangular structure is applied on both sides of the base to enhance stability.

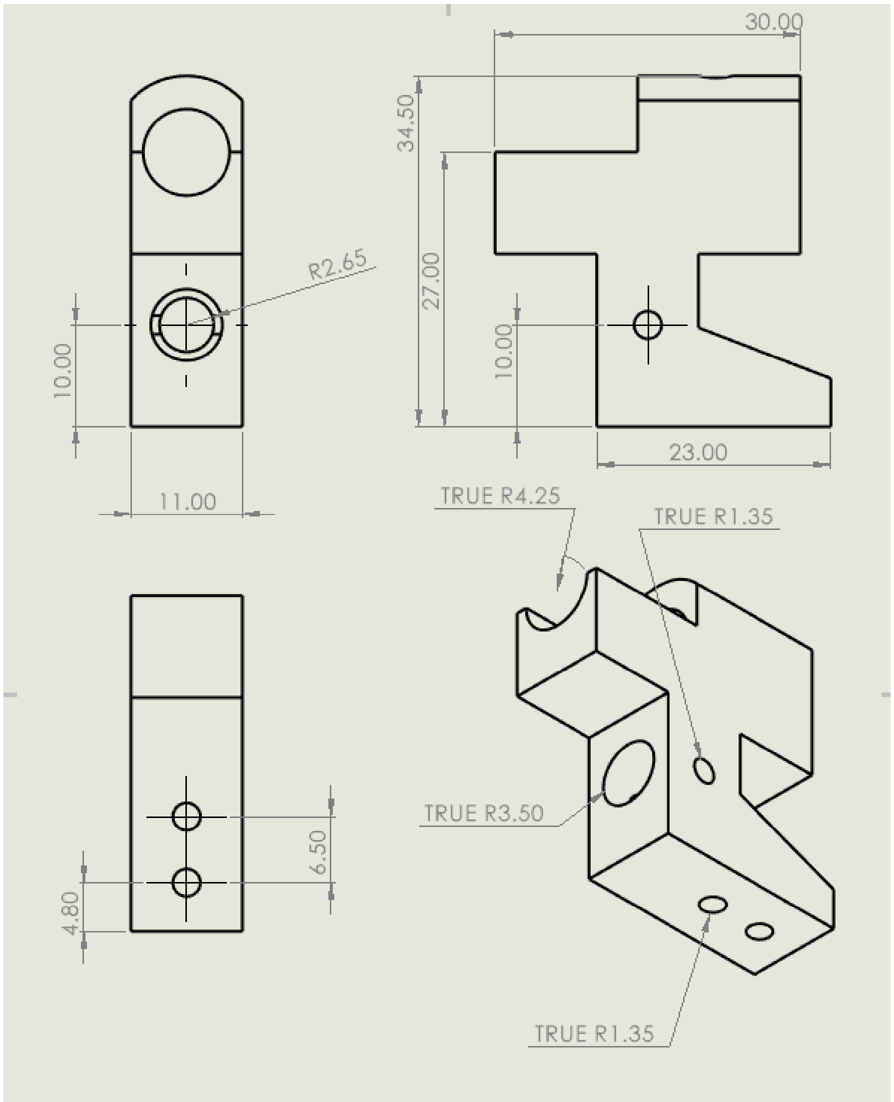


Fig6. The container form different views.

The second significant part is the linear base, of which the length, width, and height are 78, 11, and 30 mm respectively. The upper hole is designed with radius 4.25 mm and installed with a hexagonal M8 nut to hold the linear motor. The left and right boundaries are 0.5 mm to keep two wires (from the neighbor motor) as close as possible. Hence, a triangular structure is designed to enhance stability of the thin motor container. Two holes of diameter 5.9 mm and spacing 20 mm are designed in the bottom to contain the M4 thread inserts, which would help fix the base in the housing structure. In the front is a horizontal platform of length 50 mm to get IKO LWLF standard linear path installed. The IKO linear path can avoid torque in the pitch direction and has rolling balls inside the slide units, which could help smoothen the motion and keep the horizontal stability. Four holes of radius 1 mm and spacing 10 mm are set to accommodate the M1.6 thread inserts and help fix the linear path. In the very front, a baffle of height 20 mm is designed to keep the linear motion in the desired range, which is 39.1 mm determined by the length of the IKO linear path.

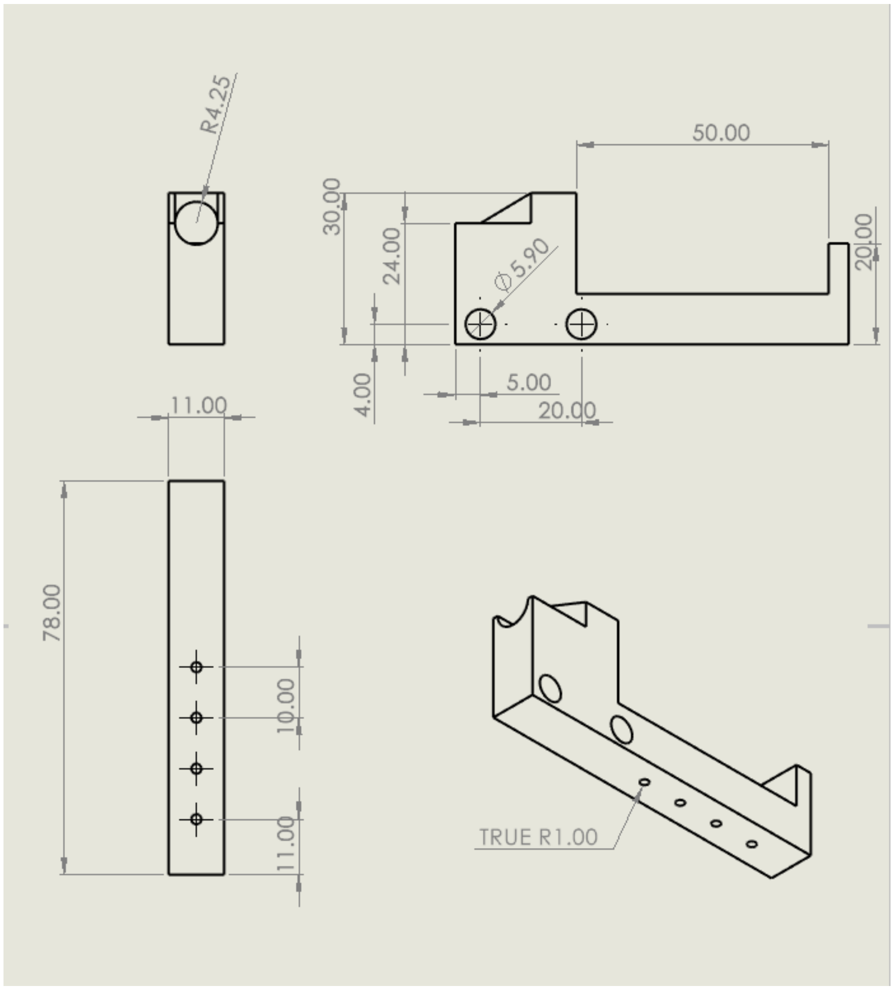


Fig7. The linear base form different views.

The third part is the housing structure, which is a grooved cuboid with holes for the M4 screws on both sides. Currently, we use it to fix two single robots together and keep the wire spacing as 11.5 mm. A nano motor interface is designed to integrate with Steady Hand Eye Robot (SHER) and expected to mount on the housing structure.

The parts mentioned are generated by 3D printer (Stratasys F170, polylactic acid, 60% fill), SLA printer (Formlabs, stereolithography), and CNC manufacture. All the detailed parameters and the logic to set up such parameters can be found in the CAD section of the wiki page.

Wiring Plan

Motor and motion control libraries are widely used in robotic applications and provide a straightforward way to directly interface with the hardware. Before calling the library, we should first make the mechanical part wired with the controller. Here we use two types of settings for rotation and translation motors.

The rotation is generated by Maxon DCX 8M (precious metal brushes, DC motor) with gear box Maxon GPX 8 (planetary gearhead) and encoder Maxon ENX 8 MAG. It needs a power supply of 4.2 and 3.3 V to actuate the motor and the encoder respectively. The maximum speed (no-load speed) and the maximum continuous current (Nominal current) can reach 11700 rpm and 199 mA respectively. The channel number of the incremental encoder is 3, which is A, B, and I. A and B are the two primary output channels providing quadrature signals to determine the direction of rotation and the relative position of the encoder. Channel I generates a pulse once per revolution and is typically used to reset the position count to a known value or to indicate a specific position or event. It is a relatively encoder with 256 counts per turn. All other detailed parameters can be found on the Wiring section of the wiki page.

The translation is generated by Maxon RE8 (precious metal brushes, DC motor) with screw drive Maxon GP 8 S (metric lead screw) and encoder Maxon MR. It needs a power supply of 6 and 5 V to actuate the motor and the encoder respectively. The maximum speed (no-load speed) and the maximum continuous current (Nominal current) can reach 13300 rpm and 155 mA respectively. The channel number of the incremental encoder is 2, which is A and B. It is a relatively encoder with 100 counts per turn. All other detailed parameters can be found on the Wiring section of the wiki page.

Our goal is to control two wires simultaneously. Hence, we should get in communication with four motors. The Maxon controller EPOS2 24/2 (390438) is applied to play a role as human machine interface. It is power by Mastech DC Power Supply HY3005F-3 in a range of +9 to +24 V and is capable of automatically adjusting the motor power demands. We use the jumper J9 which has 10 pins corresponding to motor+, fixed 5V/100mA sensor supply, ground, motor-, channel A bar, channel A, channel B bar, channel B, channel I bar, and channel I respectively. The controller interacts with the computer by USB interface. We use SABRENT 4-Port USB Hub to facilitate real-time monitoring of 4 separate motor conditions.

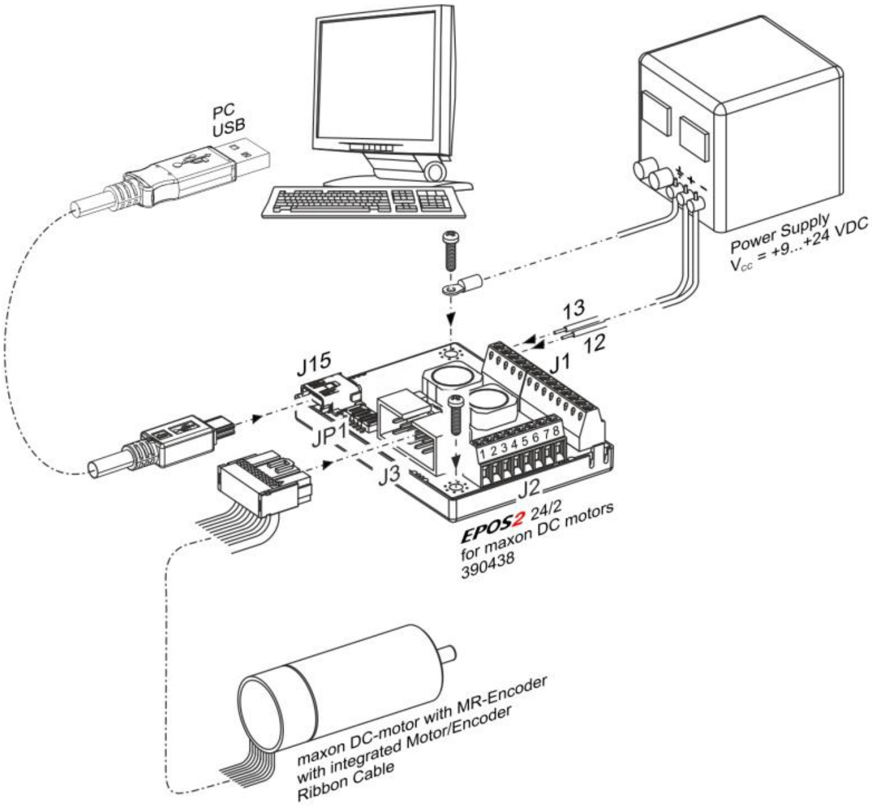
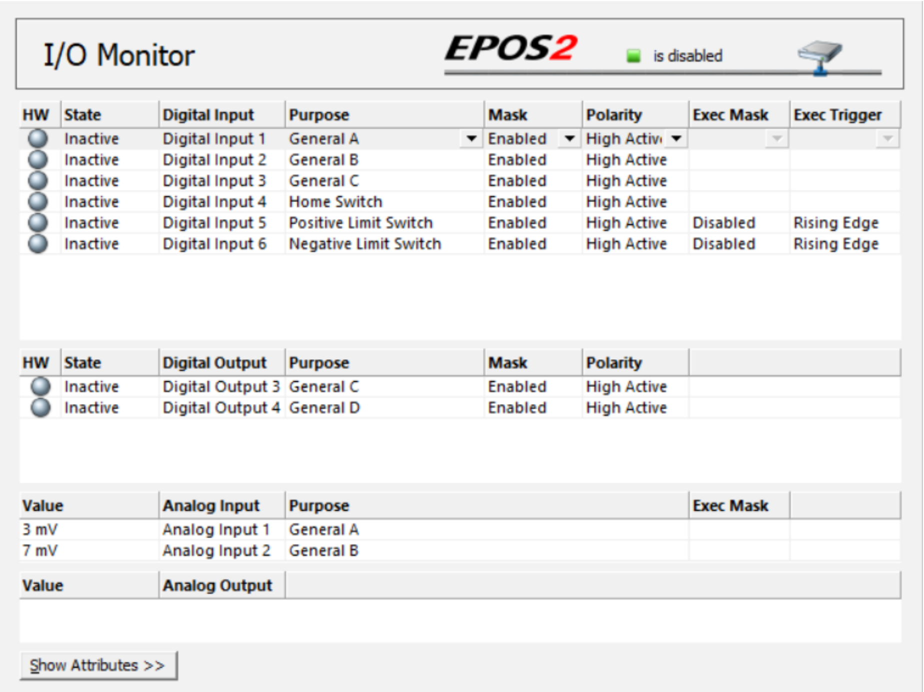


Fig8. Wiring plan of Maxon EPOS2 24/2 (390438) controller.

All the wiring to a single is integrated in a encoder wire Maxon ENX MAG. The rotation motor requires 12-pin inputs, while the translation motor requires 8-pin inputs. However, the output order of the 10-pin controller does not match either of these requirements. To address this issue, we utilized the Maxon Micromotor Adaptor, which enables 12-pin reorganization of the connections via jumper (J3 with M+ M- closed and J4 with 3.3 V closed). The last two channels of J3 are shielded in order to stay in touch with the translation motor. Further details regarding the wiring plan can be found on the Control section of the wiki page.



HW	State	Digital Input	Purpose	Mask	Polarity	Exec Mask	Exec Trigger
○	Inactive	Digital Input 1	General A	Enabled	High Activ		
○	Inactive	Digital Input 2	General B	Enabled	High Active		
○	Inactive	Digital Input 3	General C	Enabled	High Active		
○	Inactive	Digital Input 4	Home Switch	Enabled	High Active		
○	Inactive	Digital Input 5	Positive Limit Switch	Enabled	High Active	Disabled	Rising Edge
○	Inactive	Digital Input 6	Negative Limit Switch	Enabled	High Active	Disabled	Rising Edge

HW	State	Digital Output	Purpose	Mask	Polarity
○	Inactive	Digital Output 3	General C	Enabled	High Active
○	Inactive	Digital Output 4	General D	Enabled	High Active

Value	Analog Input	Purpose	Exec Mask
3 mV	Analog Input 1	General A	
7 mV	Analog Input 2	General B	

Value	Analog Output

Fig9. The input/output channel monitor of the rotation motor after successfully wired.

The current approach of using four separate controllers is error-prone and inconvenient due to communication issues. To address this, we have attempted to integrate simultaneous and precise control of all four motors using a Galil controller, specifically the DMC-2143 model. With the Galil Amplifier ICM-20105, this controller can actuate the motors within their specified operating range. However, the controller requires bipolar power supply of 5V and ±12V, which must be provided. In our future work, we plan to investigate the use of the Galil controller to improve the system.

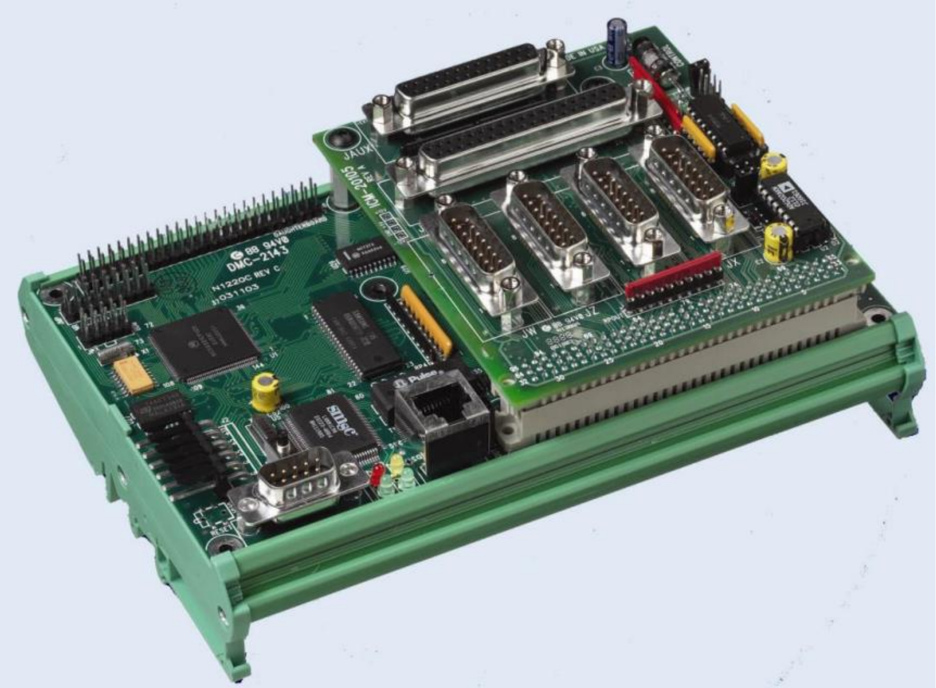
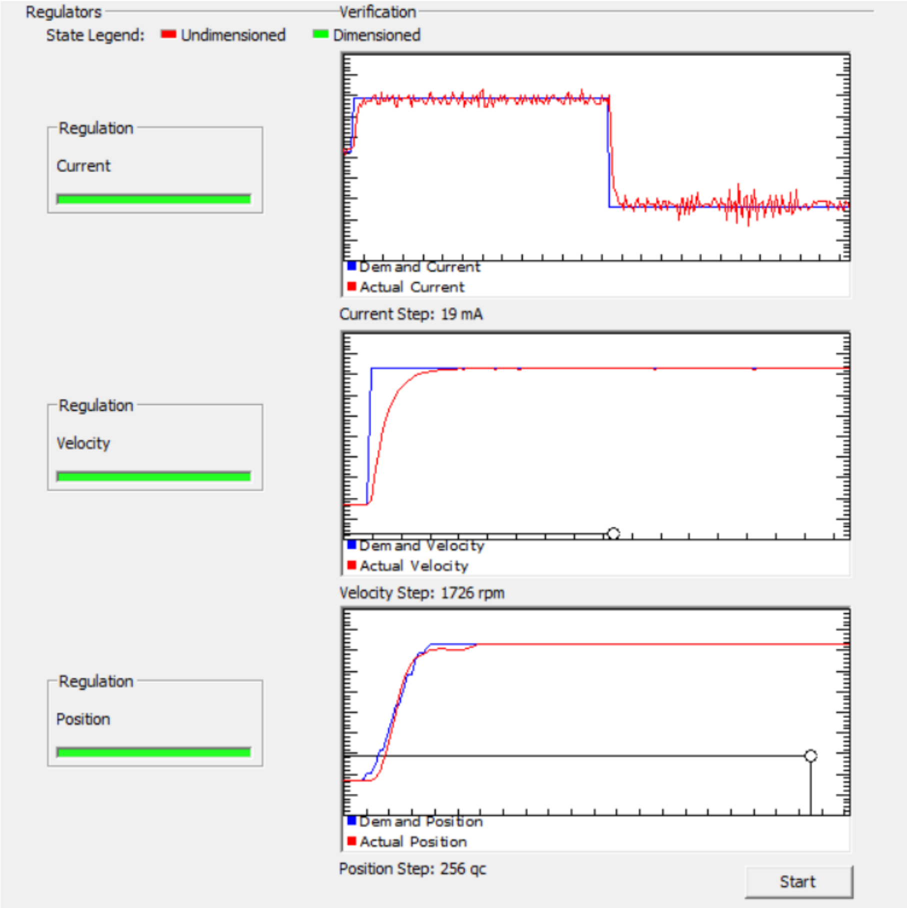


Fig9. ICM-20105 shown mounted to a DMC-2143.

Control Strategy

In order to achieve precise motion of a robot, it is necessary to develop both low-level and high-level control . This project primarily focuses on developing low level control integration for basic motions controlled by a few high-level code snippets. The low-level control is responsible for directly interacting with the actuation of the robot, including individual motor control. We use integrated motor control capabilities for PID (Proportional-Integral-Derivative) control for tuning of individual motors in preparation for future control schemes to be implemented for fully integrated robot control (most likely model predictive control or similar).

The four separate controllers are connected to the computer via a USB hub, and each channel is configured to achieve individual control. The parameter known as quadrature count (QC), which represents the number of pulse counts generated by the quadrature output signals of an encoder for a given rotation of the encoder shaft, is automatically obtained by the software and helps in accurately tracking the position and velocity of rotating machinery. The built-in control parameters are then tuned by evaluating their step response. Once all the setups are complete, the operator can precisely control the current, velocity, and position of the motor.



Current Step: 19 mA

Velocity Step: 1726 rpm

Position Step: 256 qc

Fig10. The parameter tuning process.

To implement the low-level control, the EPOS control libraries will be leveraged, as they provide a set of preset software tools for basic motion. Via EPOS studio, the operator is able to custom control orders, including homing, (profile / interpolated) position, (profile) velocity, current, and step direction mode etc.. Since the counterclockwise rotation is the positive direction, the translation motor steps backward with a positive velocity. The primary function is the current control, which forms the basis for the secondary position and velocity control. The advanced functions are subsequently developed upon this foundation. The detailed commands can be found in the attached control library. In our future work, we aim to assess the kinematic model by adapting the position and velocity mode, and the dynamic model by implementing the current mode. Deep learning and finite element analysis may be potential methods to estimate models.

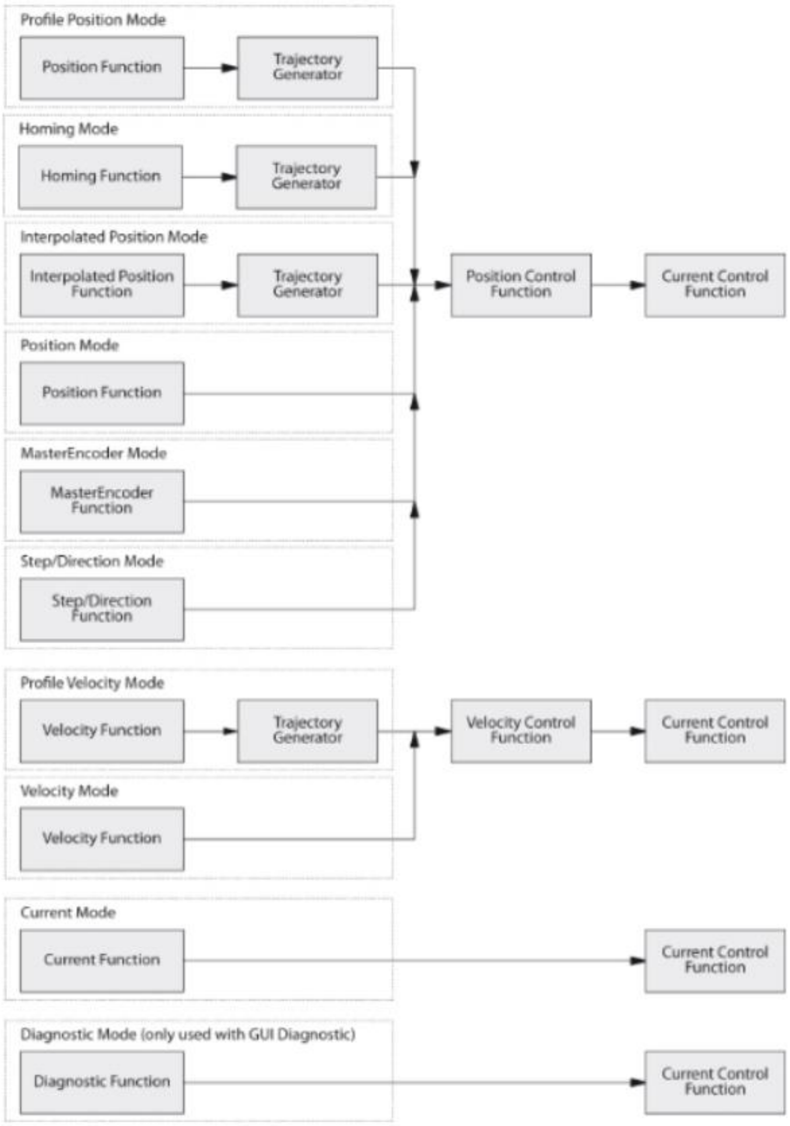


Fig11. The functional architecture of each mode.

Experiment Results and Discussion

Experiment settings and Results

Following the mechanical design, wiring plan, and the control configuration, we successfully build up the system and ready to showcase the robot motion. We can observe various states of motion through combined motor control schemes. Twist, curl, and yaw motion modes are then defined. Applying the same velocity in the rotation shifts, the wire is able to move in the roll direction and twist a node which allows the wire slide and curve in a desired shape. After the node creation, apply the opposite velocity in the rotation shifts and the wire loop will move in the pitch direction, which is defined as the curl mode. Moving the node in the opposite linear direction will actuate the wire loop in the yaw direction.

In the testing section, we first make the linear motors align to each other and arrange the wire in a loop shape, which is defined as home position. Then both rotation motors are set to be 300 rpm in the counterclockwise direction to twist a node. The velocity profile is set to be a trapezoidal shape. The rotation motors (#1 and #2) are then set to be 300 and -300 rpm respectively to make the wire loop curl upward at the node. Conversely, the wire loop could curl downward at the node with -300 and 300 rpm. We control the translation motor #1 and #2 to move in 5000 and -5000 rpm respectively to make the wire loop yaw clockwise. The counterclockwise yaw is set vice versa.

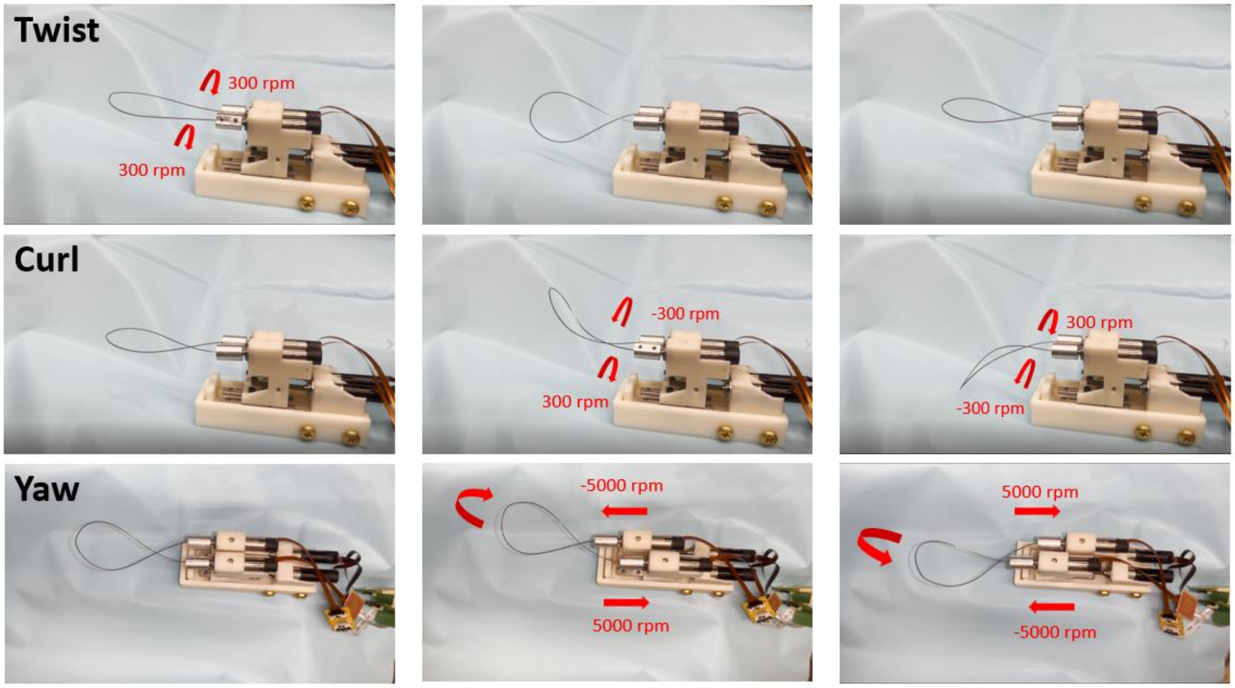


Fig12. Motion mode test.

Our next experiment is to demonstrate the robot's motion in an agar gel environment, which simulates the conditions of the human body. It is essential to gather sensor feedback data during the motion to establish kinematic and dynamic models. Any unforeseen collisions, oscillations, or resistance encountered during the process will add modified terms to the model, which will aid in the final assessment of safe subretinal gene therapy delivery into a phantom pig eye. However, due to time constraints, this aspect will be addressed after the CIS lecture.

The current experiment setting uses relative encoders, which are not able to return absolute positions. When aligning two translation motors in the home position, it is not easy to get a satisfactory result by manual operation. To address this issue, we propose designing an initialization button that can be pressed during the operation process to reinitialize the control and set a new home position. This would effectively simulate the function of an absolute encoder. One potential approach to implementing this functionality is through the use of a CAN channel. We plan to add this experiment setting in order to improve the accuracy of our test results.

Further Discussion

In our workflow, the current focus is to develop a robotic platform, estimate the forward kinematics, and showcase the motion. The successful completion of our robotic platform has piqued our curiosity about the underlying phenomena. As mentioned, twisting motion would generate a node which allows the wire slide and curve in a desired shape. How to determine the node position? How does the node together with the motor kinematics influence the wire shape? How to integrate multiple motions? Etc. A continuum robot kinematic model would be a powerful tool to answer these questions.

There are multiple methods to fit a twisted curve, such as Least Square method and Lagrange. They can generate equations to describe the curve as close as possible. Here we would like to introduce the B-spline method. A spline function of order n is a piecewise polynomial function of degree n-1 in a variable x. The places where the pieces meet are known as knots. B-splines of order n are basis functions for spline functions of the same order defined over the same knots, meaning that all possible spline functions can be built from a linear combination of B-splines, and there is only one unique combination for each spline function. Hence, we can realize a precise control on every section of the curve via control points. In the future map, we would also use deep neural network and finite element analysis to calculate the mathematical model.

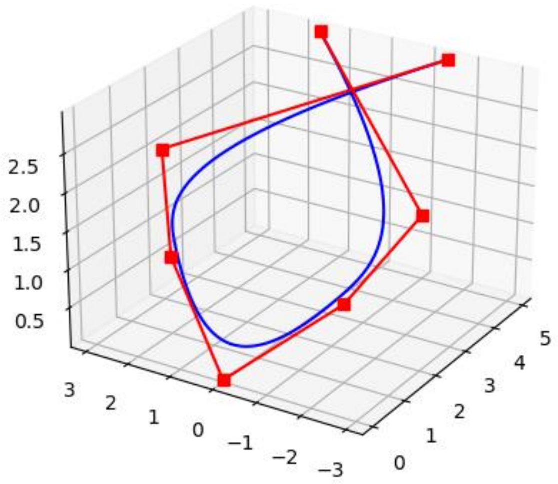


Fig13. 3D B-spline continuum model.

Once the low-level control has been implemented and tested, the high-level control basic commands can be developed to integrate the robot with a whole surgery system. One popular library which contains some tools for high-level control is the ROS (Robot Operating System) control library. ROS is a widely used framework for building robotic systems and provides a set of tools and libraries for developing distributed robotic systems. The CISST (Computer-Intuitive Surgical Systems and Technology) system is another JHU-based library that can be used for developing high-level control of surgical robots. The CISST system is a modular and flexible system that allows the integration of various components and subsystems of a surgical robot. High level control for this system will be implemented in CISST and CRTK-inspired ways, though the full CISST System will not necessarily be implemented.

After studying the series work of Dr. Desai, which conducts research on tendon-driven COaxially Aligned STeerable robot (COAST) in peripheral vascular intervention task [9, 10, 11, 12]. We are inspired by the advancement mechanism, including spool, clamp, roller, and spur gear system etc., to control the wire length and shape simultaneously. The current linear path we are using is only 39.1mm long, which is not sufficient for wire feeding and yawing tasks. Therefore, we plan to explore the feeding and retracting strategies used in COAST to help meet our project requirements.

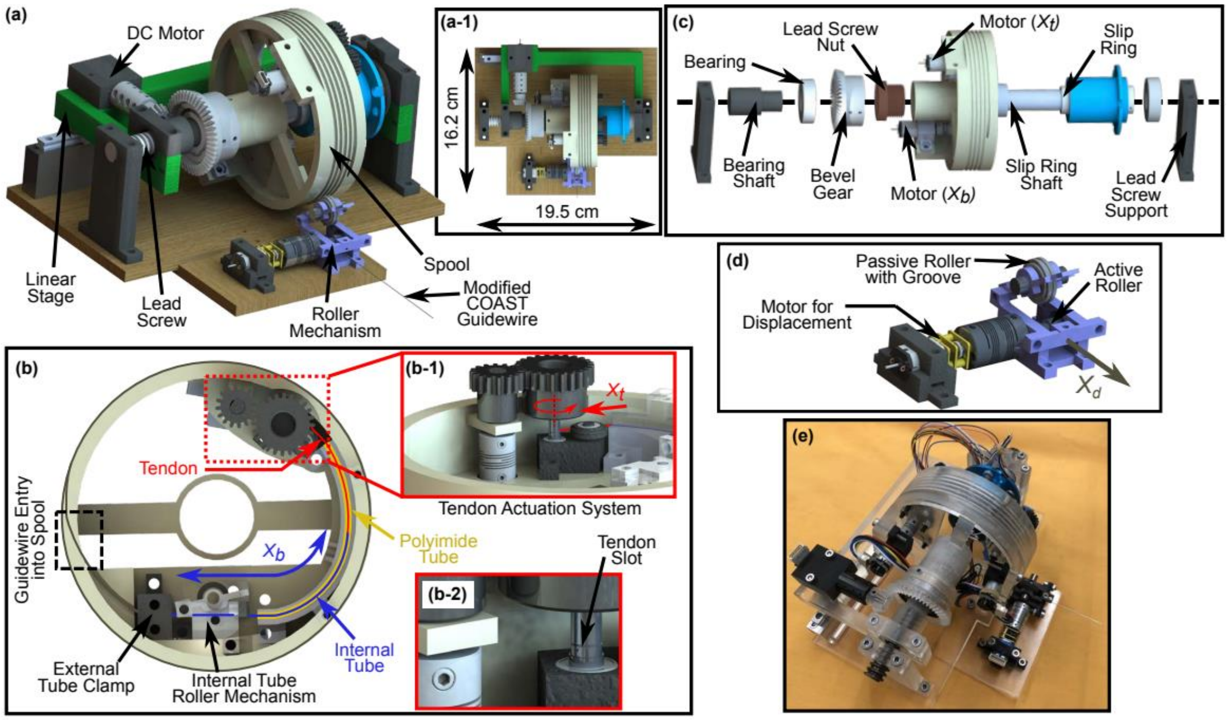


Fig14. Advancement mechanism of COAST robot.

Management

Deliverable

MINIMAL

- ✓ Design CAD Model for new robust CWM actuator.
- ✓ Select appropriate parts and make wiring plan including housing and motor controller.

EXPECTED

- ✓ Construct new robust prototype iteration.
- ➢ Build basic ROS package for actuator control of all actuators with nitinol end effector attached.

IDEAL

- ➢ Develop removable mounting hardware for SHER.

- Show motion of system inside of agar gel with integrated control, characterizing C-curve and S-curve ability.
- Incorporate system with SHER system, demonstrate motion with SHER.

Key Milestones

- ✓ Implement the whole mechanical system design containing end effector, rotation and translation motors, motion combo structure, control board, and housing.

  ***Status**: Done*

  ***Output**: After successfully completing, we can have a mechanical platform to conduct further designs and tests. This milestone signifies the completion of the minimal deliverable.*

- ✓ Conduct a package for low-level motor control.

  ***Status**: Done*

  ***Output**: Once finished, we can realize motor control. Via (if possible) kinematic, we are expected to achieve the shape control of the continuum robot. This milestone signifies the completion of the expected deliverable.*

- Testing the C- and S-curve in the agar gel.

  ***Status**: in progress; success in lab environment*

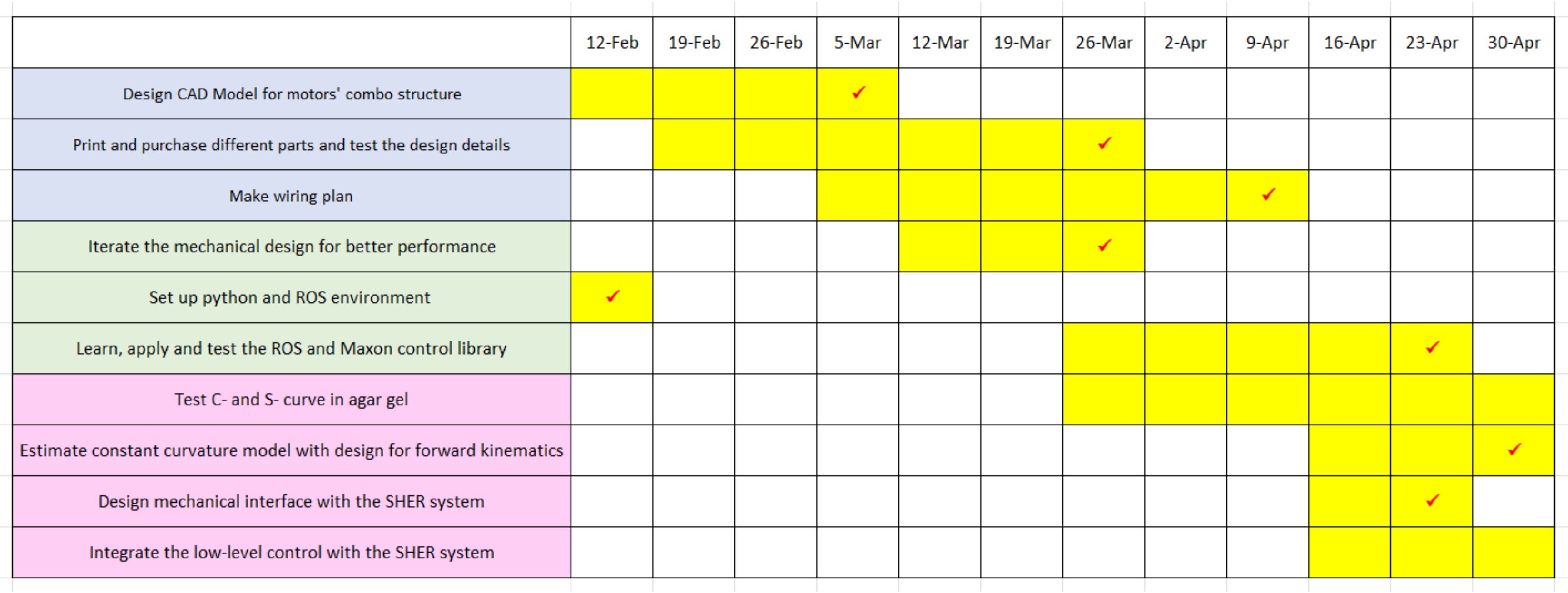
  ***Output**: The successful implementation of the kinematic is marked by the attainment of a desired shape on the end effector. This achievement is a significant step towards the application of this technology in surgeries and signifies the completion of the ideal deliverable.*

- Integrate the continuum retinal surgery system with the SHER system.

  ***Status**: in progress; developing mechanical and ROS interface*

  ***Output**: Once finished, we can interact with the continuum robot via the integrated system, which would hugely improve the user experience, and hence make it easy to use and educate.*

Timeline



	12-Feb	19-Feb	26-Feb	5-Mar	12-Mar	19-Mar	26-Mar	2-Apr	9-Apr	16-Apr	23-Apr	30-Apr
Design CAD Model for motors' combo structure	🟨	🟨	🟨	✓								
Print and purchase different parts and test the design details		🟨	🟨	🟨	🟨	🟨	✓					
Make wiring plan				🟨	🟨	🟨	🟨	🟨	✓			
Iterate the mechanical design for better performance					🟨	🟨	✓					
Set up python and ROS environment	✓											
Learn, apply and test the ROS and Maxon control library							🟨	🟨	🟨	🟨	✓	
Test C- and S- curve in agar gel							🟨	🟨	🟨	🟨	🟨	🟨
Estimate constant curvature model with design for forward kinematics										🟨	🟨	✓
Design mechanical interface with the SHER system										🟨	✓	
Integrate the low-level control with the SHER system										🟨	🟨	🟨

(The blue part is the minimal deliverable, the green is the expected, and the pink is the ideal.)

Dependencies

Dependency	Need	Status & Deadline	Contingency	Effect
Manufacture	need access to SLA printer and laser cutting machine	Done	order online & use shared printer	help to make the mechanical design into real world
Motor Controller Selection	basic parts to set up the surgey system	Done	detach parts from other robots	help to actuate and control the robot
Environment Acquired	set up python and ROS environment for robot control	Done	configurate shared computer in the lab	basic step to realize robot control
Access to SHER system	integrate the continuum robot with the SHER platform	Done	alternate with other surgey robot system, such as Da Vinci	improve the user experience and surgey applications
Agar Gel for Testing	test C- and S- curve in agar gel	not start	None	realize the kinematic of the continuum robot

Meetings

Meetings with Dr. Usevitch to discuss project goals and progress occur weekly on Tuesdays at 3 PM. Some coordination with a closely related team will help with development of motor control code and ROS development.

Platforms

Multiple platforms will be used for communication as well as documentation, file-sharing, and report writing.

- Communication: This will be supported via e-mail, Microsoft Team, and Zoom meetings.
- Code: Code will be maintained on a private repository on GitHub.
- Data & Filesharing: The data will be shared through Hopkins OneDrive, which is secure and encrypted. Files such as the report and presentations will also be shared through OneDrive and the CIS II wiki page.
- Report Writing: OneDrive will be used for basic report writing and reviewing. LaTeX (Overleaf) will be used for final manuscript preparation.

Management Summary

This is a solo project, and the majority of the credit goes to Shuyuan Wang, who was responsible for the mechanical design, wiring plan, control setting-ups, and tuning.

All minimal deliverables related to the mechanical design have been achieved, and we have designed the robot prototype and fine-tuned all mechanical parameters to achieve specific functions. Additionally, some parts have been purchased and recorded to help build the robot.

We have achieved the expected deliverables of phototype iteration and low-level motor control. We added an IKO linear path to avoid torque in the pitch direction, and the horizontal spacing distance was fine-tuned to make the wire as close as possible for precise control. Other design processes can be found on the CAD section of the wiki page. A detailed wiring plan ensures that the power supply and sensor signals are connected to the correct channels. The desired motion control was successfully achieved using the EPOS studio, while the first plan was executed in the ROS environment to integrate with the SHER system. In other words, we were successful in low-level motor control but faced communication issues with other robotic environments. This is an area that we need to focus on in the next step.

In the ideal deliverables, we estimate the motion modes and demonstrate them in the lab environment. However, we need to test in the agar gel and ex vivo environment in further work. Integration with the SHER system is still in progress, and currently, we have a mechanical interface to attach the robot to the SHER, but we lack a ROS architecture, which will be accomplished in the future.

In this summer, the research plan consists of three main goals. The first one is to build a kinematic model to control the wire shape and enable the robot to be used in further applications. The second goal is to assess the safety of subretinal gene therapy delivery into a phantom pig eye. Lastly, the team plans to make several technique improvements, including changing the controller board to Gaili DMC2143 for real-time control on four channels simultaneously, integrating the continuum robot with the SHER system for wider applications, and modifying the advancement system for better feeding and retracting functions. These improvements will further enhance the functionality and versatility of the robotic system.

The CIS II lecture provided a valuable lesson on the importance of documentation in project development. Documenting detailed designs is essential for previous developers to refer back to, as well as for new members taking over the project. Additionally, the success of the project is attributed to the close cooperation and extensive discussions among different groups. Individuals from diverse backgrounds share their professional insights, which aid in understanding and solving complex problems. This collaboration enables the transformation of clinical demands into robotic designs, ultimately resolved by the application of control theory and neural networks. The contributions of ophthalmologists, surgeons, mechanical engineers, and deep learning developers with their specialized expertise are critical to the project's success.

During the research, I gained valuable insights from Dr. Usevitch on how to optimize mechanical parameters by iterating and validating them in simulation software before 3D printing. This approach saved considerable time in the printing process. Additionally, I learned how to plan and execute electronic wiring, which involved not just connecting pins but also understanding channel relationships, validating signal input and output, adding or removing interfaces for customized tasks, and tuning configuration parameters based on control models. This was a challenging but rewarding experience for a robotic engineer to handle electronic wiring effectively.

Conclusion

In conclusion, this project proposes a novel approach for subretinal gene therapy delivery using a continuum robot. The robot's steerable and deformable wire enables safe access to the subretinal space while avoiding puncture to the key visual structures. The developed robotic platform provides stability and precision during the injection process. A detailed control strategy and wiring plan are implemented to achieve precise and instant changes in the wire shape. Future work includes the development of a kinematic model and integration with the SHER system for wider applications. This project has the potential to contribute to the treatment of retinal degenerative diseases and improve the quality of life for patients.

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