Design and Control of a Continuum Wire Manipulator (CWM) for Minimally-Invasive Surgery *(Project 2)*

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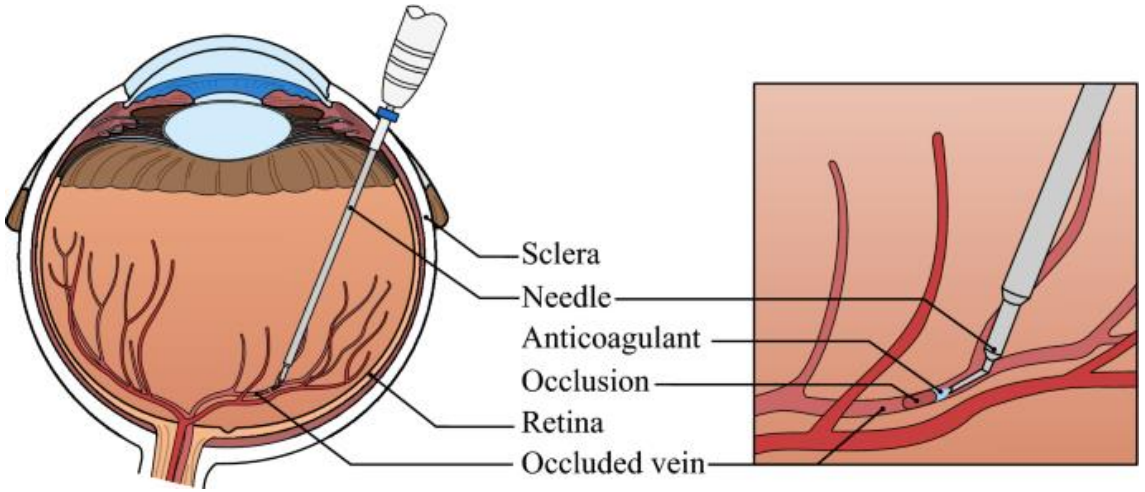
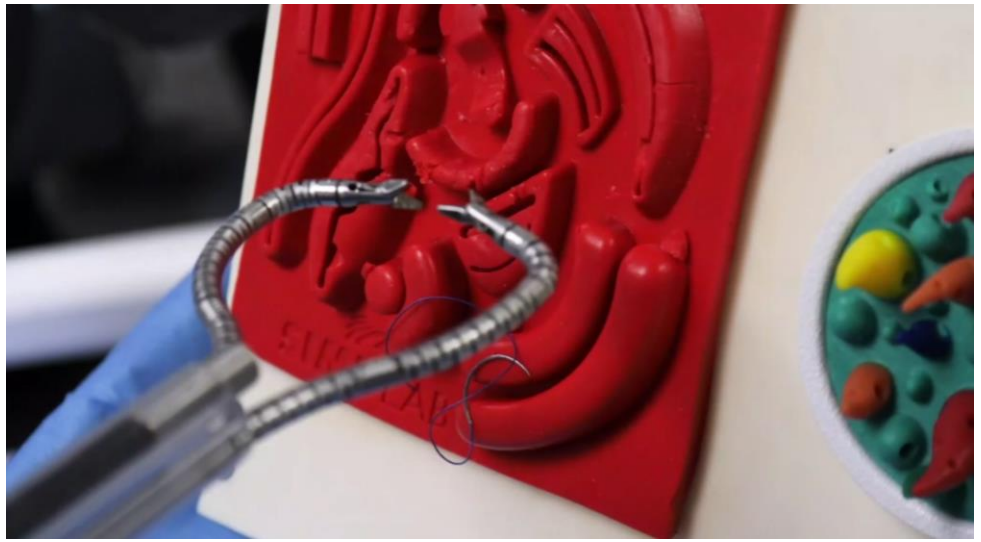
Motivation

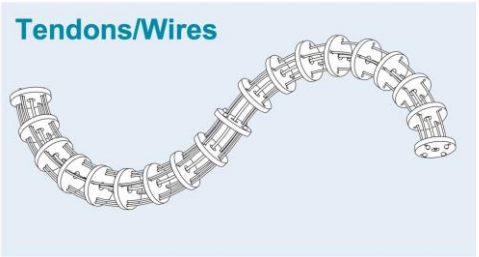
Retinal Surgery

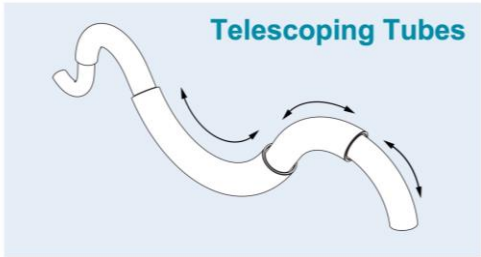


- Retinal Degenerative Diseases
  - incurable blindness
  - affect 200M people
- Subretinal Injection
  - deliver effective gene therapy pharmaceuticals

Continuum Robot

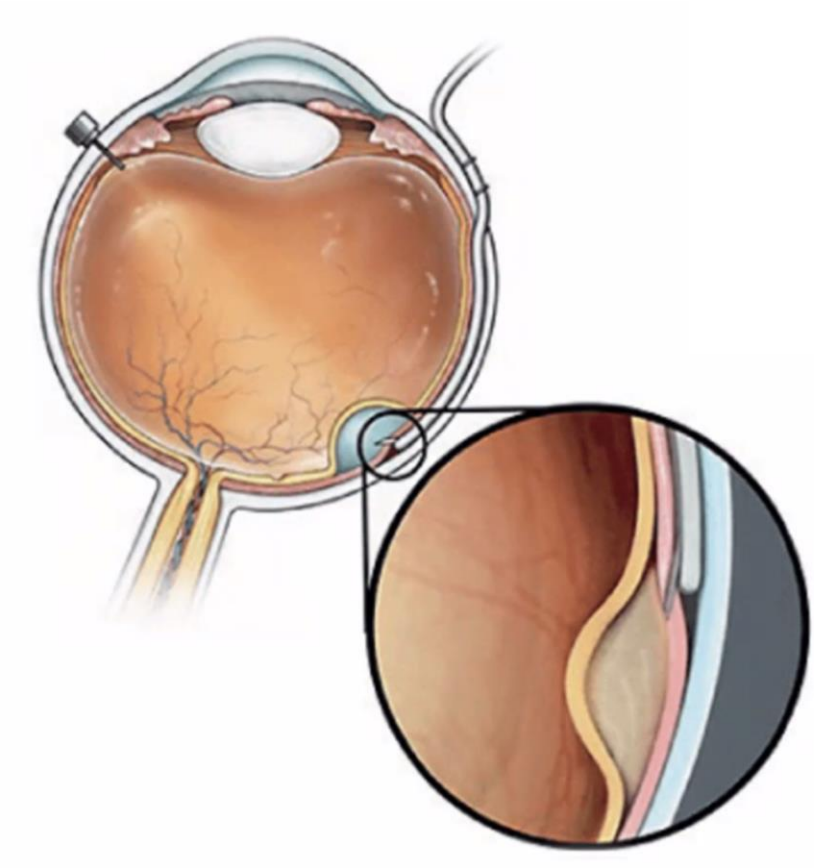






Extra Flexible ⇨ Elaborate

Applications

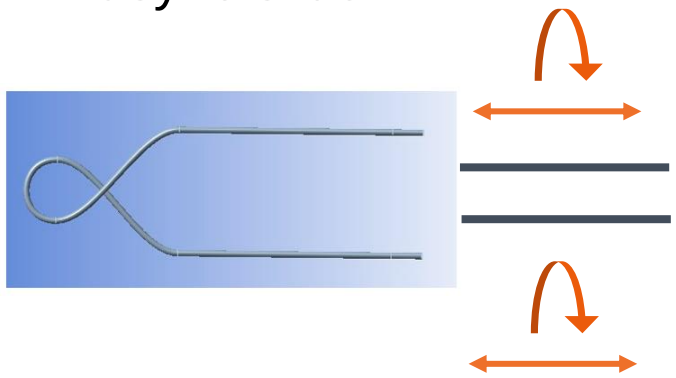


- Subretinal injection
  - minimal access
  - between scleral and choroidal layers
  - average eye diameter 22-25 mm
  - avoid puncture of retinal
- Potential
  - effective minimally-invasive tools
  - small actuated continuum wire

Goal: Design

Novel-designed end effector

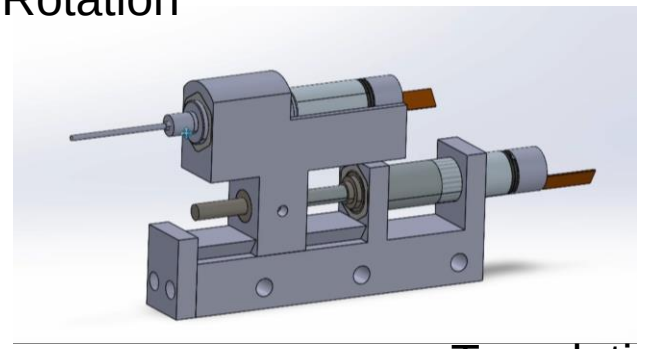
- Nitinol
- 4 DoF
- Easy to curve
- Easy to slide



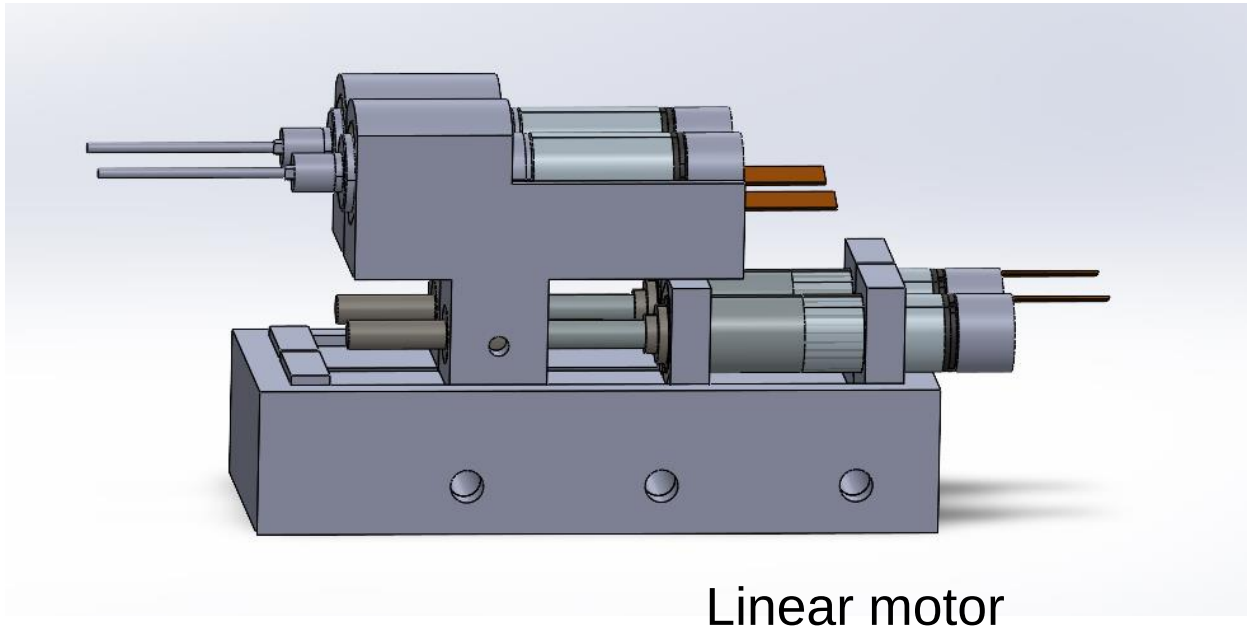
Rotation motor

- Maxon Motor DCX 8 M
- Gear box and encoders

Rotation



Translation



Linear motor

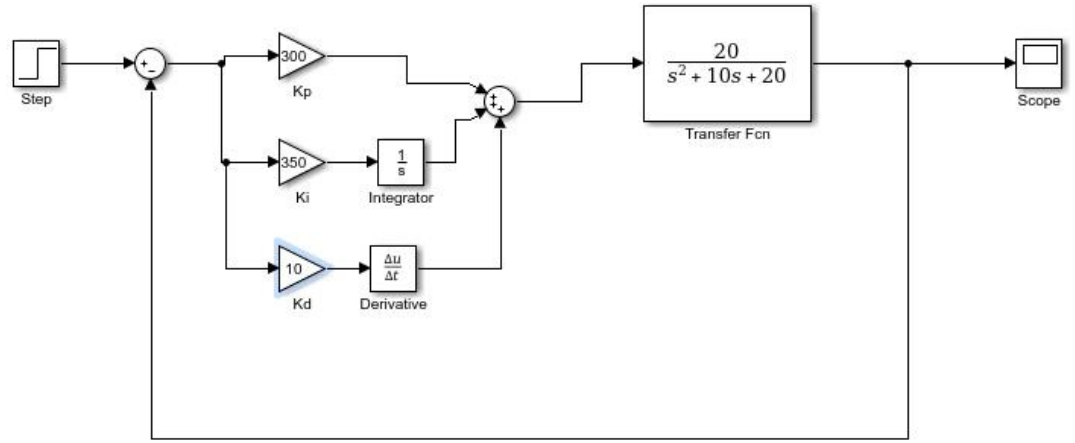
- Maxon Motor RE 8
- Lead thread

Galil Motion Controller

Goal: Control

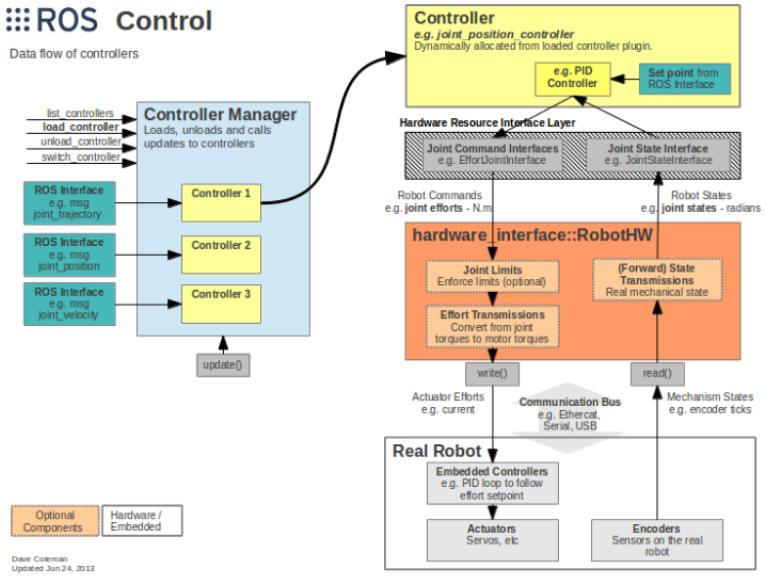
Low-level control

- Interact with the physical process
- PID for individual motor control
- Galil or other Motor controller Library

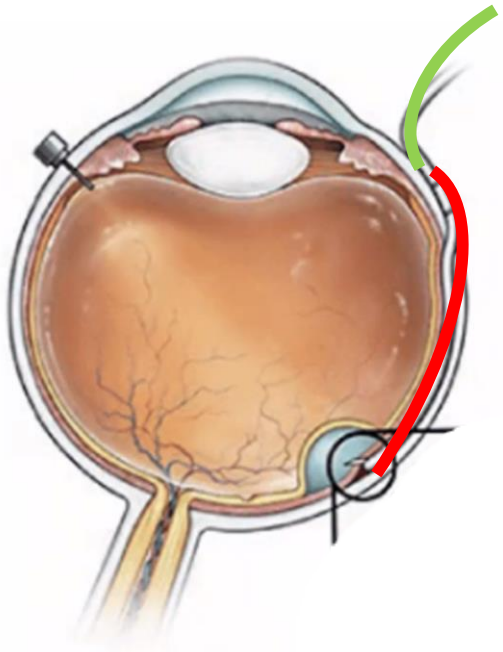


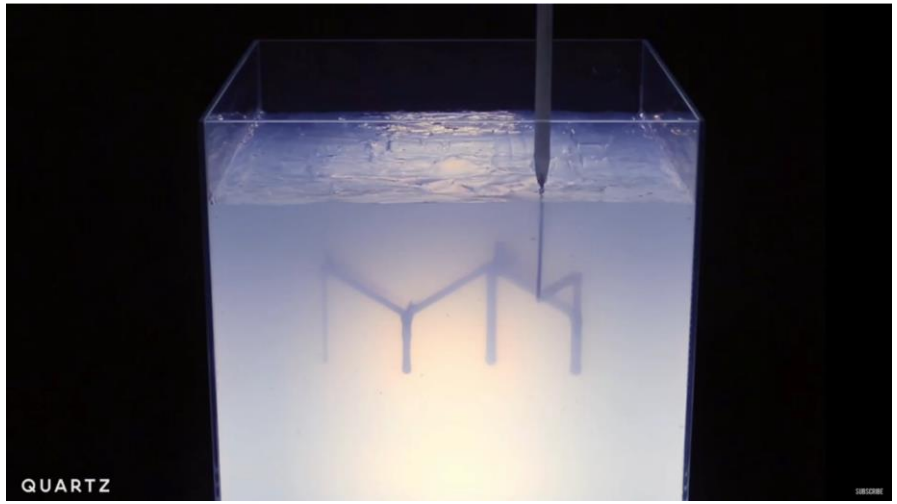
High-level control

- Integrate the system
- ROS control library
- CISST, SHER

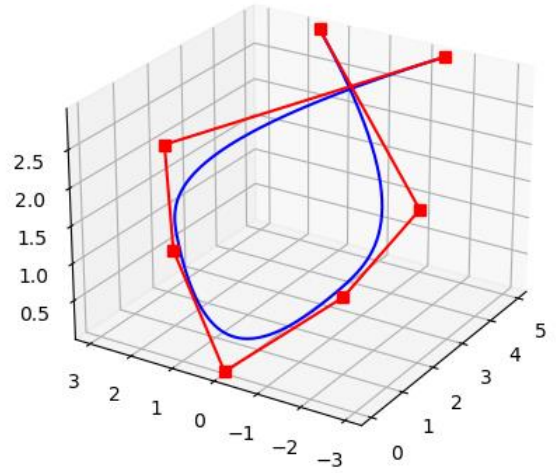


Testing





- D_{eye} = 22 - 25 mm
- C-curve (of the same radius)
- S-curve
- Agar gel testing



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 mount hardware for SHER
  - Incorporate the continuum robot in with SHER control system, demonstrate motion with SHER
  - Show motion of system inside of agar gel with integrated control, characterizing C-curve and S-curve ability.

Timeline and Milestones

- MILESTONE 1: Implement the whole mechanical system.

  ***Deadline**: March 10th*

  ***Status**: in progress*

  ***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.*

- MILESTONE 2: Conduct a package for low-level motor control.

  ***Deadline**: April 1st*

  ***Status**: in progress*

  ***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.*

- MILESTONE 3: Testing the C- and S-curve in the agar gel.

  ***Expected Date**: April 15th*

  ***Status**: not started*

  ***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.*

- MILESTONE 4: Integrate with the SHER system.

  ***Expected Date**: April 15th*

  ***Status**: not started*

  ***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 and Milestones

	12-Feb	19-Feb	26-Feb	5-Mar	12-Mar	19-Mar	26-Mar	2-Apr	9-Apr	16-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 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										

Milestone 1

Milestone 2

Milestone 3

Milestone 4

1. Full CAD Model and Robot Prototype Assembled
2. ROS Node for Controller Demonstrating Motion
3. Gel Insertion Demonstration
4. Integrate with the SHER System

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	in progress; 3/10	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
SHER system	integrate the continuum robot with the SHER platform	not start; 4/15	alternate with other surgey robot system, such as Da Vinci	improve the user experience and surgey applications
Testing	test C- and S- curve in agar gel	not start; 4/15	None	realize the kinematic of the continuum robot

Management

- Meetings
  - Weekly meetings with mentor to discuss progress (Tue 3 pm)
  - Coordination with a closely related team on the motor control and ROS
- Platform
  - Communication: e-mail, Microsoft Team, and Zoom meetings
  - Code: a private repository on GitHub
  - Data: Hopkins OneDrive (secure and encrypted)
  - Report Writing & Filesharing: LaTeX (Overleaf), OneDrive, CIS II wiki page

Reading List & Reference

[1] Mitros, Z., Sadati, S. M. H., Henry, R., Da Cruz, L., & Bergeles, C. (2021). Annual review of control, robotics, and autonomous systems from theoretical work to clinical translation: Progress in concentric tube robots doi:10.1146/annurev-control-042920-

[2] Webster, R. J., & Jones, B. A. (2010). Design and kinematic modeling of constant curvature continuum robots: A review. London, England: SAGE Publications. doi:10.1177/0278364910368147

[3] Vander Poorten, E., Riviere, C. N., Abbott, J. J., Bergeles, C., Nasseri, M. A., Kang, J. U., ... & Iordachita, I. (2020). Robotic retinal surgery. In Handbook of Robotic and Image-Guided Surgery (pp. 627-672). Elsevier.

[4] Fleming, I., Balicki, M., Koo, J., Iordachita, I., Mitchell, B., Handa, J., ... & Taylor, R. (2008). Cooperative robot assistant for retinal microsurgery. In Medical Image Computing and Computer-Assisted Intervention–MICCAI 2008: 11th International Conference, New York, NY, USA, September 6-10, 2008, Proceedings, Part II 11 (pp. 543-550). Springer Berlin Heidelberg.

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[6] Üneri, A., Balicki, M. A., Handa, J., Gehlbach, P., Taylor, R. H., & Iordachita, I. (2010, September). New steady-hand eye robot with micro-force sensing for vitreoretinal surgery. In 2010 3rd IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics (pp. 814-819). IEEE.

[7] Ferrentino, P., Seyedreza, K. T., Brancart, J., Van Assche, G., Vanderborght, B., & Terryn, S. (2021). FEA-based inverse kinematic control: Hyperelastic material characterization of self-healing soft robots. IEEE Robotics & Automation Magazine, 29(3), 2-12. doi:10.1109/MRA.2021.3132803

[8] Kuntz, A., Sethi, A., Webster, R. J., & Alterovitz, R. (2020). Learning the complete shape of concentric tube robots. IEEE Transactions on Medical Robotics and Bionics, 2(2), 140-147. doi:10.1109/TMRB.2020.2974523

Thank you!

Have FUN!!!