LABORATORY FOR Computational Sensing + Robotics

AMIRo Research Lab

JOHNS HOPKINS WHITING SCHOOL of ENGINEERING

Integrated High-Dexterity Intraocular Micromanipulation

Project Plan

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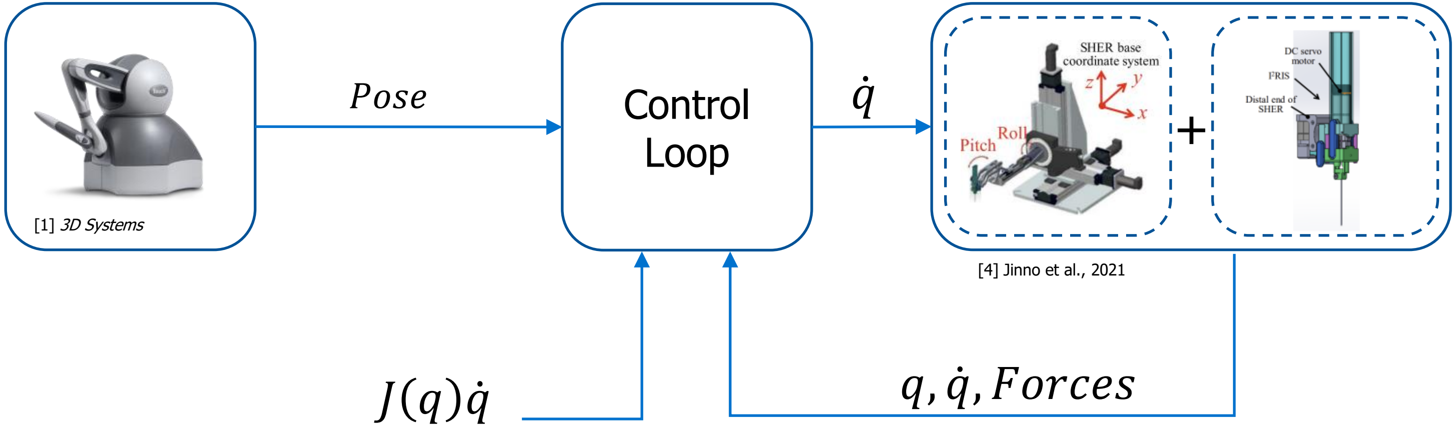
EN.601.656
Computer Integrated Surgery II

2/18/2021

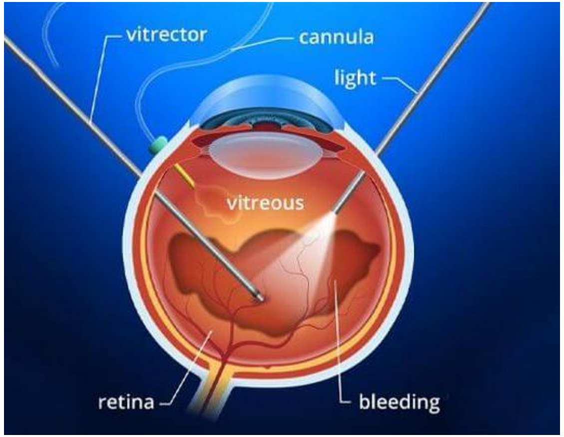
Project Description

- Integrating control of 2 DoF distal-end "snake like" manipulator with 5 DoF Steady Hand Eye Robot, for a combined 7 DoF
- Simulating in Gazebo

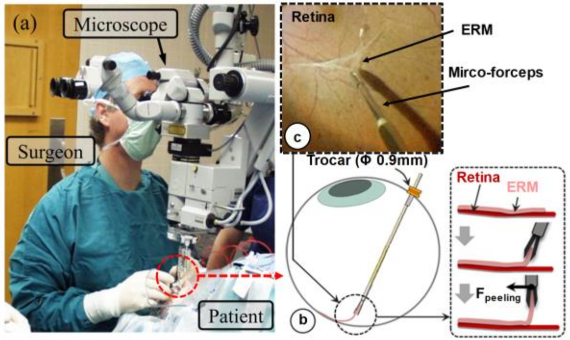


Motivation

- **Challenge:** Vitreoretinal surgery requires advanced surgical skills at or over the limit of surgeons’ physiological capabilities [4]
  - Confined intraocular space
  - Restricted free motion of surgical tools
  - The forces exerted between ophthalmic tools and eye tissues are often well below human sensory thresholds
- Epiretinal membrane (ERM) peeling [3]:
  - Forces not detectable by surgeon
  - Forces exceeding 7.5 mN can cause irreversible damage and loss of vision



[2] https://neoretina.com/



From Dr. Iordachita

Motivation

- **Solution:** Surgeon controlled robotic system with snake-like distal end
  - Tremor free tool manipulation
  - Greater dexterity – access to target from suitable directions
  - Force sensing at the tool tip enables numerous capabilities

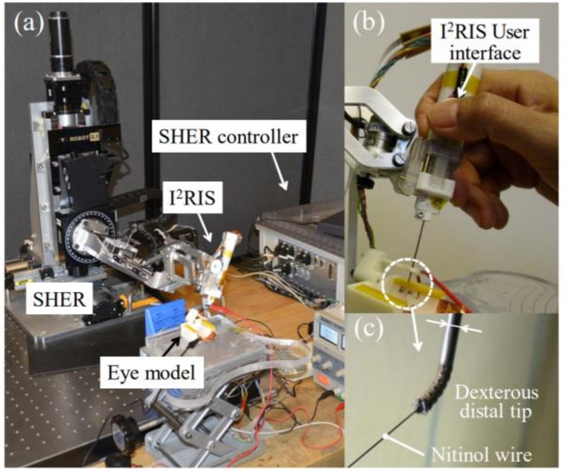
Team

- Team members:
    - Kaiyu Shi: 2nd year Robotics MSE student
    - Yishun Zhou: 1st year Robotics MSE student

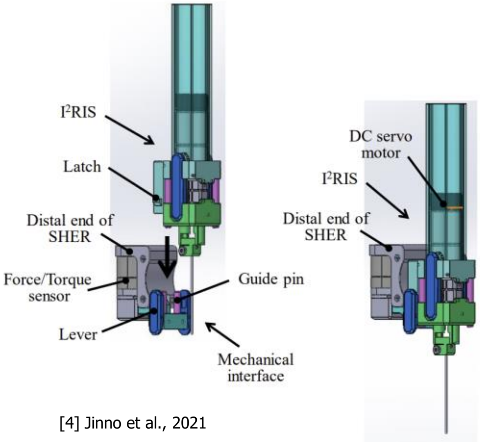
- Prof. Iulian Iordachita: principal investigator
- Dr. Gang Li: primary mentor

Prior Work

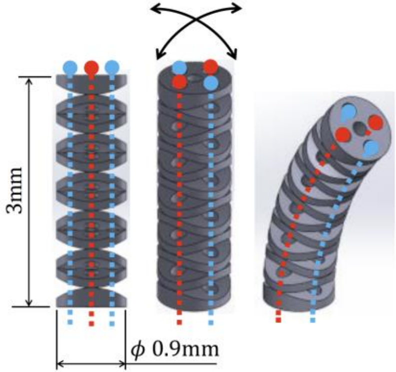
- SHER (Steady Hand Eye Robot) [5]
- I^2RIS (Improved Integrated Robotic Intraocular Snake) [6]
- Cooperative control/manual control



[4] Jinno et al., 2021



[4] Jinno et al., 2021



[4] Jinno et al., 2021

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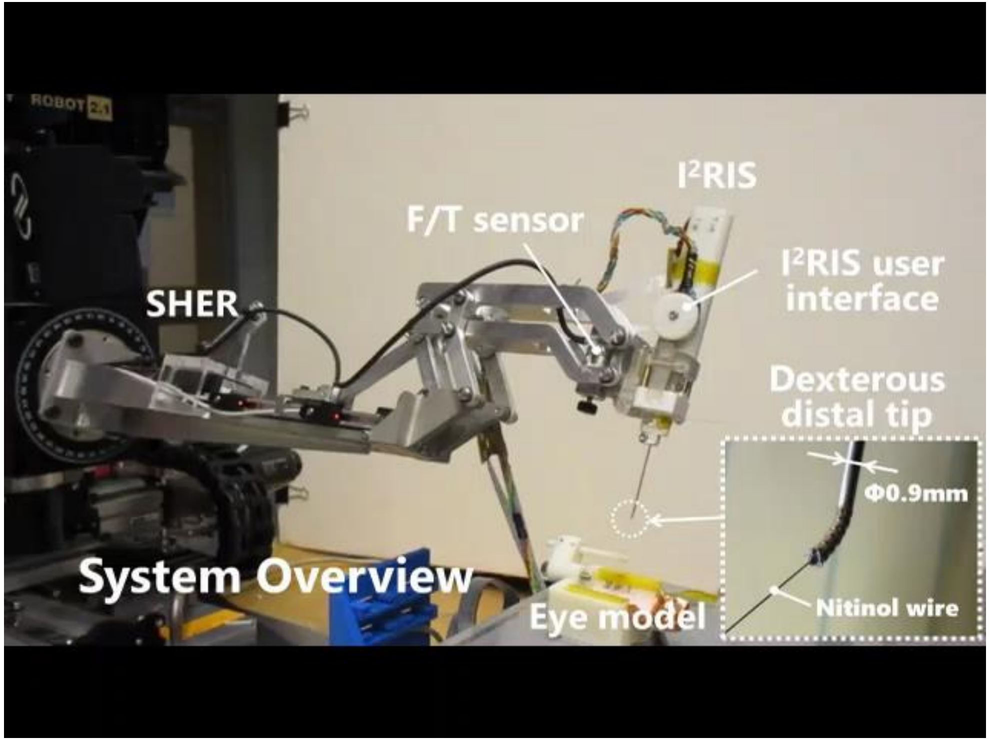
Prior Work



I²RIS
F/T sensor
I²RIS user interface
SHER
Dexterous distal tip
Φ0.9mm
Nitinol wire
System Overview
Eye model

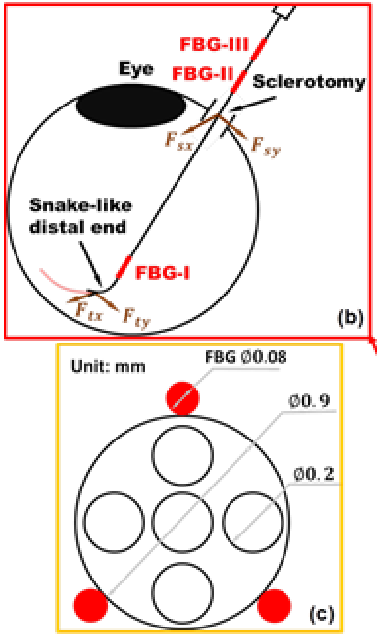
Goals for the Semester

- Analyze the kinematics and force distribution of the integrated system
  - Kinematics -> Move tool tip along trajectories
  - Force distribution -> Calculate force at tool tip and point of insertion
- Design a control algorithm to generate an optimized trajectory & remain within force limits
- Simulate the system to follow desired trajectories in Gazebo
- Control the combined robot with a Phantom Omni

[6] Nigrelli, V. et al., 2008

Technical Approach

- Generate kinematics and force distribution model
  - Get measurement of the robot from CAD model
  - Analyze the forward kinematics, inverse kinematics, and Jacobians of the integrated system
  - Calibration of the kinematics model with the real robot
  - Calculate the force between the tool-tip and retinal tissue based on FBG force-sensor readings and the pose of the snake-like distal end



From Dr. Iordachita

Technical Approach

- Develop control algorithm
  - Understand the mechanical design of SHER base and I^{2}RIS robot
  - Literature review of robot control algorithms suitable for our application
  - Requirements:
    - Tremor-free manipulation
    - Limited error between performed and desired trajectories of the robot
    - Must stay within force and space constraints

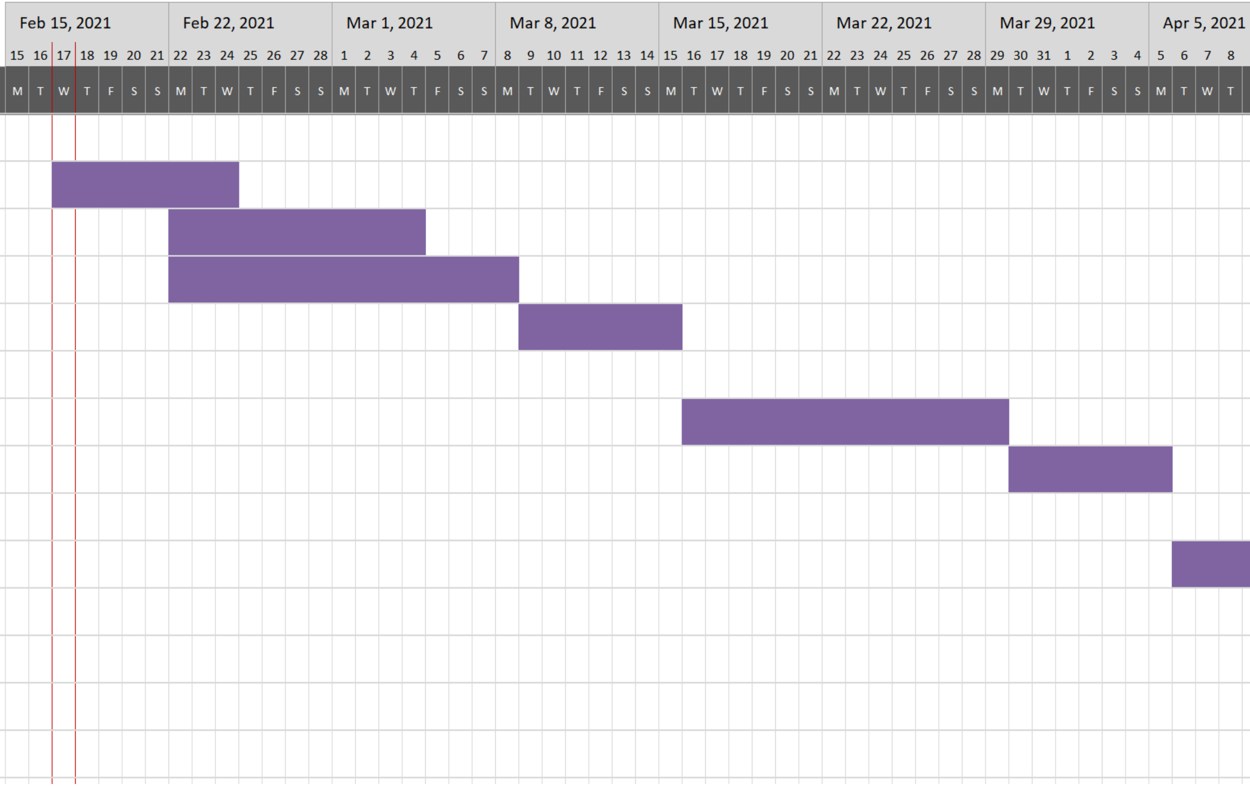
- Gazebo simulation
  - Simulate with appropriate mechanical properties & meshes
  - Control combined robot system with ROS (Robot Operating System) platform

Deliverables

	Deliverables	Deadline
Minimum	A paper that includes calculation of forward kinematics, inverse kinematics, and jacobian of the combined system	3/8
	A report on the force distribution analysis	3/15
	A schematic of the control algorithm design	3/29
Expected	A functioning gazebo simulation in which the end-effector of the simulated eye robot follow several optimized trajectories	4/5
	A report that summarizes the control algorithm, and an evaluation of the simulated system	5/5
Maximum	Implemented control system on real hardware	5/5
	Documentation of implementation	5/5

Timeline

TASK	PROGRESS	START	END
Minimum			
Literature Review	0%	2/17/21	2/24/21
Import models into Gazebo	0%	2/22/21	3/4/21
Develop combined kinematic mode	0%	2/22/21	3/8/21
Analyze force distribution	0%	3/9/21	3/15/21
Expected			
Develop control algorithm	0%	3/16/21	3/29/21
Test and validate control algorithm	0%	3/30/21	4/5/21
Maximum			
Implement algorithm with physical :	0%	4/6/21	4/12/21
Test system with same prior tests	0%	4/13/21	4/19/21
Final Report			
Write up report	0%	4/20/21	4/29/21
Presentation	0%	4/26/21	5/6/21



Assigned Responsibilities

- Yishun:
  - Create kinematics model and force distribution model of the integrated robotic system
  - Develop control algorithm
- Kaiyu:
  - Develop control algorithm
  - Simulate the controlled system in gazebo to follow desired trajectories with appropriate constraints

Dependencies

Dependency	Status	Contingency	Followup	Funding	Deadline
SHER	Exists	Simulation	-	JHU Internal Funding	-
I^2RIS	No FBG force sensors	Only implement position control/FBG in simulation	Discuss with Prof. Iordachita	JHU Internal Funding	3/29
Computer running Linux for simulation	Exists	-	-	Personal computer	-
Phantom Omni	In lab	Joy-stick input/keyboard input	-	JHU Internal Funding	-

Management Plan

- Meetings:
  - Meet weekly with Dr. Li and Prof. Iordachita over Zoom (TBD)
  - Meet with Dr. Li in lab as needed
  - Weekly team meetings (Tuesday 4:00-5:00 pm)

- Communications:
  - Email between mentors and the team
  - Slack between the team members

Reading List

- Jinno, Makoto, and Iulian Iordachita. “Improved Integrated Robotic Intraocular Snake*.” *2020 International Symposium on Medical Robotics (ISMR)*, 2020, doi:10.1109/ismr48331.2020.9312927.
- He, Xingchi. *Force Sensing Augmented Robotic Assistance for Retinal Microsurgery.* 2015. Johns Hopkins U, PhD dissertation.
- Azimi, Ehsan, et al. “Teleoperative Control of Intraocular Robotic Snake: Vision-Based Angular Calibration.” *2017 IEEE SENSORS*, 2017, doi:10.1109/icsens.2017.8234072.
- Üneri, Ali, Marcin A. Balicki, James Handa, Peter Gehlbach, Russell H. Taylor, and Iulian Iordachita. "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, 2010.
- P. Gupta, P. Jensen, and E. de Juan, “Surgical forces and tactile perception during retinal microsurgery,” in *International Conference on Medical Image Computing and Computer Assisted Intervention*, vol. 1679, 1999, pp. 1218–1225
- Zhang, Ding-guo, and Sheng-feng Zhou. “Dynamic Analysis of Flexible-Link and Flexible-Joint Robots.” *Applied Mathematics and Mechanics*, vol. 27, no. 5, 2006, pp. 695–704., doi:10.1007/s10483-006-0516-1.

References

[1] 3D Systems. “Touch.” *3D Systems*, 4 June 2020, www.3dsystems.com/haptics-devices/touch.

[2] Dr. Raja Rami Reddy PMD FRCS (Glasg). “Vitrectomy Surgery: Risks and Postoperative Care: Neoretina.” *Neoretina Blog*, 15 Apr. 2019, neoretina.com/blog/what-to-expect-after-vitrectomy-surgery-vitreo-retinal-surgery-postoperative-course-and-care/.

[3] P. Gupta, P. Jensen, and E. de Juan, “Surgical forces and tactile perception during retinal microsurgery,” in *International Conference on Medical Image Computing and Computer Assisted Intervention*, vol. 1679, 1999, pp. 1218–1225

[4] Makoto Jinno, Gang Li, Niravkumar Patel, Iulian Iordachita, “An Integrated High-dexterity Cooperative Robotic Assistant for Intraocular Micromanipulation”, 2021., Kokushikan University

[5] Üneri, Ali, Marcin A. Balicki, James Handa, Peter Gehlbach, Russell H. Taylor, and Iulian Iordachita. "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, 2010.

[6] Jinno, Makoto, and Iulian Iordachita. “Improved Integrated Robotic Intraocular Snake*.” *2020 International Symposium on Medical Robotics (ISMR)*, 2020, doi:10.1109/ismr48331.2020.9312927.