Tele-operation Control of a High Dexterity Robot for Vitreoretinal Surgery

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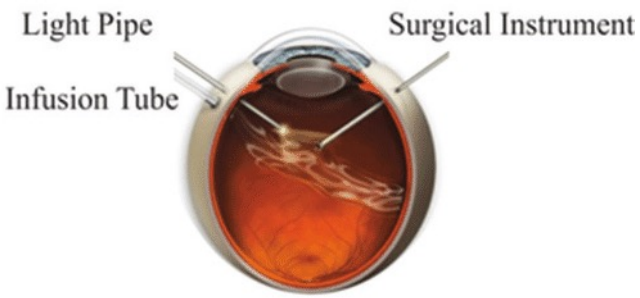
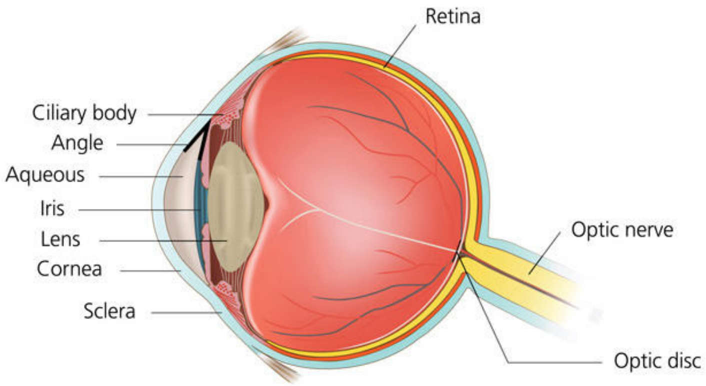
Mentors: Ali Ebrahimi, Prof. Iulian Iordachita, Adnan Munawar, Alireza Alamdar

Clinical motivation

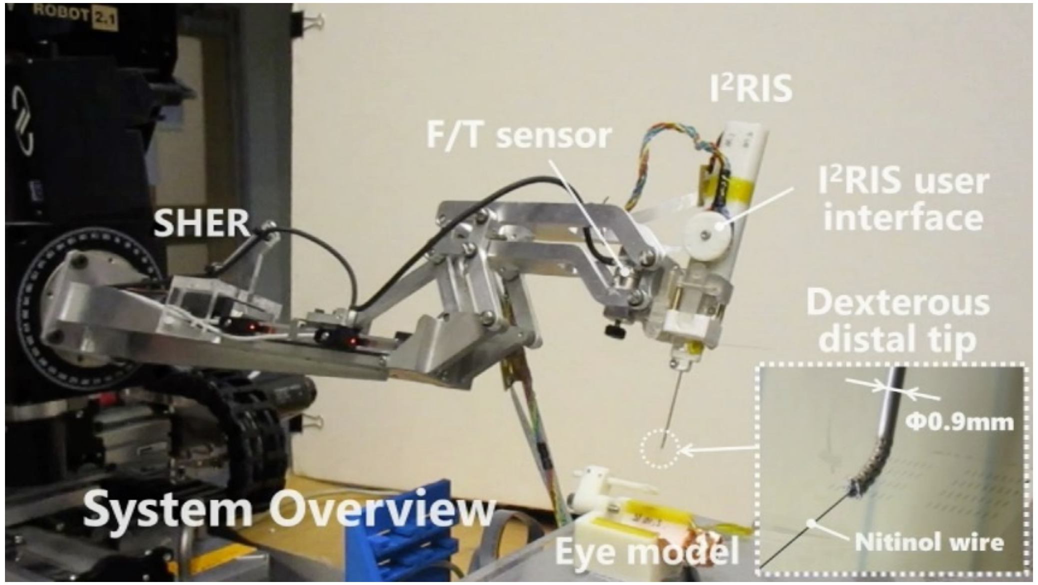
- Difficulty of retinal surgery
  - Epiretinal Membrane peeling
  - Retinal vein cannulation
- Issues with hand tremor
  - Retinal vein diameter: 80 - 120μm
  - Physiological hand tremor: 100
- Risk of retinal tears
  - <7.5 mN
- Lack of fine force feedback
- Exceptional training





Background

- Systems like **SHER** (Steady Hand Eye Robot), allow for robot-controlled surgery, allowing surgeons to mitigate physiological tremor affects
- However, even with **SHER**, some operative procedures still pose a significant enough risk
  - E.g., procedure may require movement of eye, due to trocar constraint.
- Introduction of **IRIS** (Integrated Robotic Intraocular Snake) allows for added flexibility
  - i.e., eliminate the need to move the eye by employing a more flexible end effector, with bend angles up to 55^{o} [1]



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Preexisting solutions/Similar approaches

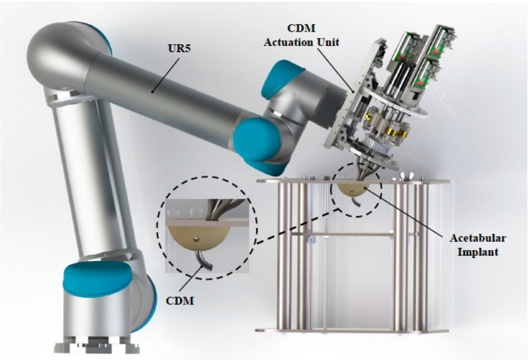


Fig. 1. Hybrid redundant surgical system for treatment of osteolysis.

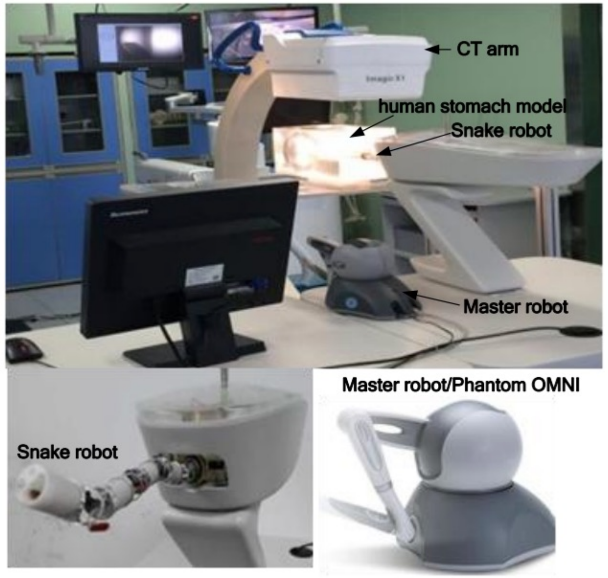
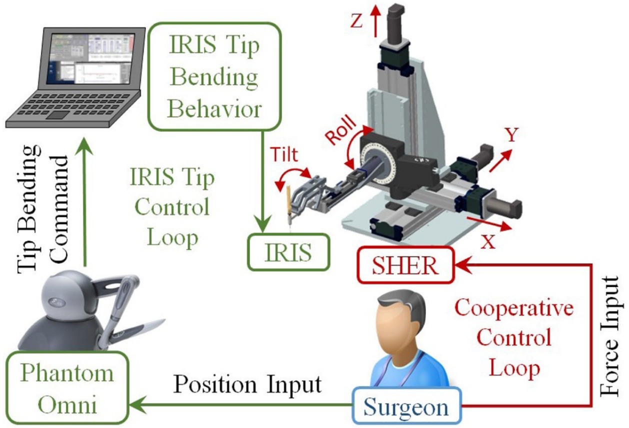


Figure 1. A MS teleoperation system of the snake robot



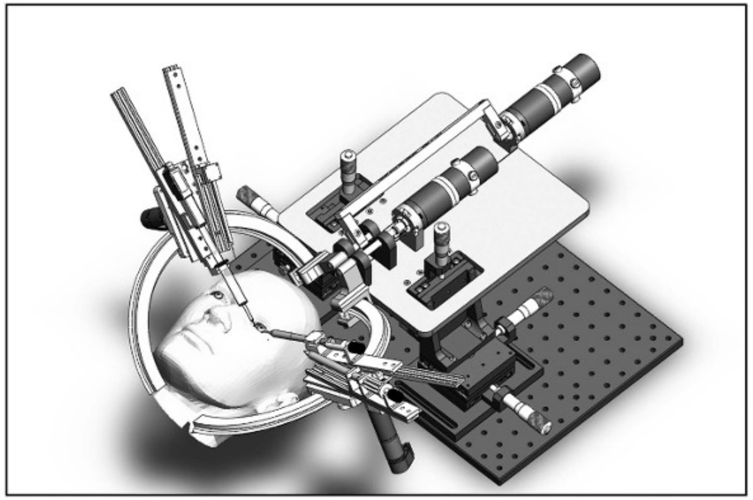


Figure 2 Computer-aided design of the IRISS slave manipulator. Each arm of the robot apparatus is mounted on a separate stage with its own remote center of motion.

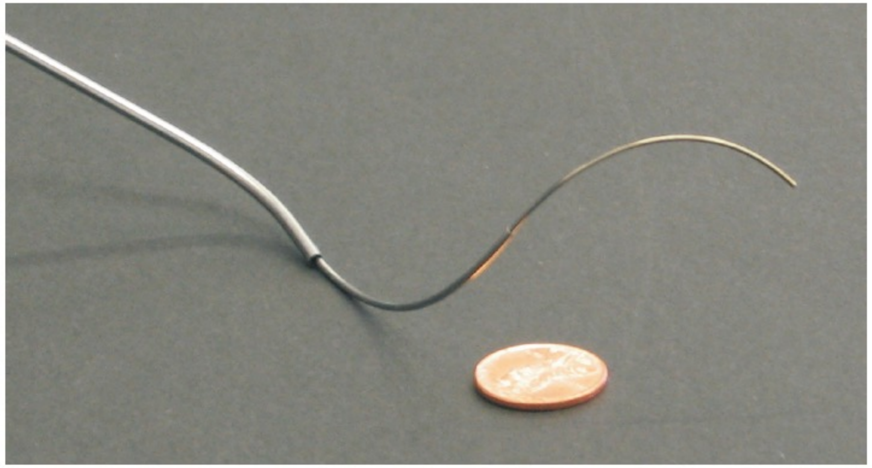


Fig. 1. Prototype active cannula made of superelastic nitinol tubes.

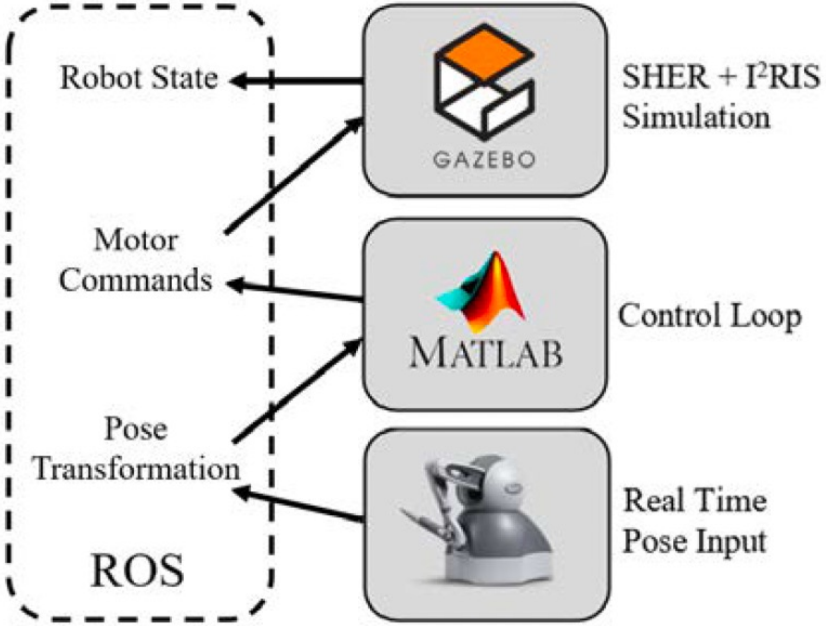
Rahimy, E., Wilson, J., Tsao, T. C., Schwartz, S., & Hubschman, J. P. (2013). Robot-assisted intraocular surgery: development of the IRISS and feasibility studies in an animal model. *Eye*, *27*(8), 972-978.

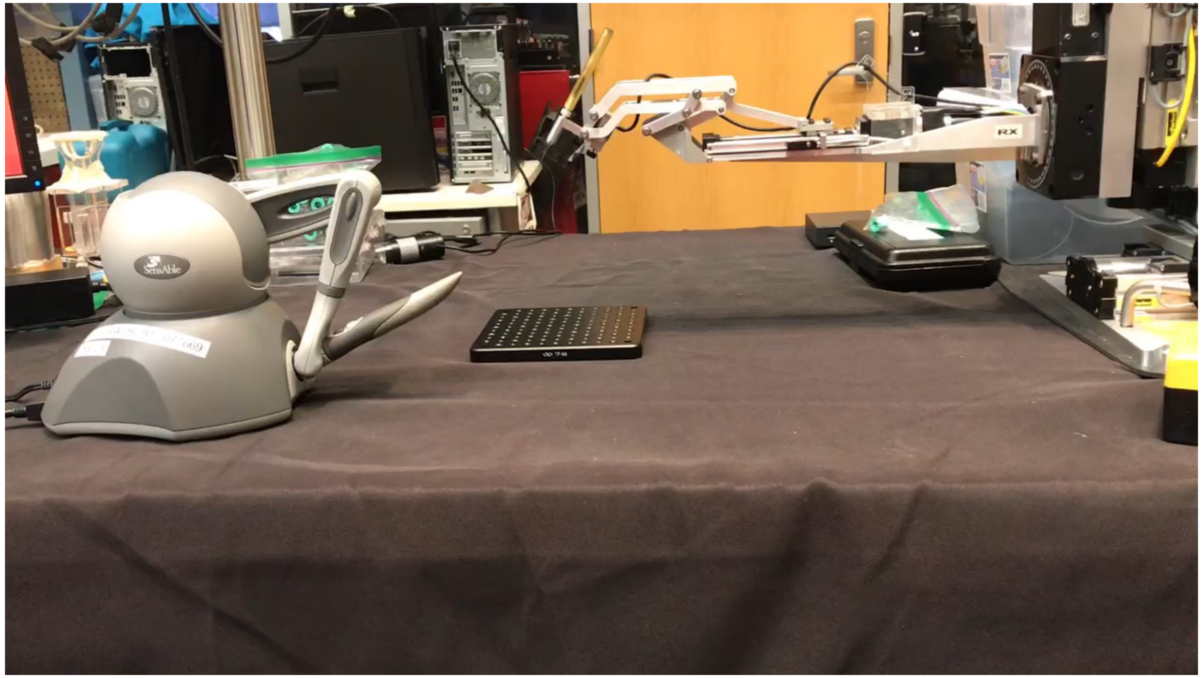
Ren, L., Omisore, O. M., Han, S., & Wang, L. (2017, July). A master-slave control system with workspaces isomerism for teleoperation of a snake robot. In *2017 39th annual international conference of the IEEE engineering in medicine and biology society (EMBC)* (pp. 4343-4346). IEEE.

Webster, R. J., Okamura, A. M., & Cowan, N. J. (2006, October). Toward active cannulas: Miniature snake-like surgical robots. In *2006 IEEE/RSJ international conference on intelligent robots and systems* (pp. 2857-2863). IEEE.

Song, J., Gonenc, B., Guo, J., & Iordachita, I. (2017, May). Intraocular snake integrated with the steady-hand eye robot for assisted retinal microsurgery. In *2017 IEEE International Conference on Robotics and Automation (ICRA)* (pp. 6724-6729). IEEE.

Current system





Teleoperation of both Eye and Snake robot (separately) accomplished by Kaiyue et al.

Shi, Kaiyu; Zhou, Yishun; Ebrahimi, Ali; Li, Gang; Iordachita, Iulian (2022), Optimization-based Concurrent Control of a High Dexterity Robot for Vitreoretinal Surgery. Manuscript submitted for publication

Ebrahimi, Ali. (2018). *CIS II Project – Spring 2022* [PowerPoint presentation], CIS II.

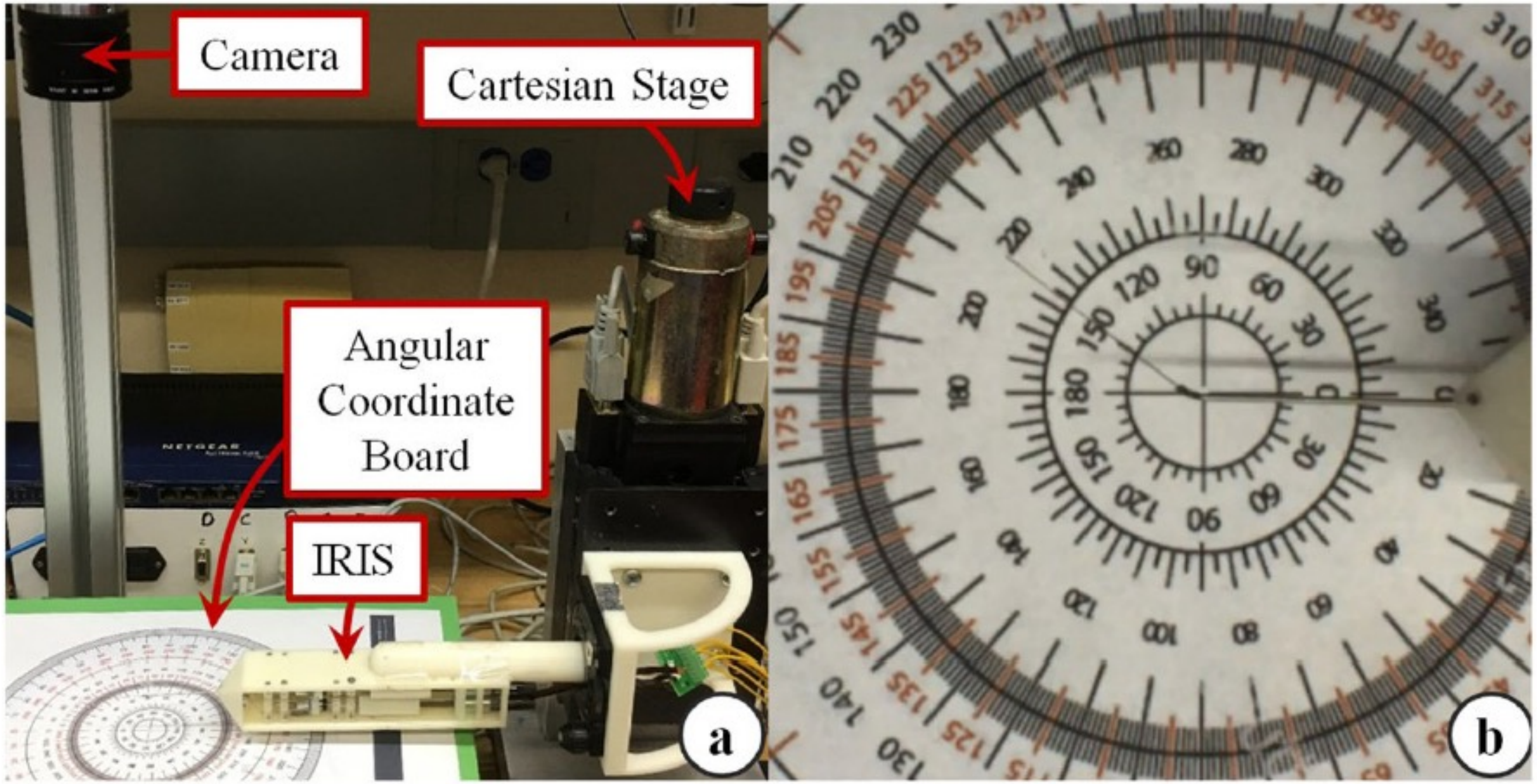
Specific aims

- Validate current snake robot controls, and calibrate the movement of the new snake robot (I^2RIS)
- Combine code package of 2 DOF snake robot with 5 DOF eye robot
- Develop and implement teleoperation algorithm for controlling 7 DOF system with 5 DOF Phantom Omni
- Design and execute experiment to validate control algorithm

Technical approach

Forward Kinematics

Calibrating I^{2}RIS



Developing a mapping between the bending angle of the IRIS robot tip and the linear displacement of the cables

Song, J., Gonenc, B., Guo, J., & Iordachita, I. (2017, May). Intraocular snake integrated with the steady-hand eye robot for assisted retinal microsurgery. In *2017 IEEE International Conference on Robotics and Automation (ICRA)* (pp. 6724-6729). IEEE.

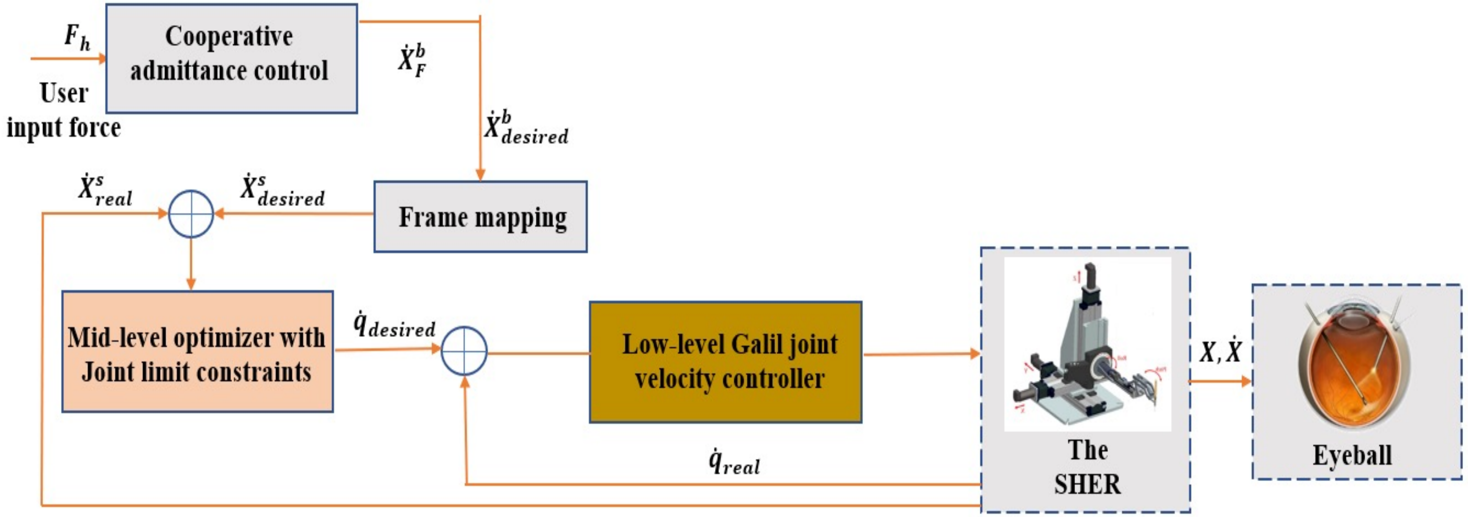
Technical Approach contd.

Control Algorithms:

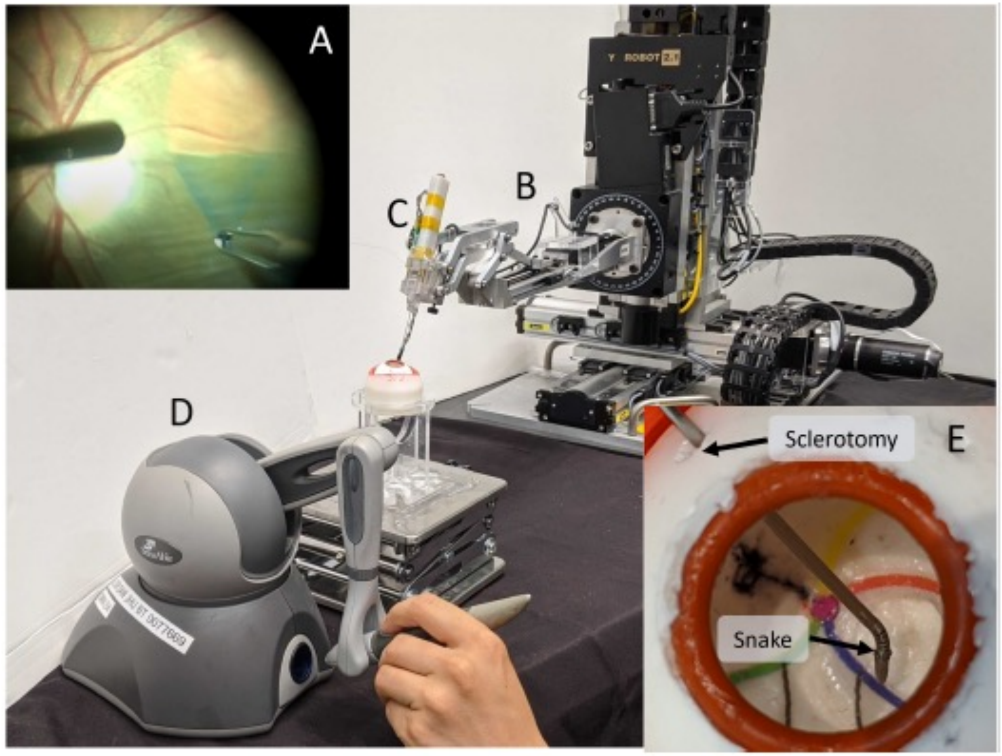
- Understand the control algorithm of the current robots
- Cooperative admittance control

Integration Interface

- Integrate snake (CISST-SAW) and eye robot code via ROS



Admittance control framework of the Steady Hand Eye Robot (SHER), Compliant and Non-Backdrivable



Envisioned high dexterity intraocular manipulator: (A) Epiretinal membrane peeling; (B) Steady Hand Eye Robot; (C) Integrated robotic intraocular snake robot; (D) Phantom Omni; (E) Distal snake-like tool-end inside eye phantom.

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Technical approach contd.

Input device:

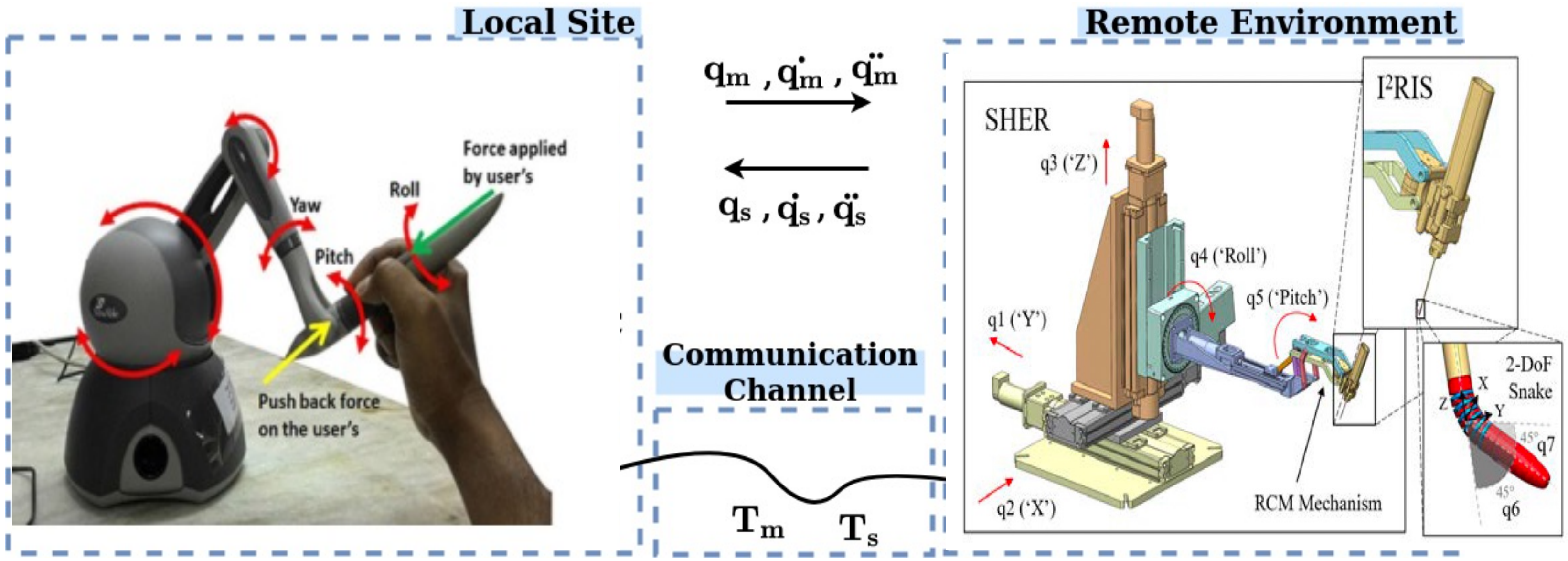
- 5 DOF Phantom Omni

Remote Robot:

- 7 DOF Snake + Eye Robot
  (I^2RIS + SHER 2.1)

Constraints:

- Velocity limits
- Joint limits



Potential models (simulation vs real)

- Free space control
- Develop an optimal inverse kinematics method with new constraints for hybrid system

Deliverables

- Minimum
  - Evaluating the already existing software of the snake robot and eye robot + tele-operation control of both
  - Integrate the Snake Robot software with the Eye Robot software
  - Develop accurate mapping of snake robot movement/calibrate I^2RIS
- Expected
  - Developing and implementing control algorithms for the tele-operated system with constraints
  - Testing teleoperation code
- Maximum
  - Evaluate complete teleoperation control vs cooperative control
  - Academic paper on teleoperation control of hybrid system (Eye + Snake Robot)

Dependencies

Dependency	Status	Point of Contact	Fallback/Contingency measure	Need by date	Result in case of failure
Eye Robot accessibility	Readily available	Ali Ebrahimi/ Dr Iordachita	No contingency	N/A	N/A
Snake Robot accessibility	Readily available	Ali Ebrahimi/ Dr. Iordachita	No contingency	N/A	N/A
Phantom Omni	Obtained	Ali Ebhraimi/ Dr. Iordachita	No contingency	N/A	N/A
Phantom eye/experimental setup	Available (Subject to alterations)	Ali Ebhraimi/ Dr. Iordachita	Verify via simulation	04/20/2022	N/A
Code packages	Partially available • Snake Robot integration incomplete	Ali Ebrahmi	No contingency	02/10/2022	Failure to accomplish any deliverable
Mentor feedback	Available	Ali Ebrahimi, Dr Iordachita, Adnan Munawar, Alireza Alamdar	No contingency	ongoing	Delay in teleoperation implementation

Timeline

Tasks	% complete	Feb.7	Feb. 14	Feb.21	Feb. 28	Mar.7	Mar.14	Mar.21	Mar.28	Apr. 4	Apr.11	Apr.18	Apr. 25	May.2
Project plan and webpage	100%													
Understanding the Eye Robot code	25%													
Understanding the Snake Robot code	10%													
Integrate snake robot code into Eye robot code package	0%													
Validate Snake robot control algorithms and reproduce movement tracking model	0%													
Develop kinematic model of hybrid system	0%													
Develop and implement control algorithim for teleoperation of hybrid system	0%													
Verify testing platform														
Internal testing of hybrid system's teleoperation	15%													
Final report and presentation	0%													

Milestones

Milestone	Start Date	End date	Buffer date
Integrating code packages	03/14	03/27	04/3
Calibrate snake model	03/07	03/20	03/27
Kinematic model	03/21	03/27	04/03
Implementing teleoperation	03/28	04/17	04/24
Testing	04/11	04/24	05/08

Project management

- Mentors
    - Ali Ebrahimi
    - Prof. Iulian Iordachita
    - Adnan Munawar
    - Alireza Alamdar
- Weekly meetings with Prof. Iordachita on Wednesdays
- Virtual meetings with Ali Ebrahimi on Fridays
- Maintain communication via Email
- Shared OneDrive folder for all presentations, literature review, and code updates

QUESTIONS?

Reading list

- He, X., Van Geirt, V., Gehlbach, P., Taylor, R., & Iordachita, I. (2015, May). IRIS: integrated robotic intraocular snake. In *2015 IEEE International Conference on Robotics and Automation (ICRA)* (pp. 1764-1769). IEEE
- Song, J., Gonenc, B., Guo, J., & Iordachita, I. (2017, May). Intraocular snake integrated with the steady-hand eye robot for assisted retinal microsurgery. In *2017 IEEE International Conference on Robotics and Automation (ICRA)* (pp. 6724-6729). IEEE.
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- Ebrahimi, A., He, C., Roizenblatt, M., Patel, N., Sefati, S., Gehlbach, P., & Iordachita, I. (2018, July). Real-time sclera force feedback for enabling safe robot-assisted vitreoretinal surgery. In *2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)* (pp. 3650-3655). IEEE.
- Wilkening, P., Alambeigi, F., Murphy, R. J., Taylor, R. H., & Armand, M. (2017). Development and experimental evaluation of concurrent control of a robotic arm and continuum manipulator for osteolytic lesion treatment. *IEEE robotics and automation letters*, *2*(3), 1625-1631.

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- 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
- Ebrahimi, Ali. (2018). *Robot Control Algorithms Based on Sclera Force Information* [PowerPoint presentation], CIS II.
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- Song, J., Gonenc, B., Guo, J., & Iordachita, I. (2017, May). Intraocular snake integrated with the steady-hand eye robot for assisted retinal microsurgery. In *2017 IEEE International Conference on Robotics and Automation (ICRA)* (pp. 6724-6729). IEEE.