

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

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Clinical motivation

Vitreoretinal surgery is a highly delicate and difficult surgery kind of intraocular surgery, one that is concerned with operating deep within the eye on the retina. Examples of this surgery are epiretinal membrane peeling and retinal vein cannulation.

However, there are several factors that could be a potential risk during such surgeries. The primary issue arises from physiological hand tremor, which, as faint as it may be, can still result complications during surgery. For example, when peeling back scar tissue during an epiretinal membrane peeling, any slight jerks from hand tremor can result in retinal tears. Similarly, exerting forces > 7.5 mN to the retina could result in retinal tears, forces which are too fine to be felt by a human. All these factors result in an exceptional level of training that surgeons must undergo to be able to perform these surgeries [1][2].

Background

To resolve the above stated issues, researcher at Johns Hopkins University, AMIRO LCSR, came up with a surgical robotic system, a Steady Hand Eye Robot (SHER), which performs robot-controlled surgery, allowing surgeons to mitigate (filter) physiological tremor affects and provide them with haptic force feedback. Systems like SHER have helped address a lot of the issues that surgeons faced in the OR. This impedance style robot drastically reduced the effects of tremor in surgery.

However, even with SHER, there are still some operative procedures that may not be easily executable, given the limited flexibility of the end effector. A straight needle attached to the end-effector of SHER does not provide enough dexterity for surgeons operating inside the eye, with surgeons often having to move the eye to navigate. Therefore, a 2 DoF Integrated Robotic Intraocular Snake (IRIS) was designed and attached to the SHER end-effector. This eliminated the need to move the eye by employing a more flexible end-effector.

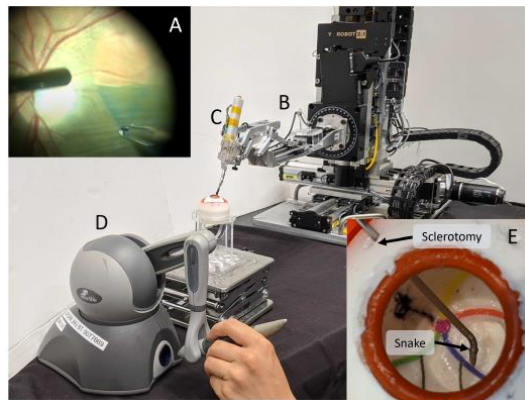


Figure 1. Envisioned high dexterity intraocular manipulator: (A) Epiretinal membrane peeling; (B) Steady Hand Eye Robot; (C) Integrated robotic intraocular snake robot; (D) Phantom Omni; (E) Distal snake-like tool-end inside eye phantom [3].

Existing approaches include teleoperation of both the snake and the eye robot, but separately, as well as a cooperative approach, which involves moving the eye robot by hand, and teleoperating the snake after moving it to the desired position. A recently accepted paper from the AMIRO lab successfully simulated the tele-operation of the 7 DoF system in question with a 5 DoF Phantom Omni.

Specific aim/Goals

The motivation to implement this teleoperation setup is multifold. First and foremost, teleoperating a device like the eye robot eases the cognitive load on the user/surgeon, which can understandably improve surgical performance. In addition, teleoperation offers a more intuitive way to manipulate the tool, in addition to granting the user enhanced flexibility when operating within the eye. The hybrid system, with its flexible end effector should theoretically allow for more flexibility once the surgeon has entered the eye, relative to a stiff tool end effector.

Once we establish the relevant control systems for successful manipulation of the I²RIS snake robot, we aim to combine code package of 2 DoF snake robot with 5 DoF eye robot. The I²RIS robot code is current housed in a CIIST-SAW package, while the eye robot is written completely in ROS. We wish to establish communication between both code packages via ROS.

After integrating the two robots and preparing the hybrid robot hardware, we intend to develop and implement a teleoperation algorithm for controlling 7 DoF hybrid robot with 5 DoF Phantom Omni. Finally, we can design and execute an experimental scenario to validate our control algorithm and establish a framework for moving this system closer to clinical assimilation.

Technical approach

Our work aims to build off the current simulation model, which employs a straight-forward optimization algorithm, with several assumptions fit for a simulation, but non-adaptable in a real-world scenario (e.g lack of calibration, lack of position or error tracking). In addition to studying different objective functions for our implementation, we also aim to establish our optimization framework in C++, moving away the MATLAB based approach used in the simulation.

Kinematics modeling:

To design a control algorithm for the snake robot, we need to have knowledge about the robot kinematics. Given that kinematics modeling of continuum robots is not as straightforward as conventional manipulators, we aim to develop an experimental forward kinematics and calibrate the movement of the new snake robot (I²RIS) to generate a mapping between the snake robot actuation space and its configuration space and finally to its task space. This will allow for a precise forward kinematic mapping, which is critical to establish any form of inverse kinematic model.

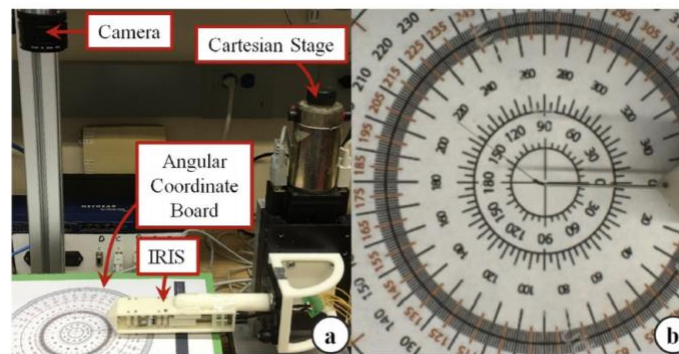


Figure 2. Developing a mapping between the linear displacement of the cables (actuation space), the bending angle of the IRIS robot (configuration space) and the IRIS robot tip location (task space) [4].

Teleoperation control

To develop a teleoperation control algorithm, we need to integrate the snake code package (CISST-SAW) and that of the eye robot via ROS. Then, using a 5 DoF Phantom Omni as a local robot, we want to control the hybrid 7 DoF Snake & Eye Robot (I²RIS + SHER 2.1) as remote robot. To do this, we intend to design an optimal inverse kinematics method with new constraints of the hybrid system. There are several constraints that should be considered in the teleoperation algorithm such as robot joint limits, motor velocity limits, and RCM constraint. A key driving force in determining the optimal algorithm for teleoperation is how to best compensate for the 2 redundant DoF of the 7 DoF hybrid system. One way to overcome this issue while maintaining the RCM constraints is to use the mechanical RCM of the eye robot by holding the three translational linkages and using the two pitch and roll motions of the eye robot and the two bending motions of the snake robot. Additional algorithms will be tested and evaluated in accordance with the proposed timeline.

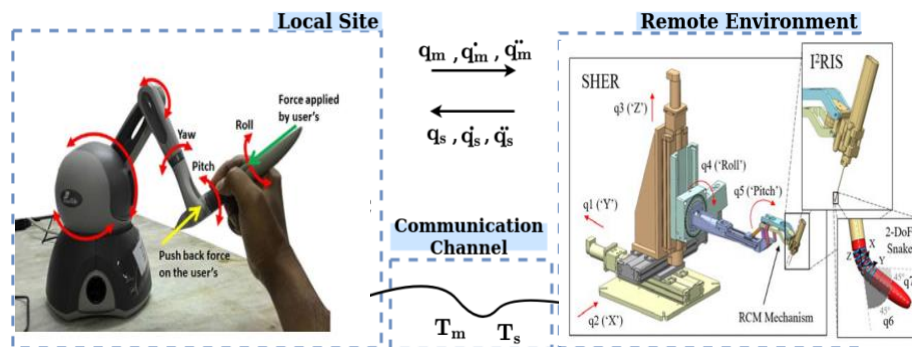


Figure 3. Teleoperation control framework, 5 DoF Phantom Omni as a local robot on the left side, and the hybrid 7 DoF Snake & Eye Robot (I²RIS + SHER 2.1) as remote robot on the right.

Deliverables

Minimum

- Evaluating the already existing software of the snake robot and eye robot + tele-operation control of both
- A short report detailing successful integration of the Snake Robot software with the Eye Robot software
- A model of accurate mapping of snake robot movement/calibration mode of I²RIS

Expected

- Code package with successful control algorithms for the tele-operated system with constraint, with appropriate documentation for ease of future development
- A comprehensive report highlighting the results of experimental testing of the implemented teleoperation code

Maximum

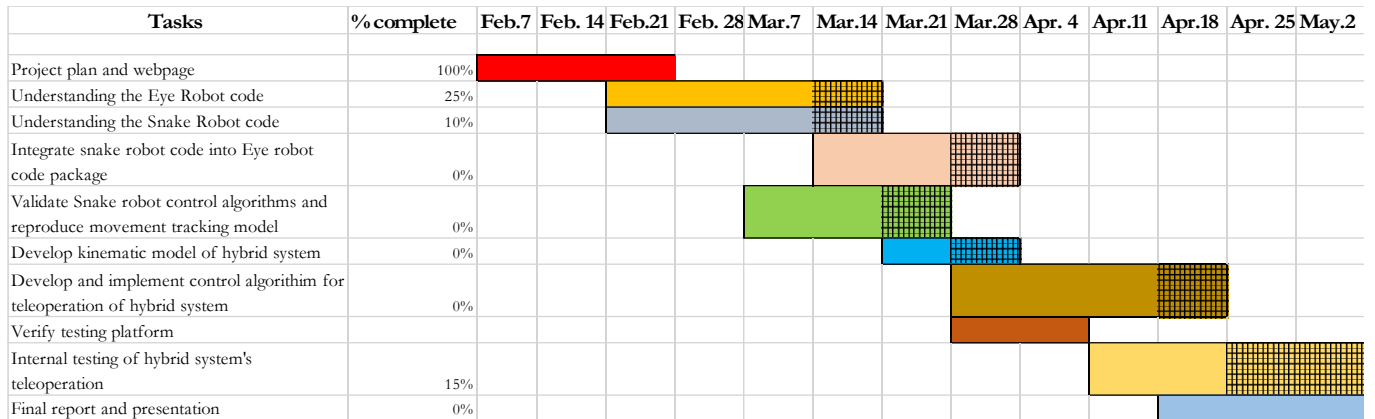
- Design and execution of experiment to evaluate complete teleoperation control vs cooperative control
- Academic paper on teleoperation control of hybrid system (Eye + Snake Robot).

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 <ul style="list-style-type: none"> Snake Robot integration incomplete 	Ali Ebrahmi	No contingency	03/10/2022	Failure to accomplish any deliverable
Mentor feedback	Available	Ali Ebrahimi, Dr Iordachita, Adnan Munawar, Alireza Alamdar	No contingency	ongoing	Delay in teleoperation implementation

All of the dependencies for this project have been met. This allows for great flexibility in the execution of project related activities, with everything, from code packages to the main robotic assemblies, to mentor feedback, readily available

Timeline



The shaded regions of the timeline represent the buffer period. This is the period a given task can be delayed in completion beyond its expected conclusion date, without impacting the final deliverable for this semester long project (i.e. completed report and presentation on experimental evaluation of teleoperation control of a real 7 DoF robot). Coding based tasks, such as code package integration, are independent of physical tasks, such as calibration, or forward kinematic mapping. The timeline is primarily drive by the expected deliverables.

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

Management plan

Our team's management plan involves weekly meetings with Professor Iulian Iordachita on Wednesday evenings. We further have a weekly meeting with Ali Ebrahimi on Friday mornings. We will also maintain communication with Dr. Alireza Alamdar and Dr. Adnan Munawar through email. Team 22 further has a non-CIS II affiliate student who has offered to help with the software integration of the project.

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The team will maintain communication through email, and other relevant messaging services. A shared OneDrive folder is employed to maintain relevant project materials, including but not limited to presentations, reference literature, and reference code.

Reading list

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