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

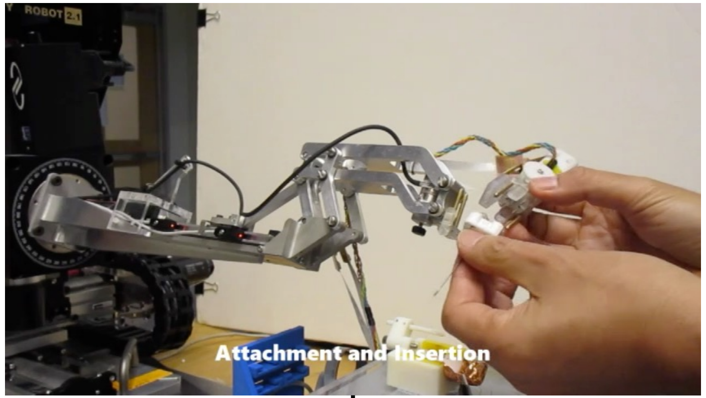
Muhammad Hadi , Mojtaba Esfandiari

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

Overview of our Project

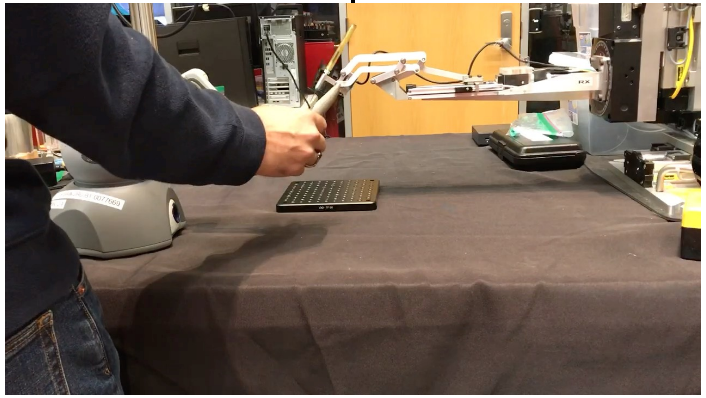
Implement satisfactory teleoperation control of hybrid robot with Phantom Omni for potential vitreoretinal surgery

- Reduce cognitive load on user
- Increased flexibility when tooltip inside eye
    - Relative to current stiffer models

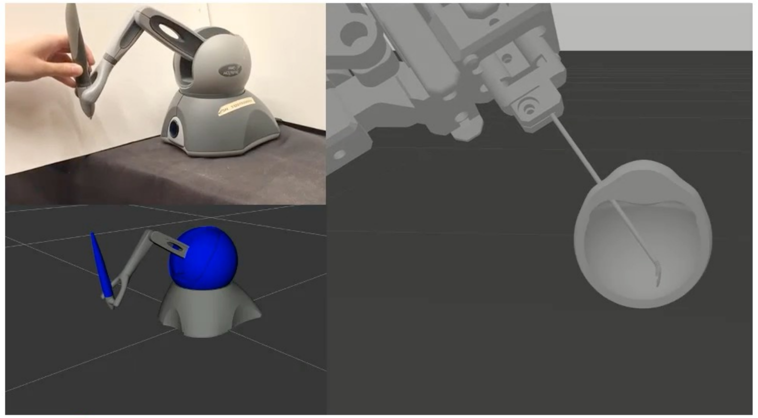


Combine snake and eye robot

Control both via teleoperation



Moving From Center To Surface



*simulated teleoperation control

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

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

Paper selection

Optimization-based Concurrent Control of a High Dexterity Robot for Vitreoretinal Surgery

- Authors: Kaiyu Shi, Yishun Zhou, Ali Ebrahimi, Gang Li, and Iulian Iordachita (all affiliated with LCSR)
- April 2022 (ISMR)
- Overview
  - Simulated teleoperated control of 7 DOF hybrid system with 5 DOF follower robot
  - Proof of concept, with a variety of tests to validate approach
- Relevance to our project:
  - Same approach to teleoperation setup
  - Same hardware (albeit simulated)
  - Similar fundamental approach to teleoperation algorithm
  - Same forward kinematic chain for base robot

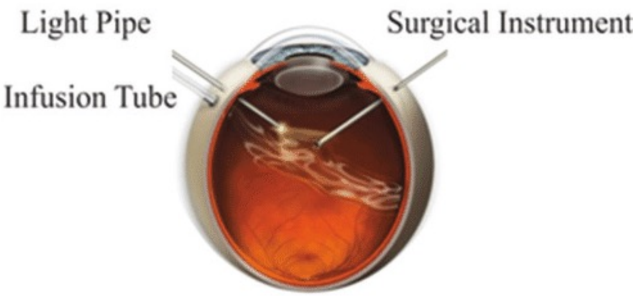
Background and Introduction of paper

Difficulty of retinal surgery

- Epiretinal Membrane peeling
- Retinal vein cannulation

Issues with hand tremor

- Retinal vein diameter: 80 - 120μm
- Physiological hand tremor: 100

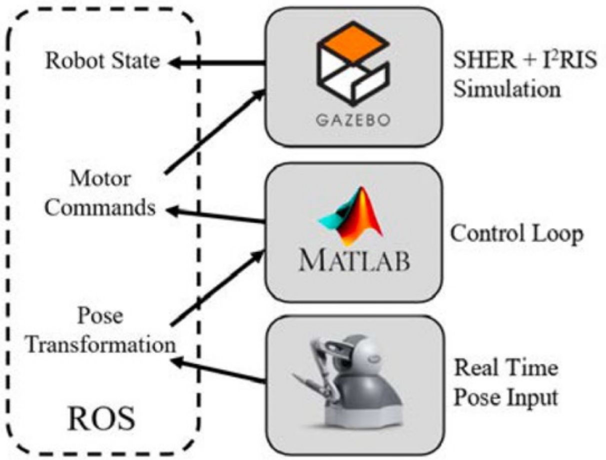


- Systems like the 5 DOF **SHER** (Steady Hand Eye Robot), allow for robot-controlled surgery, allowing surgeons to mitigate physiological tremor affects
- Introduction of 2 DOF **IRIS** (Integrated Robotic Intraocular Snake) allows for added flexibility
- Teleoperation offers more intuitive control of complex systems

"The peripheral aspects of vitreoretinal surgery," Centre for Sight, 07-Mar-2020. [Online]. Available: https://www.centreforsight.net/blog/the-peripheral-aspects-of-vitreoretinal-surgery/. [Accessed: 01-Mar-2022].

Method/Approach

High level workflow and simulation setup



- Simulation setup in Gazebo (+ MATLAB)
- Kinematic chain obtained from URDF files
- Measurements obtained from CAD files

Hardware (or simulated hardware)

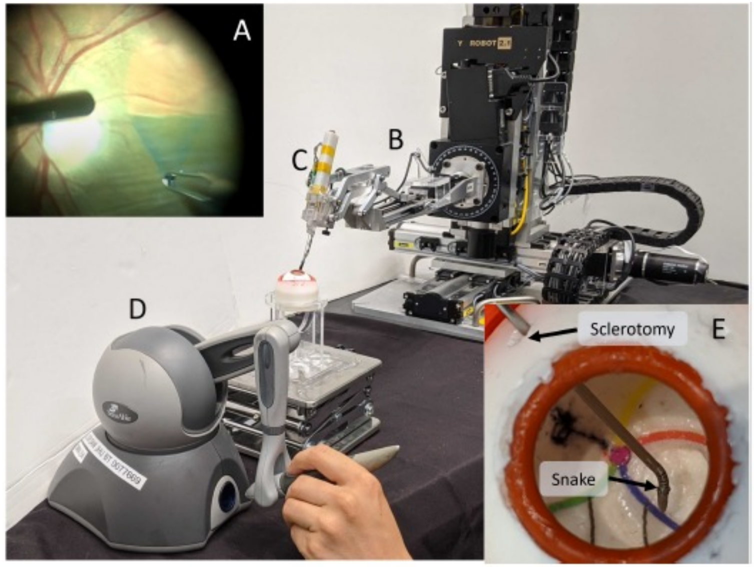
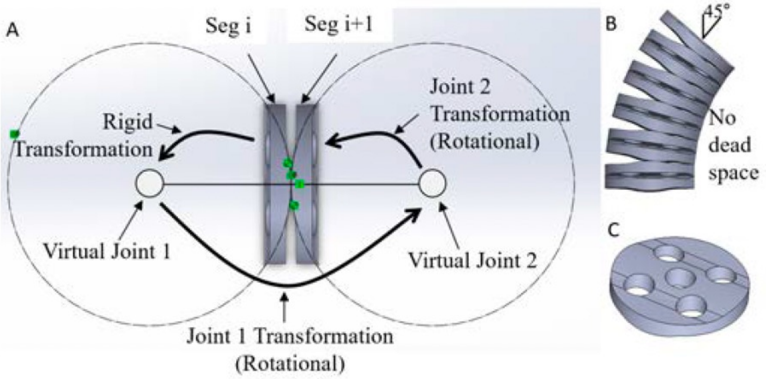


Fig 1. Envisioned high dexterity intraocular manipulator: (A) Epiretinal membrane peeling; (B) Steady Hand Eye Robot; (C) Integrated robotic intraocular snake robot; (D) Phantom Omni; (E) Distal snake-like tool-end inside eye phantom [3].

Forward kinematic chain setup

Analytical Jacobian for both the snake and the eye



Method/Approach cont'd

Teleoperation algorithm setup

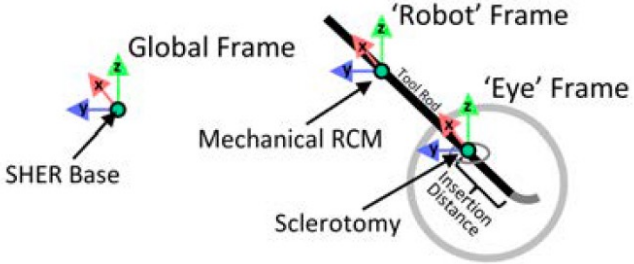
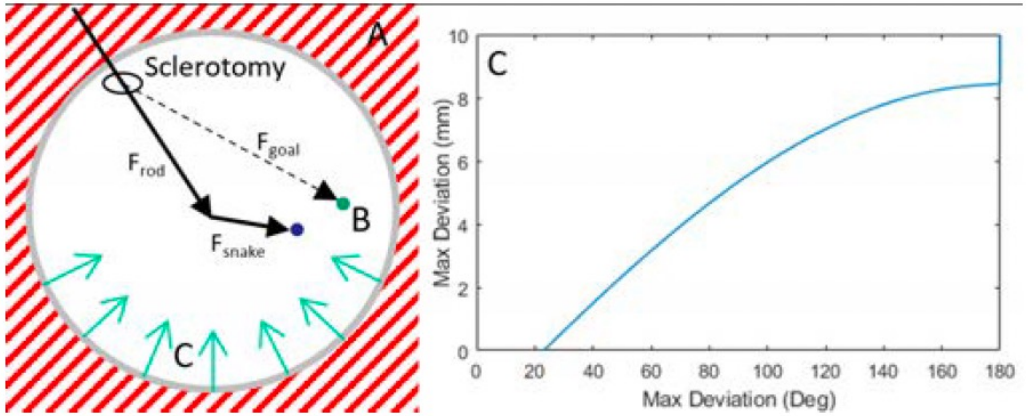


Fig. 5. Frames of reference.



$$Objective = ||Jacobian * \Delta q - \Delta X||$$

Algorithm 1 InvKinSolver

Input: Pose X_{i+1} in terms of x,y,z,$\vec{e}$, Pose X_i, and q_{eye_i}

Output: $q_{eye_{i+1}}$

while $error_{pos} > 0.05$ mm and $error_{rot} > 1.5$ deg **do**

$Jacobian \leftarrow [Jacobian_{pos}(q_{eye}); Jacobian_{rot}(q_{eye})]$

$X_{loop} \leftarrow FwdKin_{eyeorigin\_tip}(q_{eye})$

$\Delta X \leftarrow X_{i+1} - X_{loop}$

$error_{pos} \leftarrow norm(\Delta X(1:3))$

$error_{rot} \leftarrow norm(\Delta X(4:6))$

$\Delta q_{eye} \leftarrow argmin_{\Delta q}||Jacobian \Delta q_{eye} - \Delta X||$

$q_{eye} \leftarrow q_{eye} + \Delta q_{eye}$

end while

Tests, Results and Conclusion – Key Findings

4 different types of absolute and comparative tests

- Preplanned path traversal
- Phantom Omni real time control
- Comparison between dexterous tool and rigid tool
- Real time execution

Results and Conclusion – Key Findings cont'd

Preplanned path traversal

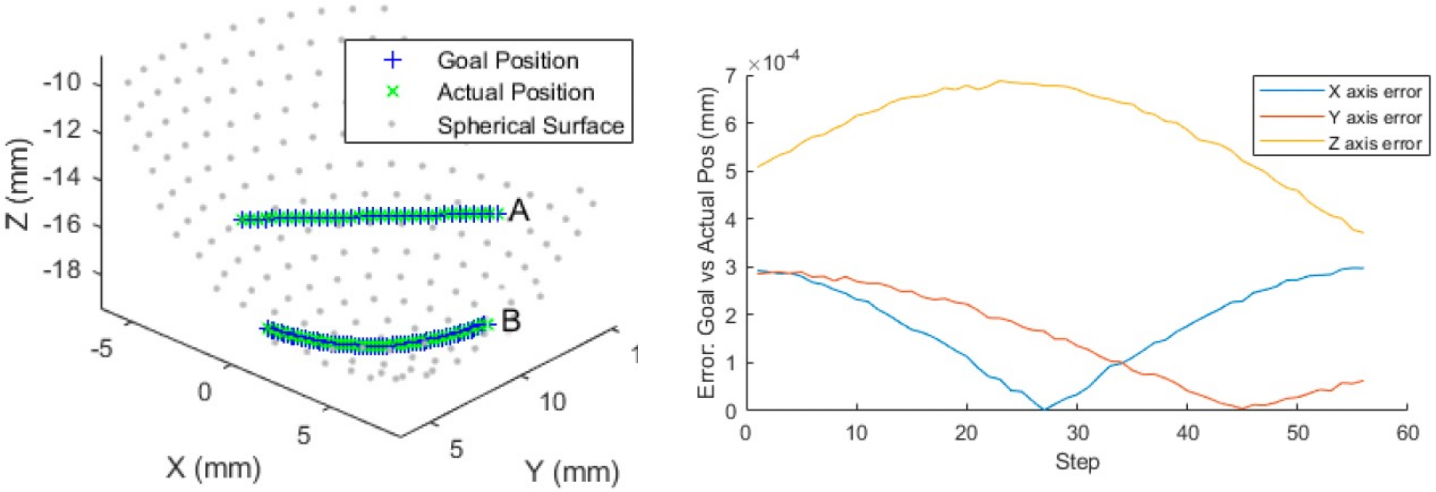


Fig 1. A) Planned path traversal : (A) linear path; (B) Arc on surface B) Error between target and actual position for arc path B

Phantom Omni real time control

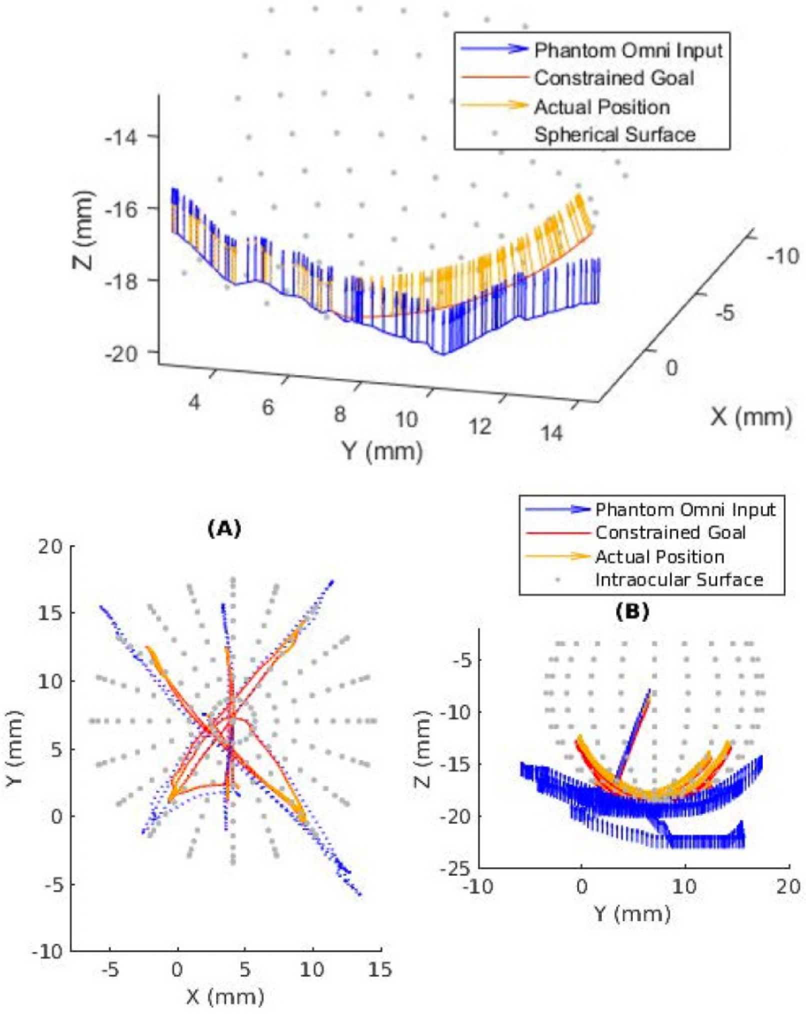


Fig 2. Real time input constrained into the intraocular space

Results and Conclusion – Key Findings cont'd

Comparison between dexterous tool and rigid tool

Dexterous tool afforded the users 180% more workable space relative to the rigid tool

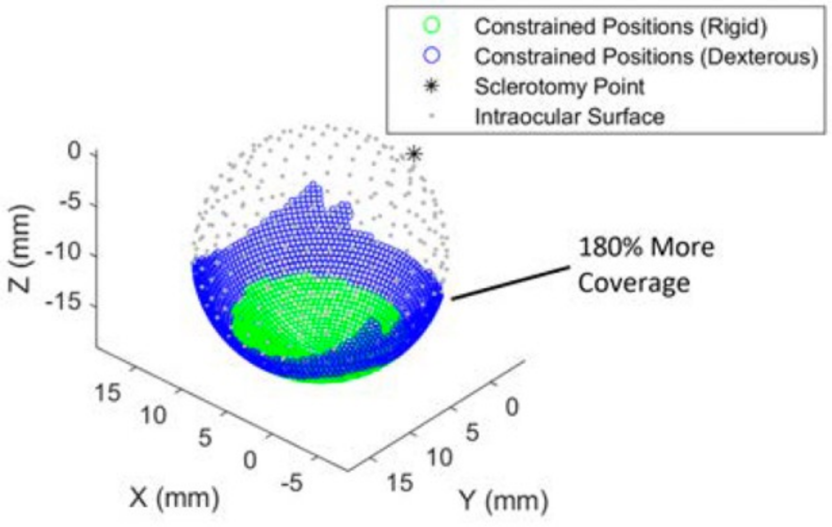
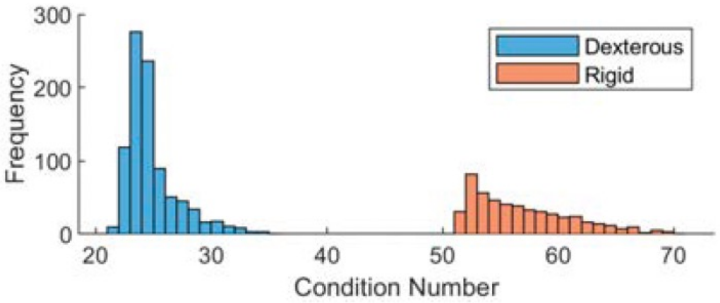


Fig 3: Comparison of rigid vs dexterous I2RIS reachability

Fig 4: Histogram of manipulability



Real time execution

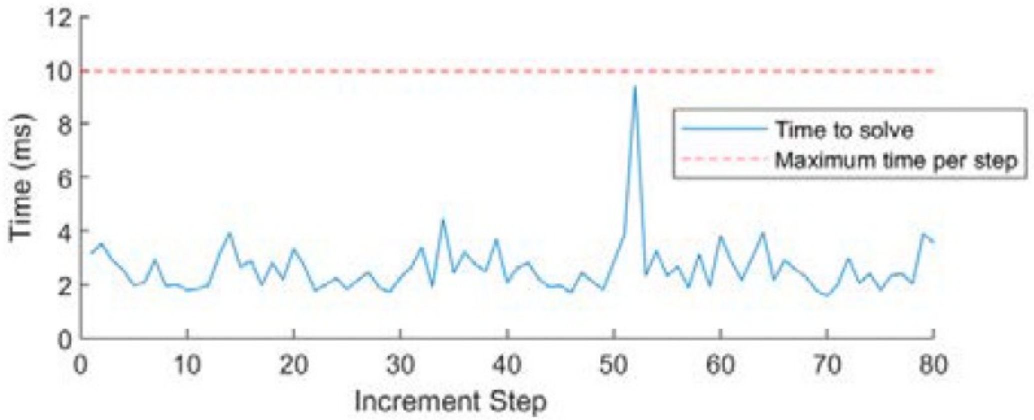


Fig 5. Time to solve inverse kinematics

Strengths and Weaknesses/Critiques of paper

Excellent framework for future studies

Healthy level of validation testing, with great diversity (4 different tests)

- Especially real time effectiveness

Addresses key constraints in teleoperation algorithm

Clever (valid) assumptions that reduce the computational/mathematical complexity

Oversimplification of starting condition – assumes position at RCM point

Lack of more well-developed constraints

- No mathematical description of constraints

Unrealistic forward kinematic mapping of snake robot

Limited number of repeat experiments/sample size too small

- Lack of quantitative analysis of results

Overall Evaluation

- Despite numerous critiques, still a very useful paper
- Teleoperation algorithm a very good basis for our project
- Proof of concept validates our project

References

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

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