High-Dexterity Intraocular Manipulation

Computer Integrated Surgery II, Spring, 2021

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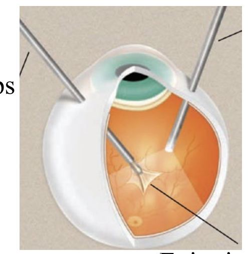
Introduction

- Created kinematics model combining SHER (5 DoF) and I²RIS (2 DoF) robots
- Implemented optimization based inverse kinematics
- Cooperative control of the combined robot with Phantom Omni input device
- Validated in Gazebo simulation

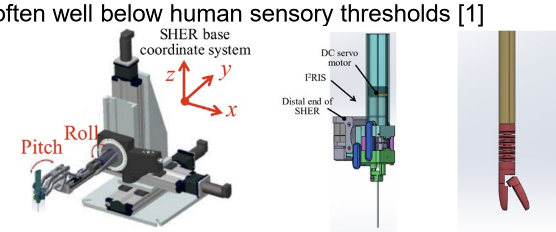
This project will help facilitate procedures like epiretinal membrane (ERM) peeling, by increasing the **dexterity** and **sensitivity** of the surgical tool in the confined vitreoretinal space, thereby **minimizing tissue damage** and increasing **ease of use** by the surgeon.



Problem and Prior Work

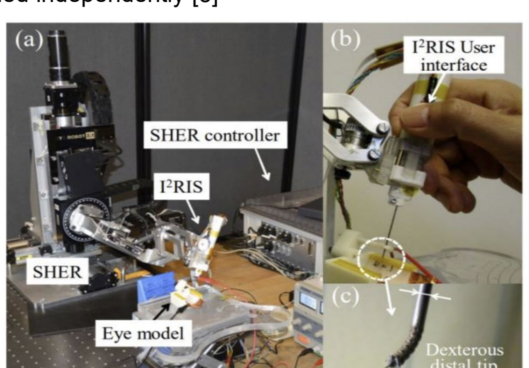
Vitreoretinal surgery:

- Confined space
- Restricted motion of surgical tools
- Forces exerted between the ophthalmic tools and eye tissue are often well below human sensory thresholds [1]

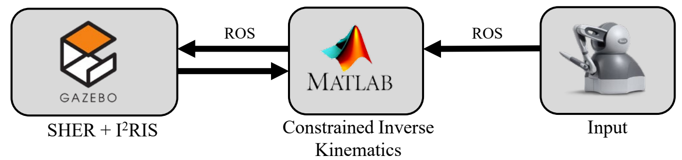


Previous work:

- Steady Hand Eye Robot (SHER) [4]
- Integrated Robotic Intraocular Snake (I²RIS) [2][3]
- A multi-function force sensing and variable admittance control algorithm [5]
- Controlled independently [5]



Solution



Cooperative control of SHER and I²RIS robots (in simulation), with input from Phantom Omni

Major Assumptions

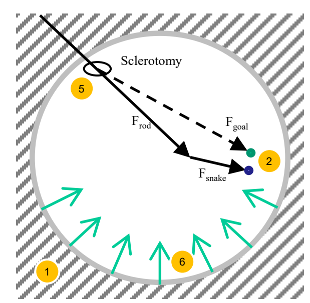
- Intraocular space is a sphere and perfectly registered
- Sclerotomy is perfectly registered
- Robot is rigid and dimensions perfect

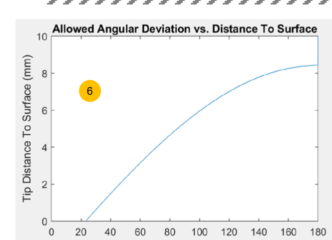
Input From Phantom Omni

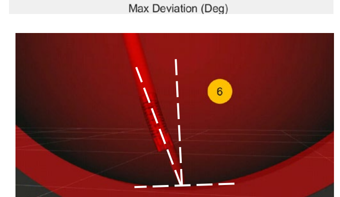
Publish to rostf → Get transform from base to tip → Scale to eyeball space

Constraints

1. The input is constrained to a *target_goal* within the eye.
2. The target goal moves towards the Omni's position at a proportionally, capped to *max_speed*
3. The joints are limited to predefined ranges [5]
4. The change in joints are limited to the maximum angular/linear velocities
5. The I²RIS robot is constrained to pass through the sclerotomy
6. The orientation is constrained towards the surface normal as a function of the distance from the surface+

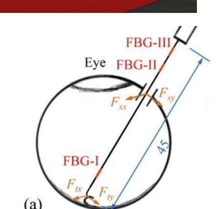






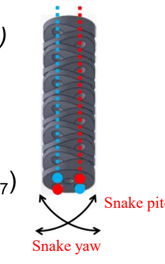
Force Model

- FBG sensors gets x-y readings only
- Use multiple sensors to approximate forces at sclerotomy and end effector.



I²RIS Forward Kinematics

- Each homogenous transformation is a rotation *(R)* and a translation *(p)*: [R p]
- Snake defined kinematically as series of no-slip virtual spheres; two "virtual joints" per segment
- Forward Kinematics: $F_{SHER}(joints_{1:5}) * F_{snake}(joints_{6:7})$
- Same description in URDF (Unified Robot Description Format) for simulation



[2] Jinno et al., 2021

Optimization Based Inverse Kinematics

- Given pos & orientation $\vec{X}_{goal}$: what is joint $\vec{q}$?

$$Jacobian = \frac{\delta FwdKin(q)}{\delta q} \qquad \Delta X = Jacobian \cdot \Delta q$$

$$\text{while } error_{pos} > 0.05\ mm \text{ and } error_{rot} > 1.5°:$$

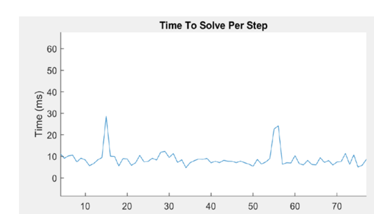
$$X_{curr} = FwdKin(q)$$

$$argmin_{\Delta q} \| Jacobian * \Delta q - (X_{goal} - X_{curr}) \|$$

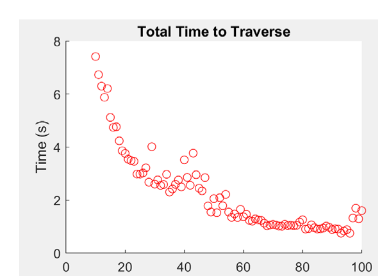
$$q = q + \Delta q$$

Outcomes and Results

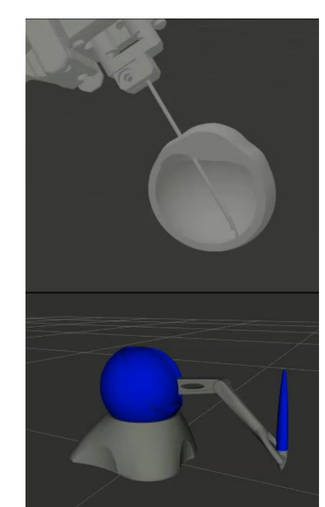
- Evaluated system by moving end effector along 2 pre-planned paths, as well as moving with Phantom Omni input
- Error between end effector in gazebo and goal is within tolerances
- Input is constrained into only "valid" spaces
- Inverse kinematics in real time is possible
- Close to real time response between user input and end effector



Time to Solve Inverse Kinematics



Speed Limit vs Time of traversal



Control with Phantom Omni

Future Work

- Implementing system with physical robots
- Explore further constraints
- Evaluate performance, edge cases
- Implement force model and FBG sensors
- Haptic feedback

Lessons Learned

- Throughout the project, we have been working with robot kinematics, robot object-oriented programming in MATLAB, robot simulation and communication using ROS, gazebo and rviz.
- Don't assume functionality described will "just work".

Credits

- Kaiyu mainly worked on creating the robot simulation, implementing the optimization based inverse kinematics and programming the control of robot.
- Yishun mainly worked on forward kinematics and implementing control of robot with Phantom Omni.

Publications

We plan to submit a paper to the ISMR conference by May 15th.

Acknowledgements

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References

[1] 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
[2] Makoto Jinno, Gang Li, Niravkumar Patel, Iulian Iordachita, "An Integrated High-dexterity Cooperative Robotic Assistant for Intraocular Micromanipulation", 2021., Kokushikan University
[3] Jinno, Makoto, and Iulian Iordachita. "Improved Integrated Robotic Intraocular Snake*." *2020 International Symposium on Medical Robotics (ISMR)*, 2020, doi:10.1109/ismr48331.2020.9312927.
[4] 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.
[5] He, Xingchi. Force Sensing Augmented Robotic Assistance for Retinal Microsurgery. 2015. Johns Hopkins U, PhD dissertation