CIS II - project plan proposal

Robot Control Algorithms Based on Sclera Force Information

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1. Motivation and goal

One of the major yet little recognized challenges in robotic vitreoretinal surgery (Figure 1) is the matter of tool forces applied to the sclera (Figure 2). Tissue safety, coordinated tool use and interactions between tool tip and shaft forces are little studied. The introduction of robotic assist has further diminished the surgeon's ability to perceive scleral forces. Microsurgical tools capable of measuring such small forces integrated with robot-manipulators may therefore improve functionality and safety by providing sclera force feedback to the surgeon. In this project, first we are going to develop two different standards for safe and adept eye manipulation based on an expert behavior. Then, using a force-sensing tool (Figure 3), we are going to implement two control algorithms on Eye-robot 2.1 (Figure 4) based on the developed criteria to boost the sclera safety and decrease the scleral forces during eye manipulation.

Figure 1: The vitreo-retinal surgery

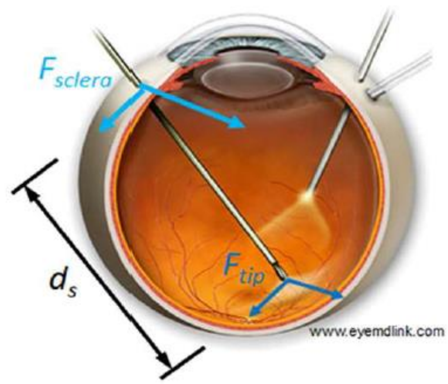


Figure 2: Different forces on the eye-ball

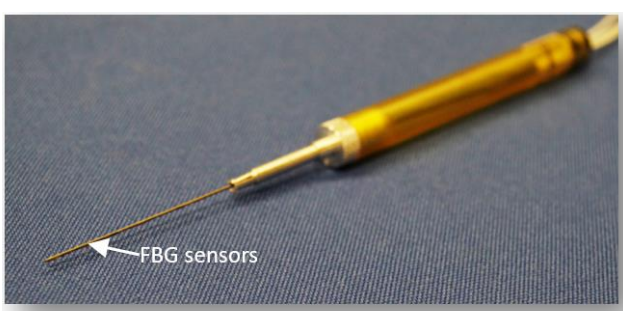


Figure 3: force-sensing tool

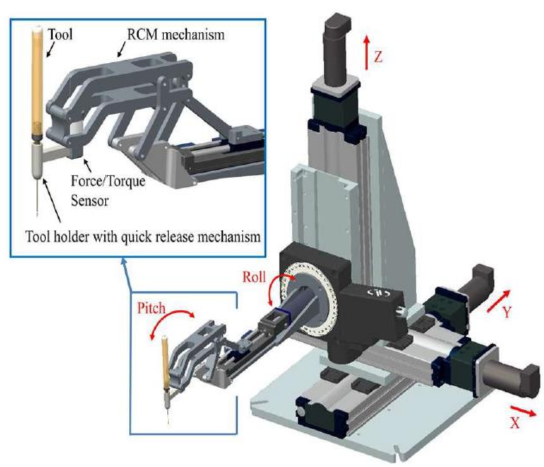


Figure 4: Eye-robot 2.1

2. Background and Material

Two major and required components of this project which have been developed recently by other researchers at JHU are 1- Steady Hand Eye-Robot 2- Force-sensing tool. The general picture of the experimental setup is depicted in Figure 5.

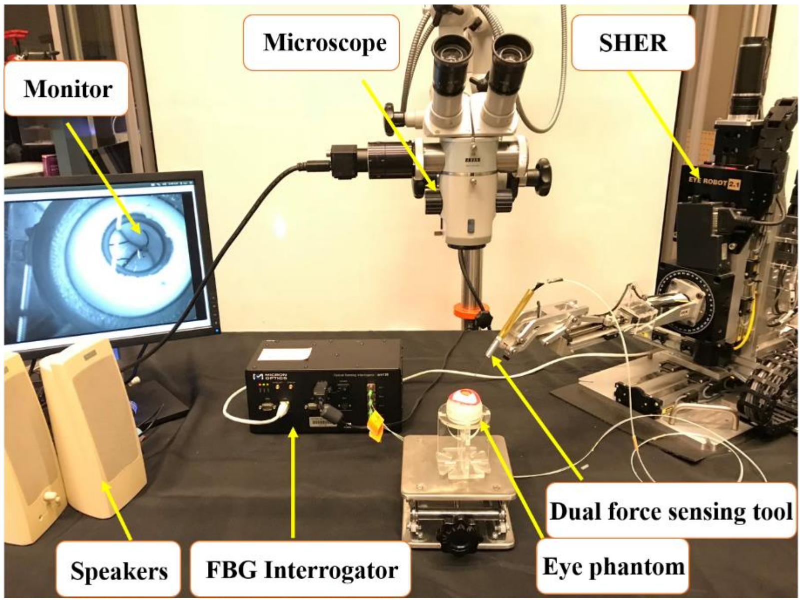


Figure 5: Experimental setup

2.1 Steady Hand Eye-robot (SHER)

The Steady-Hand Eye Robot (SHER) shown in Figure 4 is a cooperatively controlled robot that is intended to reduce hand tremor and has been developed at Johns Hopkins University [1]. Both the surgeon and the robot simultaneously hold the tool, and by an impedance control enforced by the robot the operator performs a steady and tremor-free manipulation. The robot impedance control scheme sets the end-effector velocity to be proportional to operator's contact force F_h (the interaction force between robot end-effector and operator's hand which is measured by a 6 DOF force sensor attached to the end-effector).

2.2 Dual force-sensing tool

The theory for this force-sensing tool was previously developed by [2]. As represented in Figure 6, 3 optical FBG strain sensors are attached around the perimeter of a 25-gauge nitinol needle. As explained in [2], by finding the related calibration matrices for this configuration of FBG sensors, we would be able to relate the raw optical wavelength data of FBGs to the sclera force (F_s), tool tip force (F_t) and insertion depth (F). The FBG fibers are connected to an optical sensing interrogator (sm130-700 from Micron Optics Inc., Atlanta, GA) which sends the FBG raw data with maximum frequency of 1 KH to the computer to calculate real-time force data (Figure 5).

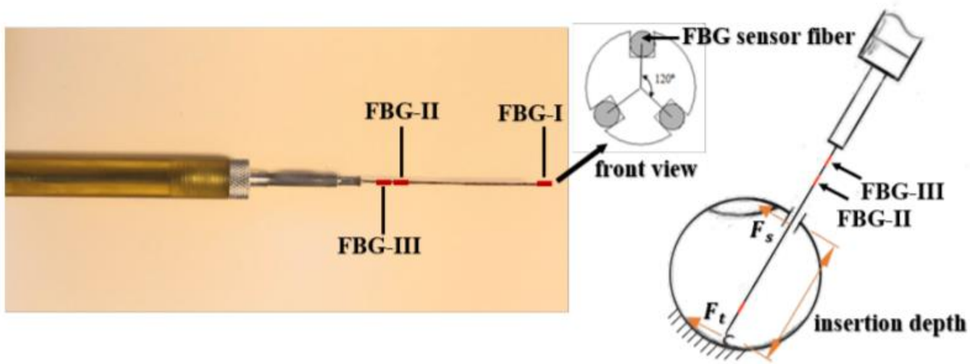


Figure 6: Dual force-sensing tool and the interaction forces of the tool with the eyeball

3. Detailed proposal

Vitreoretinal surgery continues to be one of the most challenging surgical procedures as it requires micron scale tool manipulations and delicate tissue interactions in which physiological hand tremor may degrade the performance during the surgery. Over the last two decades, several kinds of robotic systems including Master-Slave and Cooperatively controlled robots have been deployed to either eliminate or diminish the hand tremor to provide more accurate surgical tool positioning. The robotics assistance could definitely provide precise tool motion; however, the dominant stiffness and inertia of the robot prevents the surgeon from perceiving very small scleral forces (resulting from contact between the surgical tool shaft and the sclera). This diminishes the surgeon's ability to bimanually manipulate the eye and puts the sclera at risk for injury.

Therefore, the focus of this project is to increase sclera force safety by implementing different control algorithms on the Eye-robot 2.1 using the online sclera force data. In first step we are going to perform some experiments with an expert surgeon to get the following curves for the surgeon. The general architecture for the control problem is shown in Figure 7.

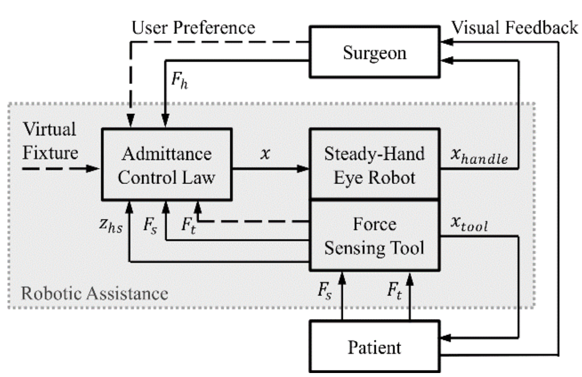


Figure 7: Control architecture

- The first curve we should get from the surgeon's behavior is the variations of sclera force vs time. By having such figure, we would be able to define a maximum safe value for the sclera manipulation which would be our basis for the first Variable Admittance Control. A typical curve for this part is shown in Figure 8. In other words, our aim for this part is set at developing a Variable Admittance Control to increase the robot resistance to movement when the sclera force is approaching the upper safe limit developed from surgeon's behavior. This controller is mainly focused on increasing safety of sclera tissue.

- The second curve we should get from the surgeon's behavior is the curve of sclera force vs insertion depth. By having such figure, we would be able to define a measure of dexterous manipulation which would be our basis for the second Variable Admittance Control. Indeed, we set our aim in this part at developing a Variable Admittance Control to coerce the robot to move in such a way to have the sclera force – insertion depth curve be similar to the previously established standard curve. A typical curve for this part from a novice subject is shown in Figure 9. In contrary to the previous controller, this one would be focused on boosting the dexterity in manipulating the eye.

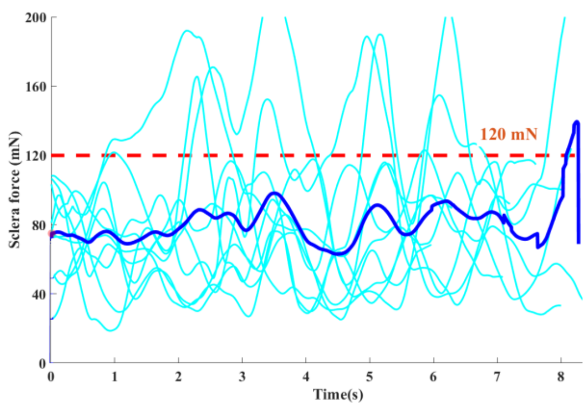


Figure 8: Maximum sclera force information from a surgeon's behavior

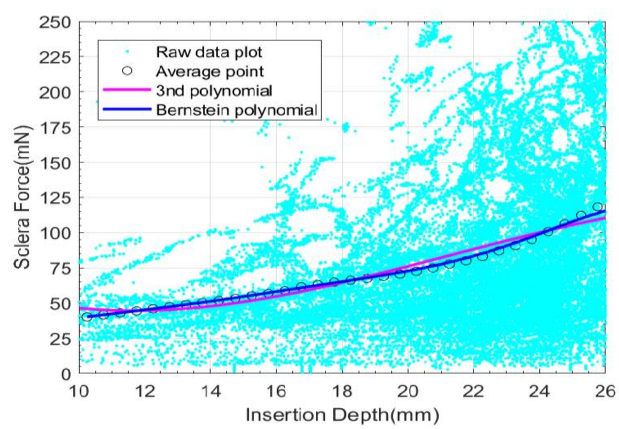


Figure 9: Sclera force vs insertion depth in a typical eye-surgery task (for a novice operator)

At each part after developing and implementing the controller, we will conduct some experiments to evaluate the utility of these control methods. We expect to have safer sclera forces and more dexterous manipulation after implementing such controllers, respectively.

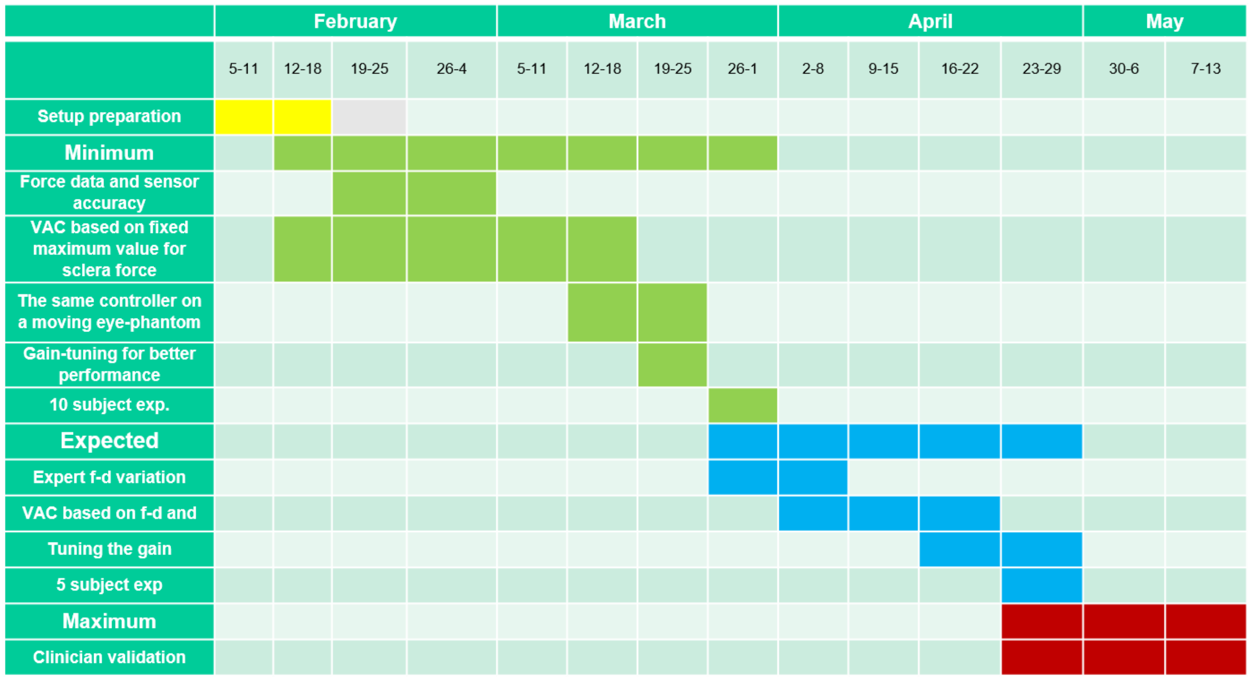
4. Deliverables

Minimum	• Developing a stable and precise sclera force sensing tool. • Ensuring about the accuracy of the dynamic sclera force information being recorded and working with all sensors attached. • Implementing the variable admittance control algorithm based on the fixed maximum sclera force approach on a moving eye phantom. • Tuning the controller gains to have a smooth robot behavior. • Doing experiments with 10 subjects and performing statistical analysis.
Expected	• Obtaining the force-depth variation for an expert surgeon as a measure of skill in eye manipulation • Implementing the variable admittance control algorithm based on the force-depth variation curve on a moving eye-phantom • Tuning the new controller gains to have a smooth robot behavior. • Doing experiments with 5 subjects and performing statistical analysis.
maximum	• Conducting the experiments with clinicians and validating the control schemes

5. Dependencies

No.	Dependency	Resolve by	Status	Plan B
1	Complete understanding of the problem and survey for possible approaches, based on feedback from mentors.	03/01/2018	In Progress	No Alternative
2	Procure eye-robot codebase	02/01/2018	Done	-
3	Stiffer and more accurate force-sensing tools	02/20/2018	Done	Using the current tool
3	Accurate real-time force sensing information, restore the full setup to state.	03/01/2018	In Progress	Filtering the non-accurate part of the data
4	Microscope.	02/01/2018	Done	-
5	Moving stage for eye phantom	03/01/2018	In Progress	Building simpler stages
6	Doing preliminary experiments with surgeons	03/01/2018	In Progress	No Alternative

6. Plan schedule



7. Key Dates and Milestone

- 02/18 – Preparing the setup
- 02/28 – Deciding about the control approach by talking to the mentors

Minimum

- 03/05 - Force data accuracy and reliability
- 03/18 - Implementing the VAC algorithm and tuning
- 03/28 - Experiments with 10 subjects based on VAC

Expected

- 04/06 – Obtaining the f-d relationship for an expert surgeon
- 04/18 - Implementing the new VAC algorithm and tuning
- 04/29 - Experiments with 5 subjects based on the new VAC

Maximum

- 05/10 – Performing the validation experiments with clinicians

8. Management Plan, Reading List and References

We will have a regular weekly meeting with all of the mentors on Fridays in the evening. I will also be in touch with mentors in case a challenging problem happens.

[1] R. Taylor, P. Jensen, L. Whitcomb, A. Barnes, R. Kumar, D. Stoianovici, P. Gupta, Z. Wang, E. Dejuan, and L. Kavoussi, "A steady-hand robotic system for microsurgical augmentation," The International Journal of Robotics Research, vol. 18, no. 12, pp. 1201– 1210, 1999.

[2] X. He, M. Balicki, P. Gehlbach, J. Handa, R. Taylor, and I. Iordachita, "A multi-function force sensing instrument for variable admittance robot control in retinal microsurgery," in Robotics and Automation (ICRA), 2014 IEEE International Conference on. IEEE, 2014, pp. 1411–1418.

[3] Adaptive filtering, prediction and control, Graham C. Goodwin, Englewood Cliffs, N.J.: Prentice Hall, 2009

[4] A. Gijbels, E. B. Vander Poorten, P. Stalmans, and D. Reynaerts, "Development and experimental validation of a force sensing needle for robotically assisted retinal vein cannulations," in Robotics and Automation (ICRA), 2015 IEEE International Conference on. IEEE,2015, pp. 2270–2276.

[5] J. T. Wilson, M. J. Gerber, S. W. Prince, C.-W. Chen, S. D. Schwartz, J.-P. Hubschman, and T.-C. Tsao, "Intraocular robotic interventional surgical system (iriss): Mechanical design, evaluation, and master–slave manipulation," The International Journal of Medical Robotics and Computer Assisted Surgery, 2017.

[6] K. Willekens, A. Gijbels, L. Schoevaerdts, L. Esteveny, T. Janssens, B. Jonckx, J. H. Feyen, C. Meers, D. Reynaerts, E. Vander Poorten et al., "Robot-assisted retinal vein cannulation in an in vivo porcine retinal vein occlusion model," Acta ophthalmologica, vol. 95, no. 3, pp. 270–275, 2017.

[7] S. Tanaka, K. Harada, Y. Ida, K. Tomita, I. Kato, F. Arai, T. Ueta, Y. Noda, N. Sugita, and M. Mitsuishi, "Quantitative assessment of manual and robotic microcannulation for eye surgery using new eye model," The International Journal of Medical Robotics and Computer Assisted Surgery, vol. 11, no. 2, pp. 210–217, 2015.