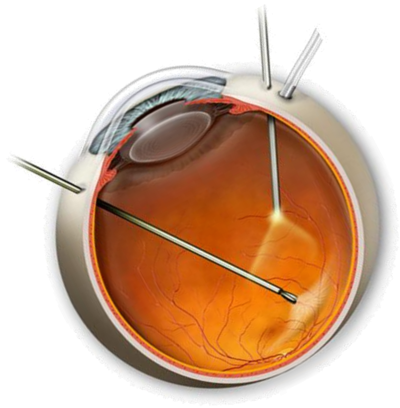


Robot Control Algorithms Based on Sclera Force Information

Johns Hopkins University
Laboratory for Computational Sensing and Robotics

By Ali Ebrahimi

Mentors: Prof. Marin Kobilarov, Prof. Iulian Iordachita, Prof. Russel Taylor

and Dr. Niravkumar Patel

Feb 20, 2018

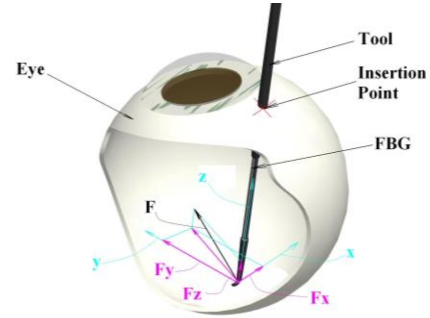
LABORATORY FOR Computational Sensing + Robotics THE JOHNS HOPKINS UNIVERSITY

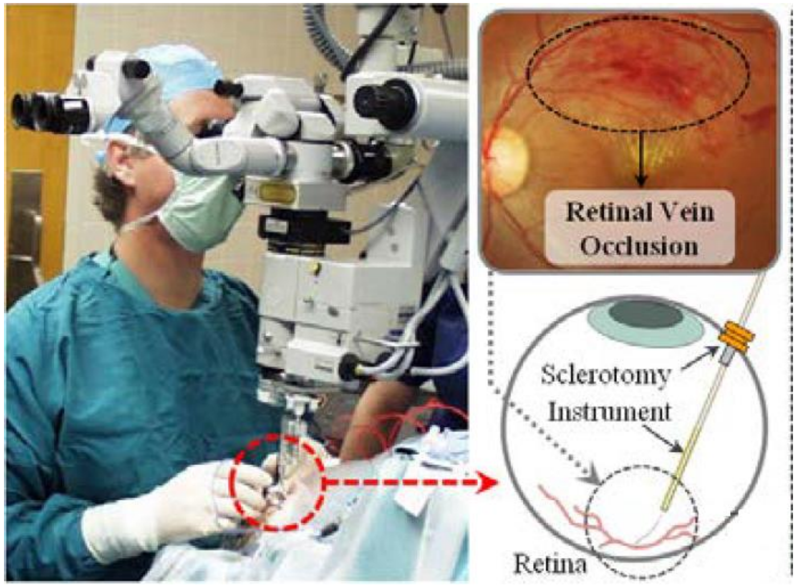
JOHNS HOPKINS UNIVERSITY

Motivation

Challenges in eye surgery:

- Hand tremor of the surgeon
- Excessive forces on the sclera leads to corneal striae
- High risk of retinal tears (vision loss)
- Inability of human to detect feeble forces
- Eye surgery is difficult, requires intensive surgical training and practice





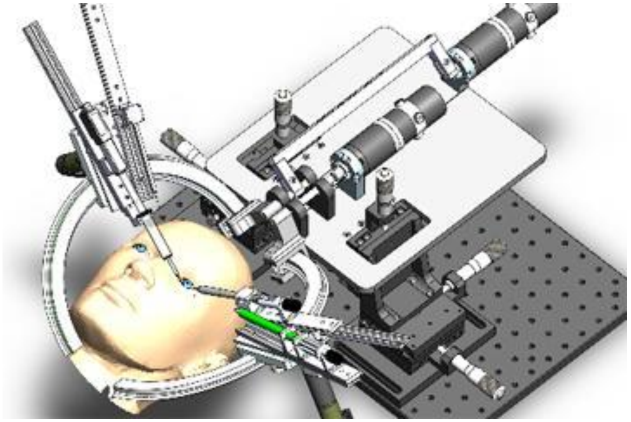
LABORATORY FOR Computational Sensing + Robotics THE JOHNS HOPKINS UNIVERSITY

JOHNS HOPKINS UNIVERSITY

Motivation

To decrease hand tremor

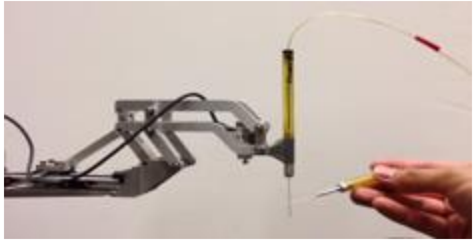
Robotic Systems

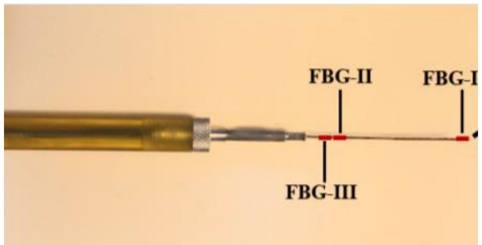


- IRISS (UCLA), 2017
- Eye Surgery robot (Leuven University), 2016
- Steady-Hand Eye Robot (JHU), 2010

To increase tissue safety and excessive force prevention

Force-sensing Tools

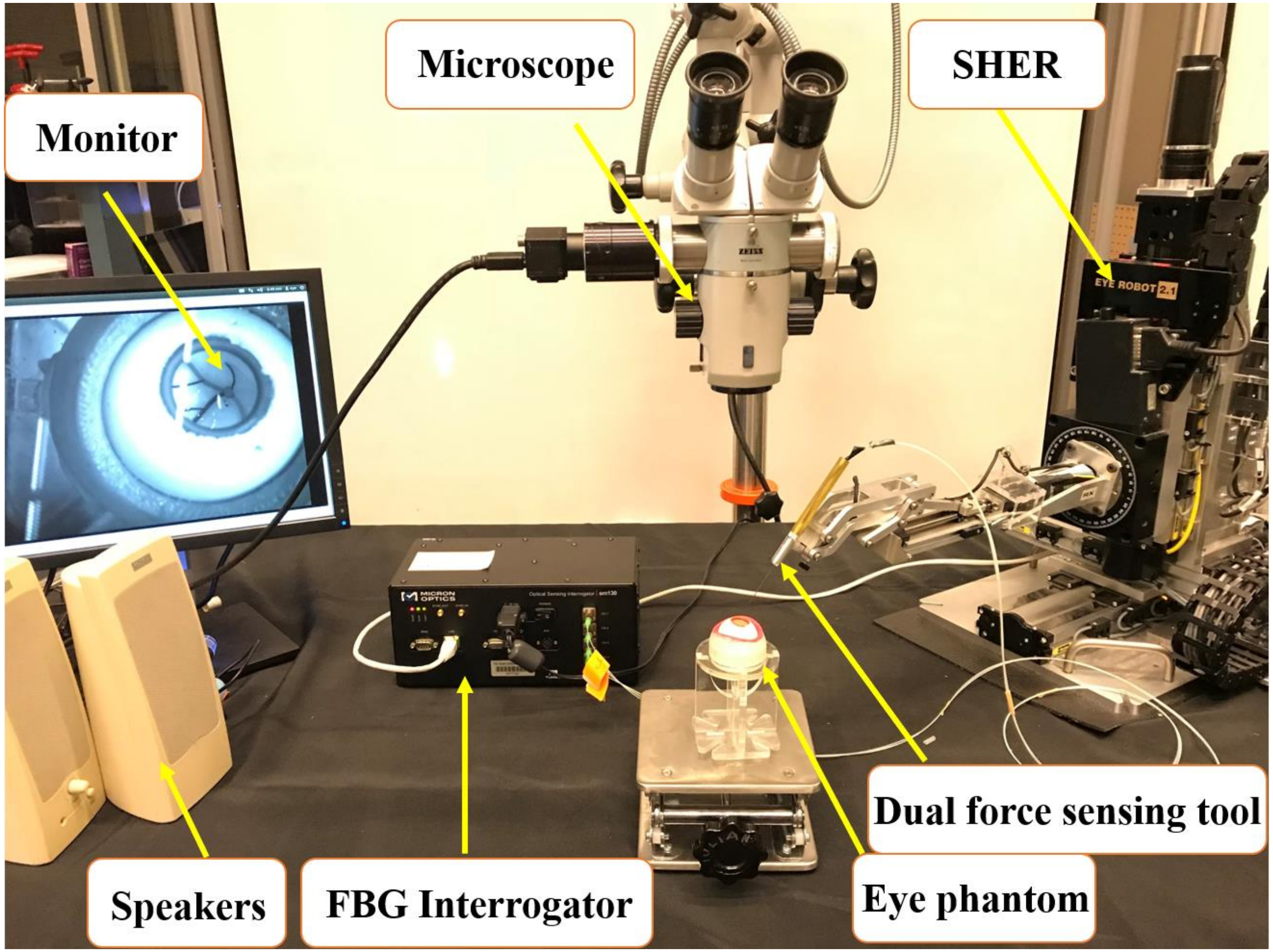




- He et al. 2014 (JHU)
- Gibels et al. 2015, (Leuven University)
- Ginenc et al. 2017 (JHU)

GENERAL IDEA:

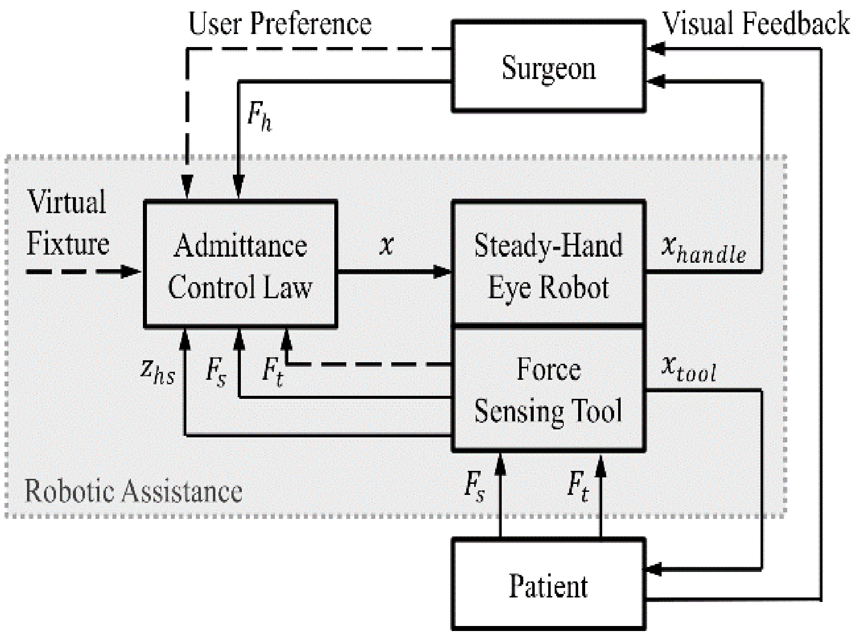
Steady-Hand Eye Robot (SHER) control algorithm based on force-sensing tool information



background

- Constant Admittance Control
  - Isotropic admittance
  - Constant Impedance
  - The user input force applied on the instrument handle (F_h) controls the velocity with which the robot follows the user motion.

$$\dot{x}_{des} = \Lambda F_h$$

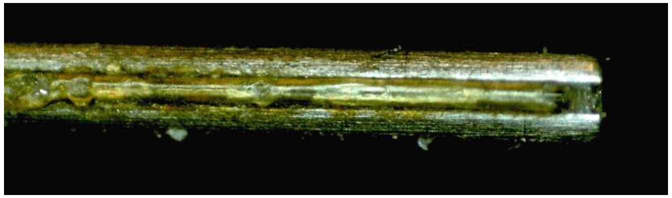


The Solid lines in the above figure show the signal flow in current robot control algorithm, dashed lines show the signals that can also be incorporated into the control law. The constant admittance control is given by equations below.

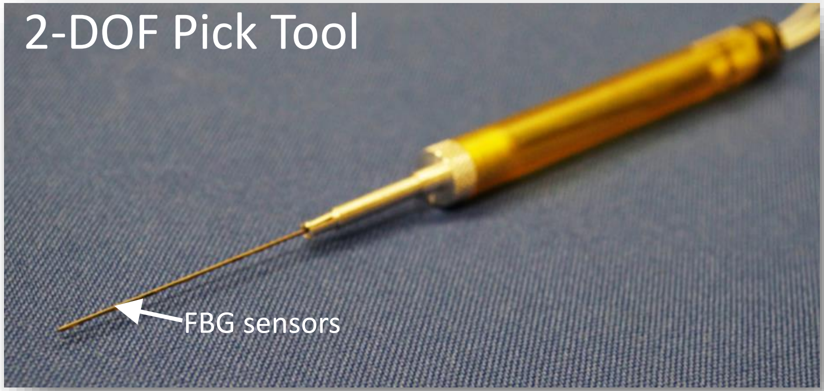
background

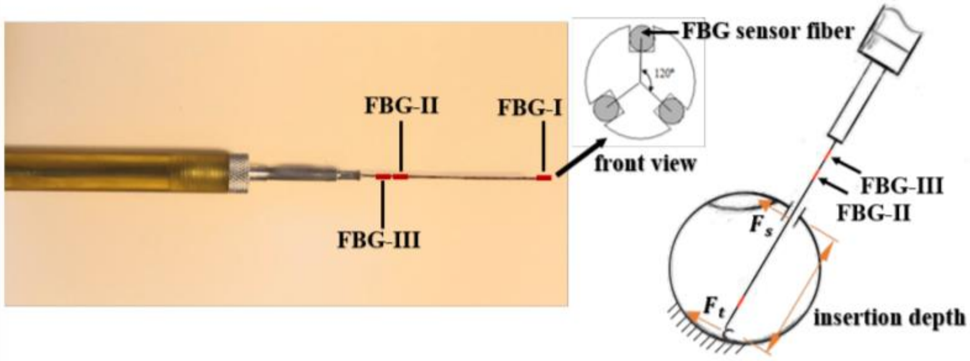
- Expansion/contraction of FBG causes shift in wavelength. The theory for finding calibration process which relates these wavelengths to interaction forces was developed by He et al, 2014

- A similar tool has been built and calibrated



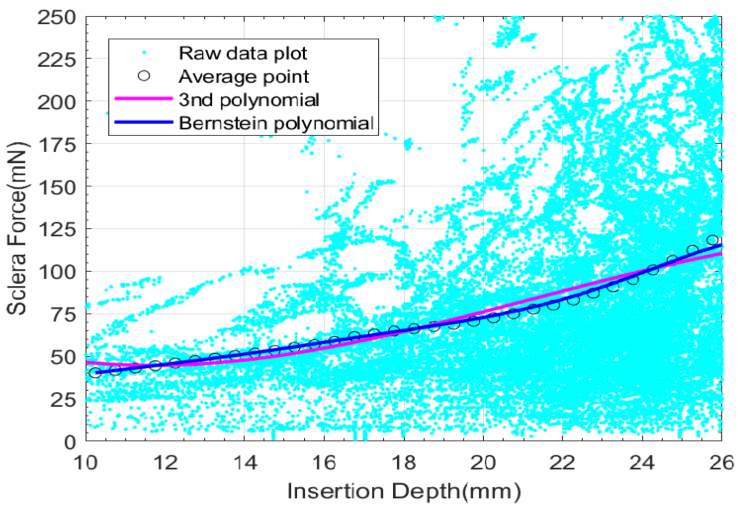
Enlarged needle and FBG fiber



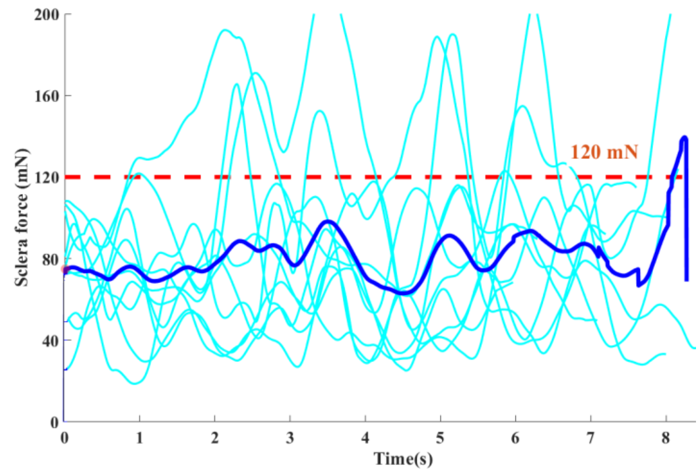


background

Capturing an expert surgeon behavior



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



Maximum sclera force information from
a surgeon's behavior

Overview

- Using the fixed maximum allowable force to implement a variable admittance control scheme to increase the robot resistance when the sclera force is increasing (to increase sclera tissue safety).
- Finding the force-depth variation for an expert surgeon which represents the level of skill and dexterity of safe eye manipulation.
- Using the expert's force-depth variation curve to apply another variable admittance control which helps operator to manipulate the eye like a surgeon.
- Implementing the control schemes on a moving eye phantom to simulate the head movement during the surgery.
- Applying these control schemes on the Eye-Robot and performing several experiments with different subjects and doing the statistical analysis.

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.

Deliverables

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

Dependencies

No.	Dependency	Resolve by	Status	Plan B
1	Complete understanding of the problem and survey for possible approaches, based on feedback from mentors.	3/1/2018	In Progress	No Alternative
2	Procure eye-robot codebase	02/1/2018	Done	-
3	stiffer and more accurate force-sensing tools	02/20/2018	In Progress	Using the current tool
3	Accurate real-time force sensing information, restore the full setup to state.	3/1/2018	In Progress	Filtering the non-accurate part of the data
4	Microscope.	02/1/2018	Done	-
5	Moving stage for eye phantom	02/20/2018	Should talk with Dr. Iordachita	Building simpler stages
6	Doing preliminary experiments with surgeons	02/27/2018	Should set a meeting with Dr. Gehlbach	No Alternative

Plan schedule

	February				March				April				May	
	5-11	12-18	19-25	26-4	5-11	12-18	19-25	26-1	2-8	9-15	16-22	23-29	30-6	7-13
Setup preparation														
Minimum														
Force data and sensor accuracy														
VAC based on fixed maximum value for sclera force														
The same controller on a moving eye-phantom														
Gain-tuning for better performance														
10 subject exp.														
Expected														
Expert f-d variation														
VAC based on f-d and														
Tuning the gain														
5 subject exp														
Maximum														
Clinician validation														

Key Dates and Milestone

- 02/18 – Preparing the setup
- 02/26 – 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

Reading material

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

Reading material

- 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.
- 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.