Robot Control Algorithms for Sclera Eye Surgery

Members: Ankur Gupta, Saurabh Singh

Mentors: Dr. Marin Kobilarov, Dr. Iulian Iordachita and Dr. Russell H. Taylor

Motivation:

The microsurgeries related to the retina and sclera of the eye have many challenges. Some of them can be classified in terms of motion(hand tremor of surgeon), force(so small to be felt by the surgeon), feedback(unavailability of haptic feedback), surgical skills(these surgeries are hard to perform, require intense practice and dexterity). Since robots provide precise and accurate motion which is helpful to operate the delicate eye tissue. To address such issues Johns Hopkins University has been working to build/improve eye robot for the last 15 years.

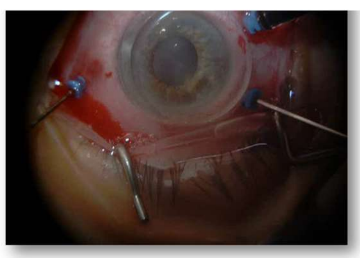


Fig. 1 The vitreo-retinal surgery

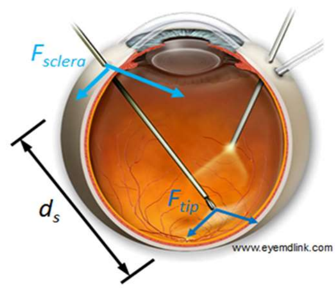


Fig.2 Description of the eye and the forces on the tool

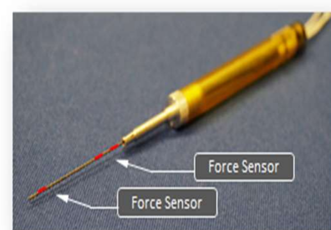


Fig.3 The multi force sensing tool required for the surgery

Background:

The problems to design a control algorithm for the eye robot are numerous-:

1) RCM is not fixed in the vitreoretinal surgery and can move upto 12 mm.
2) The eye robot in various situations blocks the view of the surgeon and makes it difficult to view the retina/sclera in the microscope.
3) To make the eyeball fixed the use of two sclerotomies is employed by the surgeons. It involves the use of two dual robot setup and the distance between the two incisions(sclerotomies) has to be made fixed. This problem of eyeball motion becomes worse when the surgeon cannot feel the force exerted at the two sclerotomies.

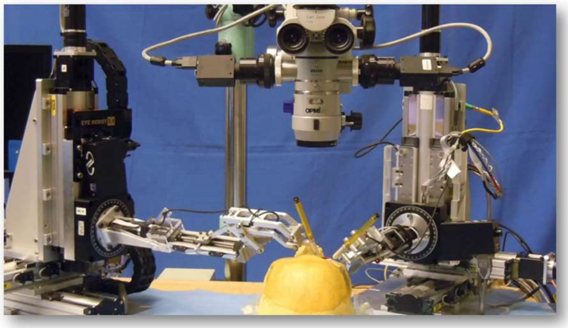


Fig. 4 The dual eye surgery robot setup

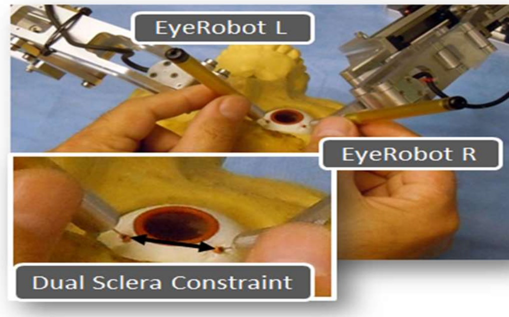


Fig. 5 The dual sclera constraint

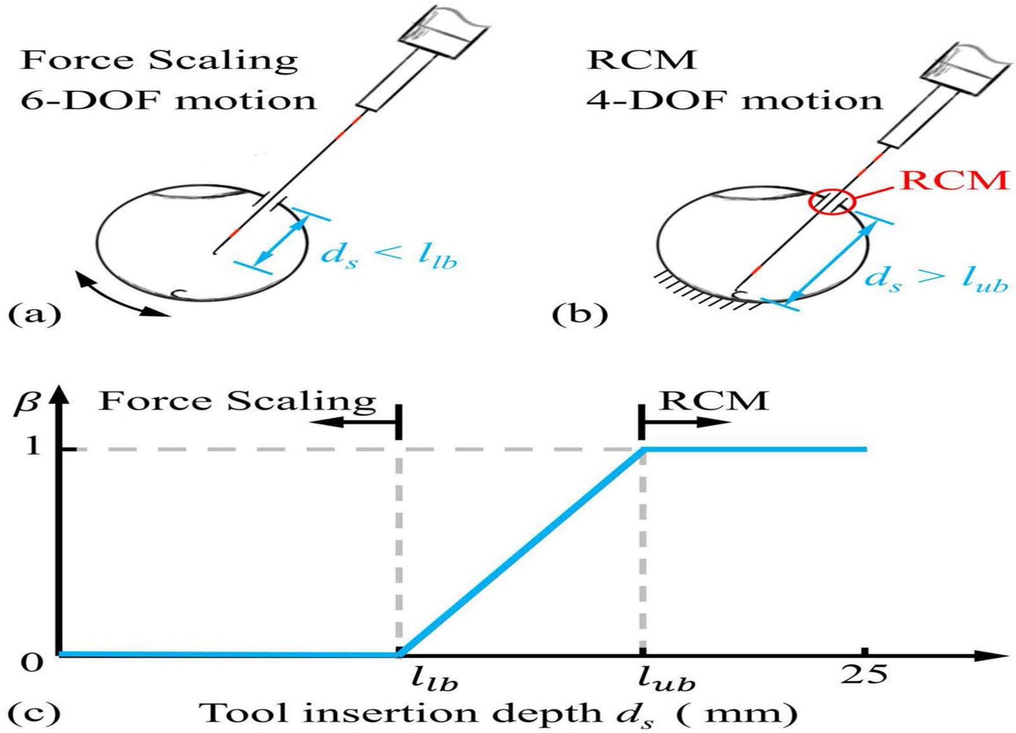
In such scenario, a surgical robot which can assist a surgeon to interact with the patient tissues i.e., by providing quantifications of the real time interactions of the tissue manipulation at the tool tip and the contact between the tool shaft and sclerotomy comes in handy. These objectives in the current control methodology are gained by using the variable admittance control. Despite the effectiveness of the robot has been tested on the rabbits the various interaction parameters, force scaling parameters and the control methodology switch from the force scaling to the variable admittance control has a linear intermediate path. This is path is considered to be nonlinear for the human operative conditions.

Project Proposal:

The aim of the project is to develop control algorithms which surpasses the efficiency of the existing control algorithms for Johns Hopkins Eye Robot 2.1 in terms of smoothness of motion, force sensing, high intraocular dexterity, natural motion guidance, RCM tool guidance and tool coordination. Currently, the robot works on the hands-on cooperative control. The admittance robot control both in the constant and variable form have been employed and tested on the robot.

The first task in the project will be to procure the codes from Xingchi He' works and the tool created for the experiments he conducted. The next step will be to restore the robot and the other components back to the state when they were running appropriately. The research portions of the work will be :

1) Variable admittance changes between the force scaling and virtual RCM mode. The force scaling mode enables 6-DOF free motion with force scaling haptic feedback the figure below shows (a). The virtual RCM mode allows 4-DOF motion (b). Variation of Admittance varies the insertion depth (c). The section between lower bound length and the upper bound length is the transition between pure force scaling of the sclera force and pure RCM. The transition between the lower bound and the upper bound is considered to be the straight line function but the study has to be conducted for the nonlinear functions as it is assumed that it won't be a linear function for human operative conditions.



2) Develop a learning based control algorithm. The learning is aimed to be performed by demonstration by the experienced surgeons. This will guide, train and provide a conducive environment for the surgery by the less experienced/novice doctors.

3) Robot Structure

a) Robot Structure: The eye robot 2.1 offers 5 DOFs. The 3 of the 5 DOF comes from the translation degrees of the freedom in terms of the motion of X,Y and Z motion of the platform of the robot. The remaining 2 DOF are the two rotational degrees of freedom which provide rotations to the robotic arm in form of roll and the pitch at the tool wrist. The robot is a passive rotational DOF at the tool. The complete kinematic model of the robot for the surgical process has been studied thoroughly from XingChi He Phd thesis.
The robot provides a pitch from -45 to +45 degrees at wrist for the motion of the RCM.

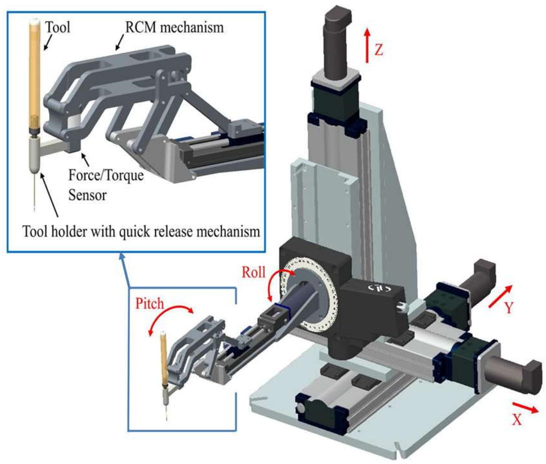
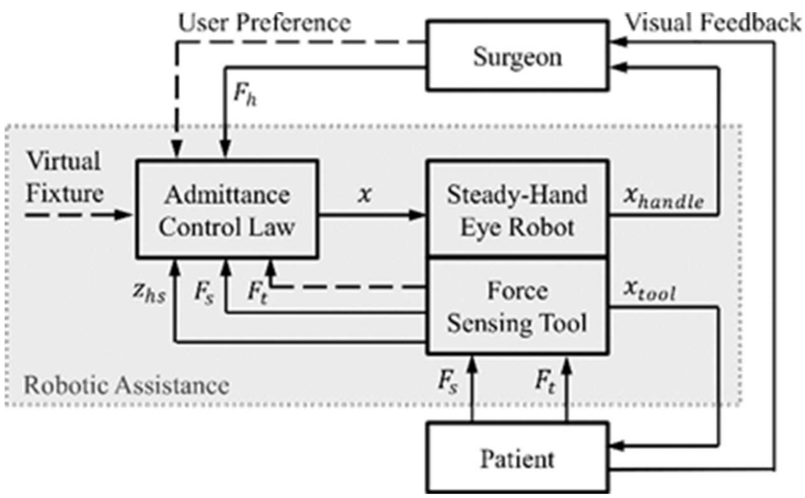


Fig. 7 Eye Robot 2.7

b) Variable Admittance control: The robot currently works on the variable admittance control which



is designed based on the force scaling and the admittance velocity controls.

Fig. 8 Flowchart of the current control algorithm

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.

$$\dot{x}_{hh} = \alpha F_{hh}$$

$$\dot{x}_{hh} = \alpha(F_{hh} + \gamma F_{hs})$$

The governing equation for variable admittance control is given by the equation below where it also incoproartes the force from the sclera.

$$\dot{x}_{ss} = \alpha(A_{sh}F_{sh} + \gamma A_{ss}F_{ss})$$

Based on the task, necessity and depth of the tool inside the eyeball the tool admittance and the control model can be varied from the 6DOF to 4DOF by setting the motion guidance constraint such as the virtual RCM by setting the appropriate value of beta in the below given matrices

$$A_{sh} = diag([1-\beta,\ 1-\beta,\ 1,\ 1,\ 1,\ 1]^T)$$
$$A_{ss} = diag([1+\beta,\ 1+\beta,\ 1,\ 1,\ 1,\ 1]^T)$$

$$\beta \in [0,1]$$

Dependencies:

1) Develop a formal understanding of the project and a meeting time with the mentors to discuss about the project.
2) Xingchi He's (graduated) time to discuss the existing code and the procedure for guidance.
3) The surgery tool from Dr. Iordachita (needs to be searched).
4) Microscope.
5) Time with FBG Machine (Currently three projects are using it).
6) Development/sharing of the phantom and sharing of the tissues/ membranes for the eye surgery.
7) Getting time with doctors to collect the data and validate the results the results obtained for the nonlinear function.
8) Unavailability of the license for the eye robot for conducting tests on the living animals.

Deliverables:

Minimum:

- Procured software and Algorithm bridge source code
- Ported backbone code to C++, if required
- Procured and Calibrated Fiber-Optic Force sensing tool
- Replace Fiber Optic tool, with low cost workable tool, if FO tool not procured
- Identified and documented source code that pertains to Sclera force sensing, drivers, APIs, and backbone algorithm
- Restored the full setup to state, working with all tools and sensors attached.

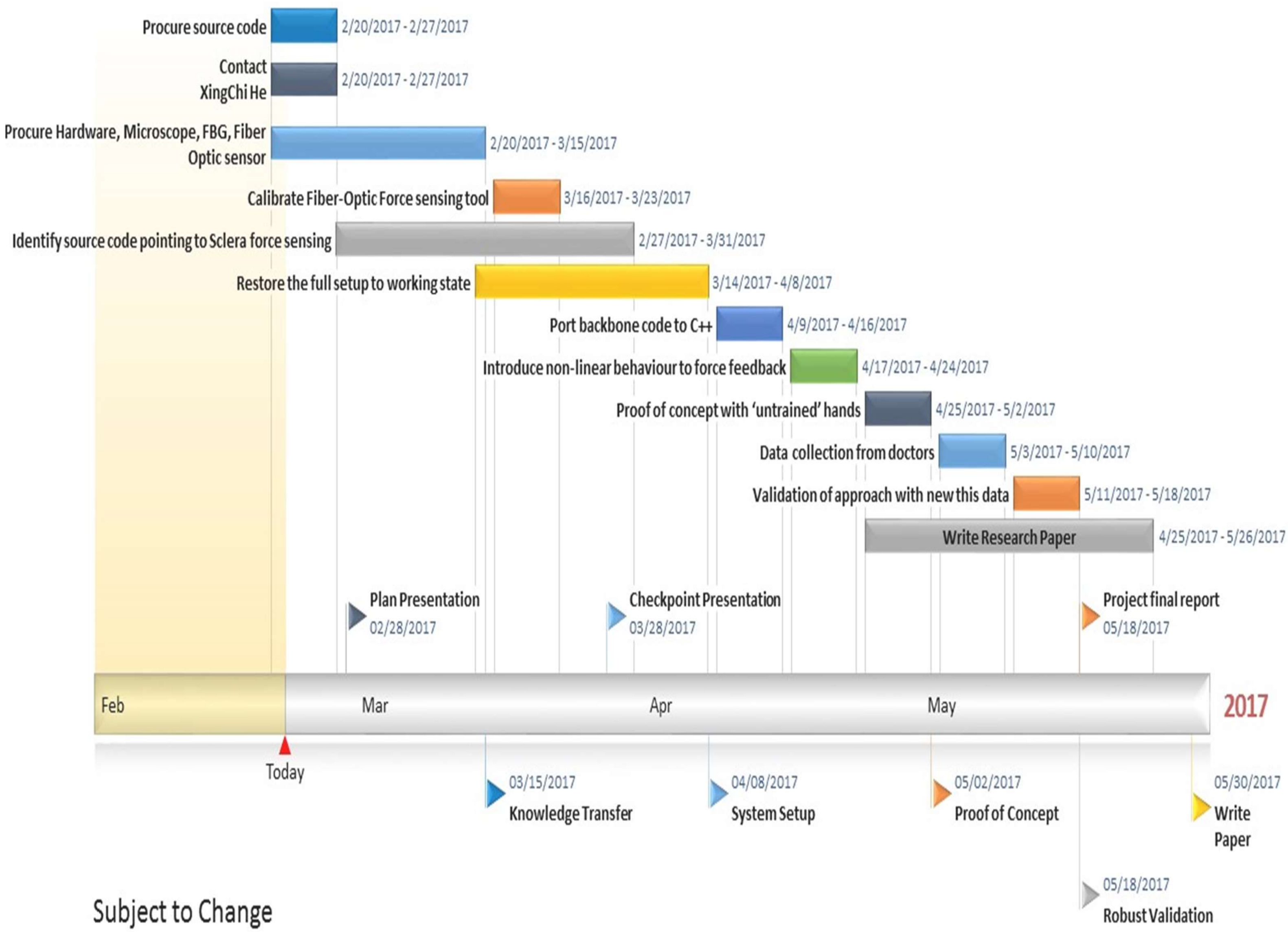
Expected:

- Analysis of force feedback curve with multiple and unique coefficients
- Introduction of non-linear behaviour to force feedback
- Proof of concept with 'untrained' hands on incubated chicken eggs or synthetic sclera-impersonator membrane, such that forces seem natural in the process.

Maximum:

- Data collection from 'experts' or doctors to validate our model with ground truth force feedbacks.
- Written research paper with modified approach.

Timeline:



Procure source code
2/20/2017 - 2/27/2017
Contact XingChi He
2/20/2017 - 2/27/2017
Procure Hardware, Microscope, FBG, Fiber Optic sensor
2/20/2017 - 3/15/2017
Calibrate Fiber-Optic Force sensing tool
3/16/2017 - 3/23/2017
Identify source code pointing to Sclera force sensing
2/27/2017 - 3/31/2017
Restore the full setup to working state
3/14/2017 - 4/8/2017
Port backbone code to C++
4/9/2017 - 4/16/2017
Introduce non-linear behaviour to force feedback
4/17/2017 - 4/24/2017
Proof of concept with 'untrained' hands
4/25/2017 - 5/2/2017
Data collection from doctors
5/3/2017 - 5/10/2017
Validation of approach with new this data
5/11/2017 - 5/18/2017
Write Research Paper
4/25/2017 - 5/26/2017
Plan Presentation
02/28/2017
Checkpoint Presentation
03/28/2017
Project final report
05/18/2017
Feb
Mar
Apr
May
2017
Today
03/15/2017
Knowledge Transfer
04/08/2017
System Setup
05/02/2017
Proof of Concept
05/30/2017
Write Paper
05/18/2017
Robust Validation
Subject to Change