Force Control Algorithm for Sclera-Eye Surgery

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Introduction

- Study the variation of forces on Sclera as a function of depth of insertion of the operating tool
- Need careful experimental setup that gives consistent force measurements across trials and subjects.
- Based on the profile of data and behavior of application of force on sclera vs depth of tool insertion, devise a function from the force scaling mode to RCM mode of the co-operative variable admittance control.

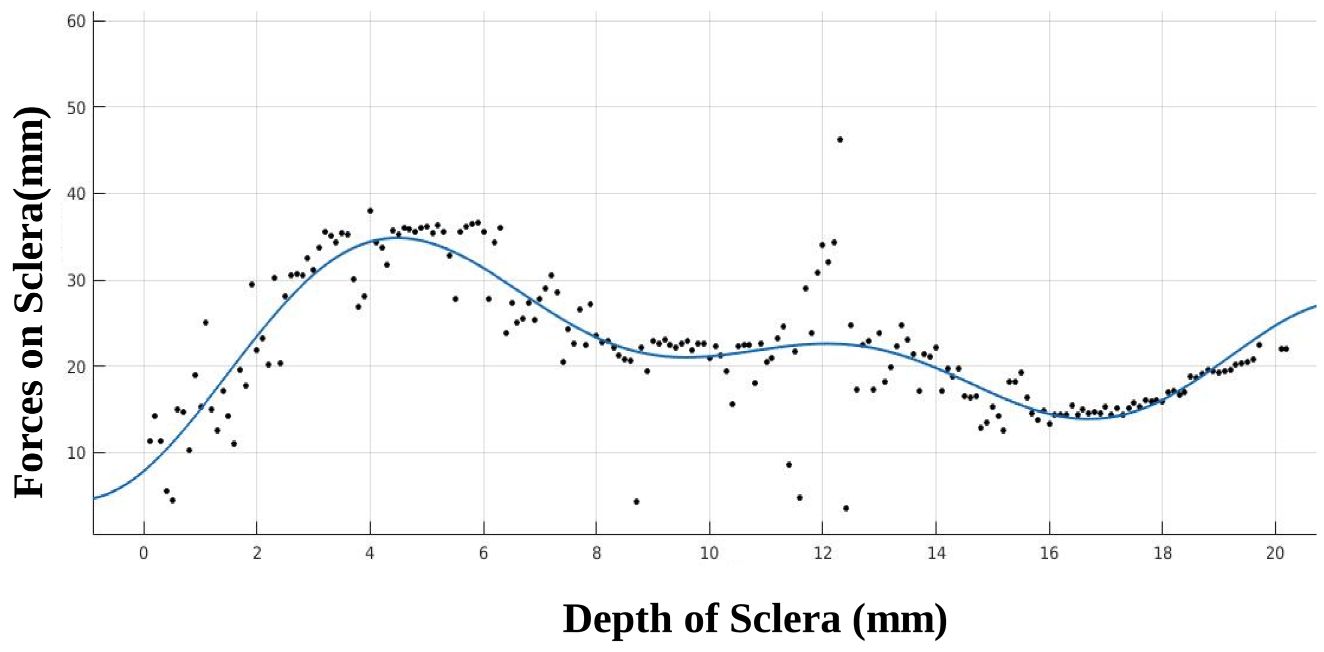


Fig 1: Force depth profile from a novice user. Y axis = force on sclera in mN and x-axis = tools insertion depth beyond sclera in mm

The Problem

- Vitreoretinal Surgery is a procedure involving manipulation of delicate tissues inside the eye.
- Desired forces applied at the tool tip imperceptible to untrained humans. (typically, below 8 mN).
- Potential risks of excess force behaviors include Retinal hemorrhage, Retinal Tear, Corneal Striae
- Real-time control algorithm based on depth of insertion of tool is required to minimize risk.
- State of art is a linear transformation between depth and force based on many assumptions of how surgeons perform vitreoretinal surgery.

Lessons Learned

- The team learnt about the milli-newton order force sensing tool fabrication, it's calibration and force measurement from the used FBG sensors.
- The eye robot structure, kinematics, workspace and admittance control were crucial information that we understood while working on the project.
- The project provided experience of building, compiling and using C++ library and Qt.
- The force sensing tool and FBG Interrogator should be handled with care. High forces and bending can bring permanent deformations to the tool.

Experimental Setup and Approach

- Created new Eye Socket Phantom to reduce friction between Eye and Socket
- Conducted various calibration and validation experiments with two different force sensors: Lightpipe and Dualbone
- Designed repeatable Experiment for data Collection: Touch Markers at +/- 30^0 radial axis. Optical Centre marker for alignment disambiuity. Measured quantity of lubricant for frictional consistence.
- Collected user data to support claim that force doesn't change linearly with insertion depth.
- Designed Control Algorithm which makes EyeRobot follow force profile collected from data at variable depth.

$$A_{sh} = diag([1-\gamma, 1-\gamma, 1, 1, 1, 1])^T$$
$$A_{ss} = diag([1+\gamma, 1+\gamma, 1, 1, 1, 1]^T)$$
$$where\ \gamma = F_{desired} / F_{actual}$$

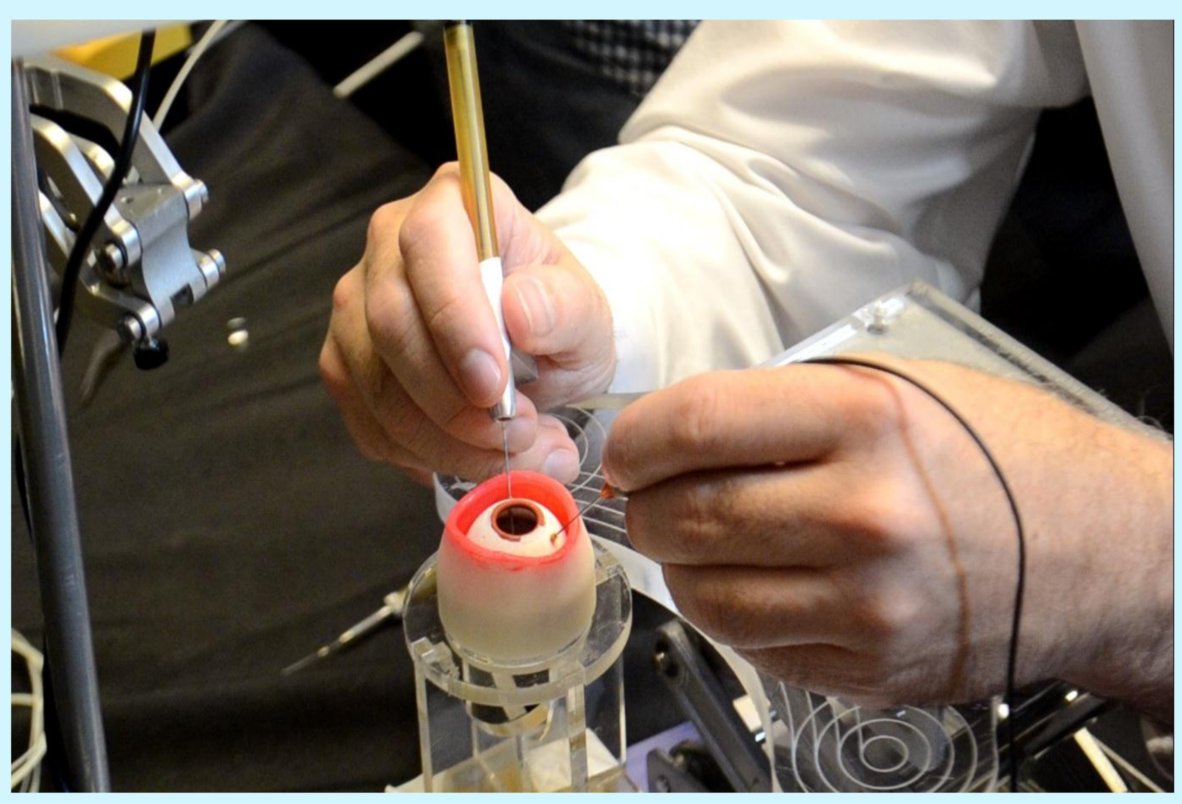


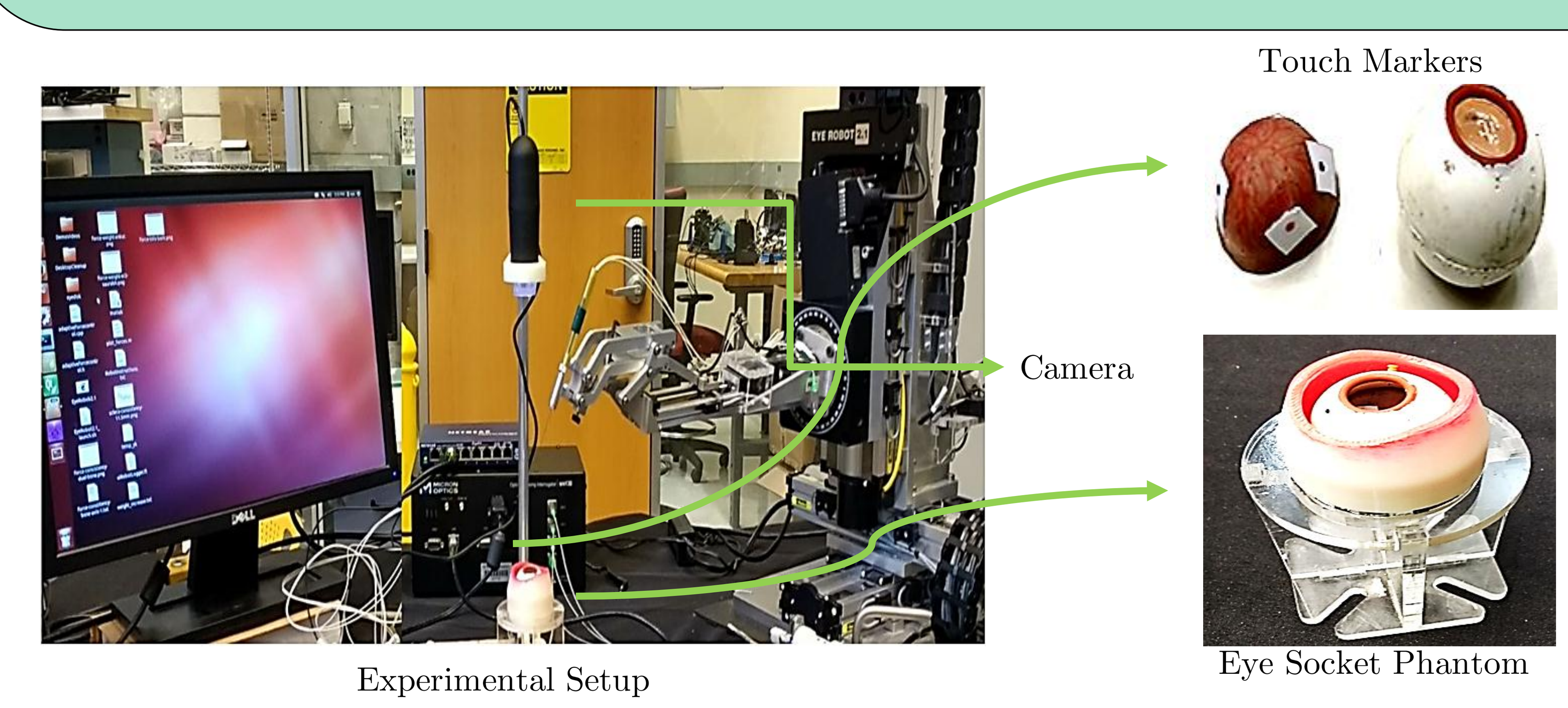
Fig 2: Data Collection from Microsurgery Expert

Outcomes and Results

- The Eye Robot(code and the hardware including 2 force sensing tools) was restored to it's proper functioning state.
- Developed a control algorithm based on the data collected, which computes end-effector velocity to follow desired force profile based on the ratio γ. γ is a function of depth and desired force.
- Used Sum of Sines and 4^{th} Degree Polynomial for curve fitting. These are simple curves to make sure that the response is smooth, we don't overfit the data and maintain generalization across all subjects

Future Work

- Collect Data from more expert Vitreoretinal surgeons.
- Model Statistical behavior from all data points.
- Integrate with 3D model of eye and Force-Position predictions to accurately control the robot.



Credits

- Ankur Gupta: Developed codes to collect data, developed imaging system and the optical center marker
- Saurabh Singh: Fabricated the camera mount, worked on the phantom development and the eye lubrication.
- The force sensing tool and FBG Interrogator should be handled with care. High forces and bending can bring permanent deformations to the tool.

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