Robot Control Algorithms Base on Sclera Force Information

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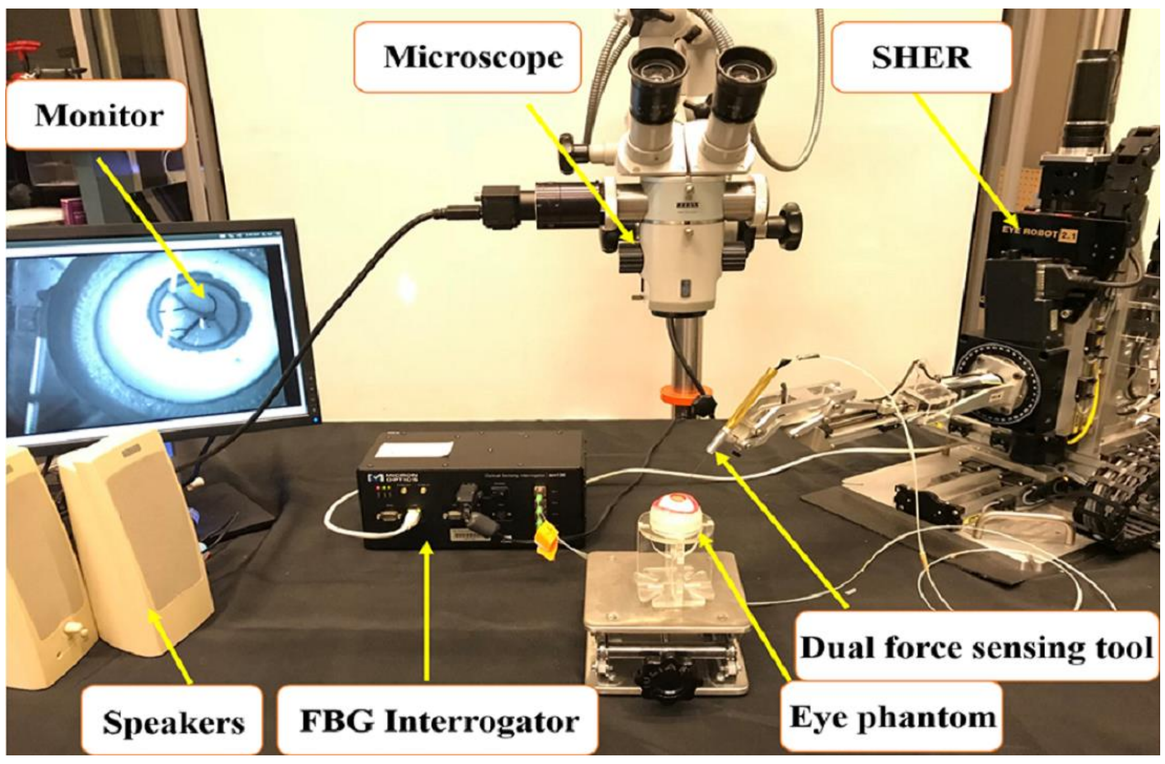
Introduction

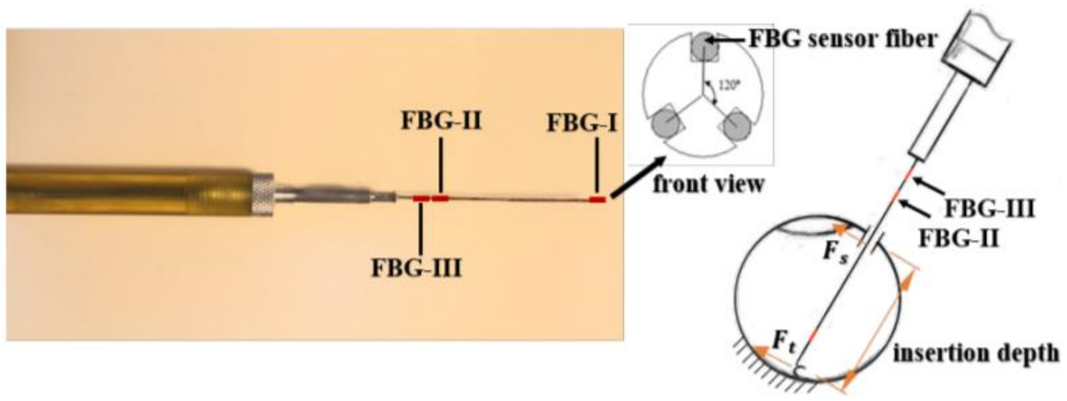
- One major challenge in robot-assisted vitreoretinal surgery is the matter of tool forces applied at the sclera.
- The introduction of robotic assist could further diminish the scleral force perception.
- In this project, using a force-sensing tool attached to the Eye-robot 2.1, we have implemented different force control algorithms and also auditory feedback to inform the subject about unsafe amounts of sclera force.
- We have also conducted multi-user robot-assisted eye manipulation experiments to evaluate the utility of the auditory feedback.

Experimental Setup



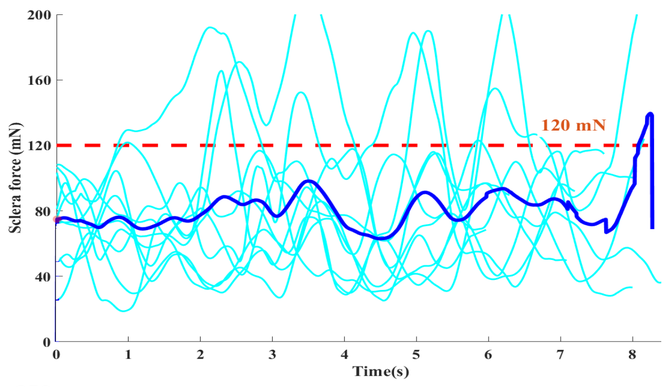
Dual Force-Sensing Surgical Tool

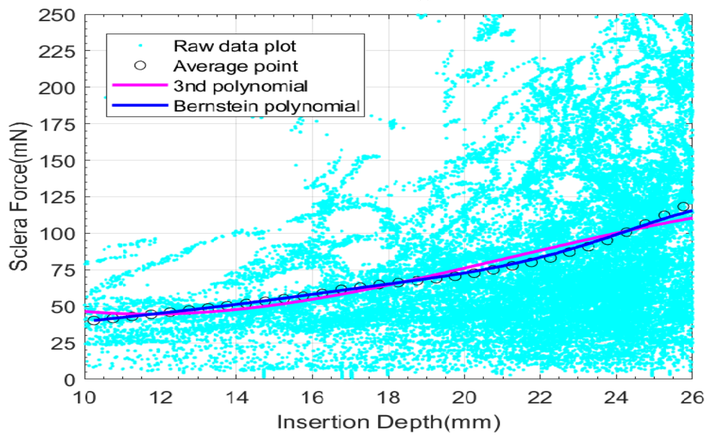
- Tool accuracy: sclera force, 1 mN , insertion depth, 0.5 mm



Surgeon's behavior

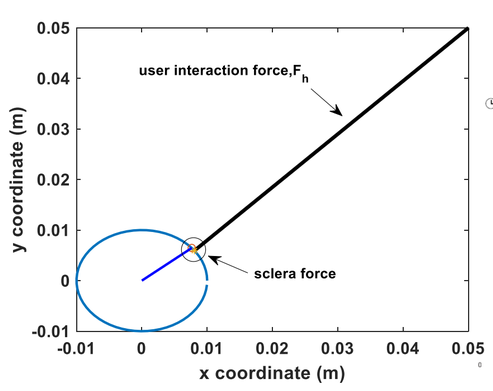
- Safe sclera force region based on the expert surgeon experiment in freehand experiment was defined to be 120 mN.
- In addition to the safety measure above, the measure of dexterous manipulation is F-d curve obtained from surgeon's behavior. This should be implemented using the adaptive control scheme.



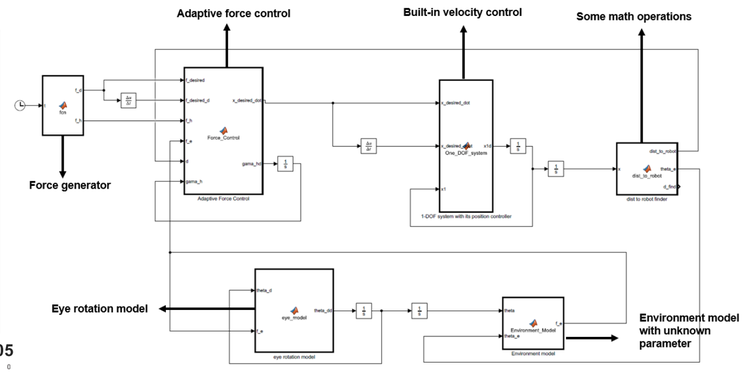


Adaptive Force Control Method (SIMULINK):

- By applying this control method, the real sclera force would be able to follow any kind of bounded reference signal by estimating the environment compliance in an adaptive manner.



1DOF eyeball manipulation simulation



SIMULINK block diagram

- Control law

$$\dot{x}_d = \hat{\gamma}(t)\dot{f}_d(t) - k_f(f_d(t) - f_c(t))$$

- Adaptation law

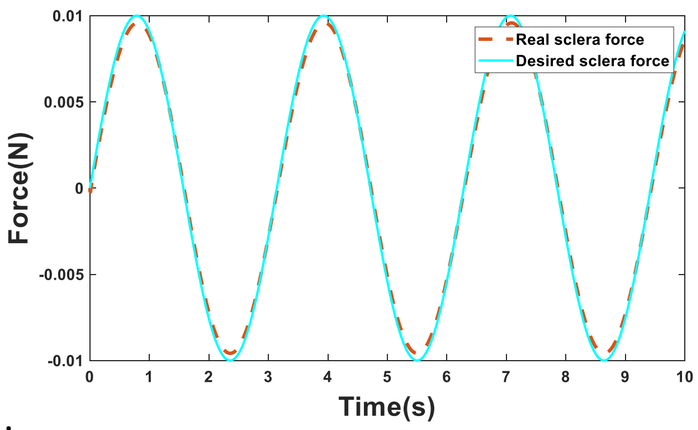
$$\dot{\hat{\gamma}}(t) = -\alpha\dot{f}_d(t)(f_d(t) - f_c(t))$$

- Desired force for figure (1):

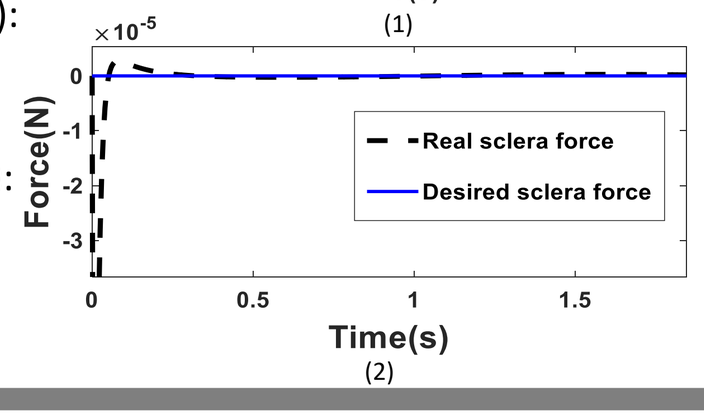
$$f_d(t) = 0.01\sin(2t)$$

- Desired force for figure (2):

$$f_d(t) = 0$$



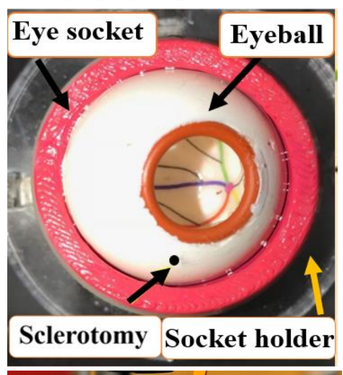
(1)

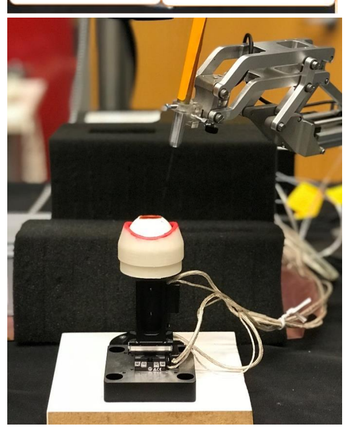


(2)

Multi-User Experiments with 10 users

- Setup: The Steady-Hand Eye Robot (SHER), dual (force-and-depth) sensing tool, an optical sensing interrogator (SM 130-700, Micron Optics Inc.), PI piezo-actuated moving stage, eye phantom, microscope, speakers.
- Procedure: following the colored vessels on retina with and without robot assistance in cases of moving eye or steady eye.
- 5 trials/experiment and switching target in random order. The insertion depth and forces were measured by the force-sensing tool and recorded .





Results for Multi-User Experiments

	Robot-assisted experiments			
	T = Total time elapsed average (s)		*Ratio of the time spent on forces more than 120 mN to the total time T*	
	Steady eye	**Moving eye**	**Steady eye**	**Moving eye**
Subject 1	66	52	0.11	0.19
Subject 2	50	42	0.52	0.4
Subject 3	50.5	65	0.16	0.15
average	55.5	53	0.263	0.247

	Freehand experiments			
	T = Total time elapsed average (s)		*Ratio of the time spent on forces more than 120 mN to the total time T*	
	Steady eye	**Moving eye**	**Steady eye**	**Moving eye**
Subject 1	46	39	0.12	0.04
Subject 2	43	33	0.06	0.016
Subject 3	48	40	0.170	0.014
average	45.67	37.33	0.1167	0.023