Force Feedback of Dual Force-sensing Instrument for Retinal Microsurgery

Critical Journal Review

Group 8
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Project Goal: To develop and assess different force feedback methods (auditory, haptic, etc.) for a dual force sensing instrument for retinal microsurgery

Paper Selected:
M. Balicki, A. Uneri, I. Iordachita, J. Handa, P. Gehlbach, and R. Taylor, "Micro-force sensing in robot assisted membrane peeling for vitreoretinal surgery," In *International Conference on Medical Image Computing and Computer-Assisted Intervention*, pp. 303–310, 2010.

Reason:

Our project uses the Eye Robot to assist retinal microsurgery, a delicate procedure which requires force sensing at a level routinely less than 7.5mN. A tool with integrated fiber bragg grating sensors was manufactured for this purpose. An eye phantom that simulates the sclera forces and the peeling procedure was made to test the surgical system. This paper investigates on the same surgical procedure with the same experimental tools, which is why it was selected for review. Multiple force correlated robot control methods were analyzed to find out an optimal haptic feedback method. Following this paper, we can understand the surgical procedure as well as haptic feedback methods better.

Background

Microsurgical manipulation requires precise manual dexterity, fine visual-motor co-ordination, and application of forces that are well below human tactile sensation. Epiretinal membrane (ERM) peeling is a typical task in retinal microsurgery where a thin membrane is carefully peeled off the surface of the retina. Surgeons manipulate the instrument at very low velocity (0.1-0.5mm/s), and simultaneously visually monitor the local surface deformation that may indicate undesirable forces. Surgeons then react to such cues by retracting the tool and using an alternative approach.

This task is extremely difficult to master due to near imperceptible visual cues. To reduce tremor and improve the control, the Steady Hand Eye Robot with a 2-DOF micro-force sensing instrument is introduced. Multiple force sensing feedback methods to assist in membrane peeling were investigated and compared.

Experiment Setup

The cooperatively controlled steady hand robotic assistant is a 5-DOF system designed as a development platform for microsurgery research. A 6-DOF force/torque sensor mounted at the tool holder senses forces exerted by the surgeon on the tool, for use as command inputs to the robot.

Force sensing levels for vitreoretinal microsurgery are very low, routinely less than 7.5 mN. Also, the force sensor for this instrument must be able to be mounted into the very thin tool tip to obtain measurements below the sclera. A tool with 3 integrated fiber Bragg grating (FBG) sensors was manufactured for this purpose. FBGs are robust optical sensors that detect changes in strain, or the bending of the tool, to calculate the force in the transverse plane with a sensitivity of 0.25mN.

To test the performances of control and auditory feedback methods, a phantom was developed to simulate the eye during surgery. The ERM peeling procedure was simplified to a straight line peel, where surgeons use a hooked instrument to peel 2mm wide strips of sticky tabs from Clear Bandages. These bandages were chosen because they can be peeled multiple times from its backing, and increased force led to increased peeling velocity.

Methods and Results

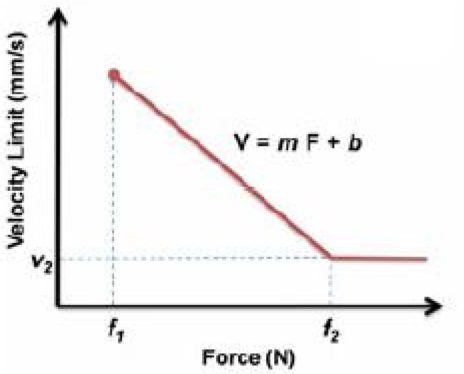
There were 3 cooperative control methods developed and tested for the experiment. The control method parameters considered handle input force range (0–5 N), and peeling task forces and velocities. Audio sensory substitution serves as a surrogate or complementary form of feedback and provides high resolution real-time tool tip force information. The experiments centered the objective to compare the effectiveness of the various methods employed. A single subject tested the experiment running each method (with and without auditory feedback) 5 times with 5 minute breaks permitted between each trial. The subject was trained for ~3 hours prior to the trials. Details for each method are introduced below.

In Proportional Velocity Control (PV), the velocity at the tool is proportional to the user's input force at the handle (F_h): $\dot{x} = \alpha F_h,\ \alpha = 1$(mm/s)/N

In Linear Force Scaling Control (FS), the tip force were amplified to modulate robot velocity: $\dot{x} = \alpha(F_h + \gamma F_t)$, $\alpha = 1$(mm/s)/N, $\gamma = 500$

In Proportional Velocity Control with Limits (VL), PV is employed with an additional constraint on the tip force:

$$\dot{x}=\begin{cases} V_{\lim}(F_t), & -F_h < V_{\lim}(F_t) \wedge F_t < 0 \\ V_{\lim}(F_t), & -F_h > V_{\lim}(F_t) \wedge F_t > 0 \\ \alpha F_h, & otherwise \end{cases}$$



As explained earlier, visual feedback requires significant experience and a high level of concentration and focus details, which requires high expertise from expert surgeons. To provide a clearer alternative feedback method, these forces were measured directly and reported to the surgeon through real time auditory sounds. Different tempos of audio “beeps” alert surgeons of different force levels, or safety zones.

Results for each method are listed below:

Forces(mN)	FH	FHA	PV	PVA	FS	FSA	VL	VLA
Mean	4.11	3.80	4.20	3.64	3.34	3.22	3.58	3.45
StdDev	0.97	0.59	0.95	0.51	0.54	0.40	0.36	0.33
Max	7.85	6.21	6.93	4.74	4.10	3.59	4.03	3.83
Time(s)	93.03	125.25	62.30	85.98	103.80	96.80	88.67	80.58

In each method tested, auditory feedback decreased the maximum tip forces as well as variability. It significantly raised completion time for some experiments while decreasing the others. All the control methods employed improved outcomes upon the freehand trials. Force scaling control yielded the best overall performance in terms of mean forces, though using the longest time. For all trials, the mean force hovered around 3.5 mN.

In all, robotic assistance and cooperatively controlled manipulation with real time force sensing has proved significant potential to improve surgical practice, especially when combined with audio sensory substitution. The results from this investigation encourage further research to optimize vitreoretinal microsurgery.

Critique

The paper introduces the background very well and explains the motive for this research perfectly. It also did a thorough explanation of the Steady Hand Eye Robot and the FBG sensor tool, but the phantom used was not introduced as clearly. It would help if models or pictures of the phantom can be shown, so that readers may have a better view of the mock surgery, how the forces are measured, and how well they simulate the human eye.

The algorithms for the 3 control methods were explained well, which helps our understanding of the feedback methods when designing similar experiments. However, the reason that these methods were selected is not illustrated. If included, it will give the successors a clearer idea of how to develop new methods and improve upon previous ones.

Readers are informed enough information to understand the experiment and its significance clearly. However, I expected the focus of the paper to be on the latter half, which is the feedback methods employed, and a more detailed analysis of the results. The brief discussions in the end make the results and conclusions of the experiment rather obscure to the readers. Also, it would have been very informative if subject feedback was collected and analyzed as well. Surgeon comfort is an important factor in surgical safety, and it would provide great information on how to further develop this technology.

As the author suggests, the outcomes of this research is very encouraging. Future research in the field would concentrate on in-vivo experiments to verify the results of this paper, and to improve the force sensing tool to 3-DOF sensing, namely adding an axial force sensor. I believe that for now, it is also useful to gain more information on how different control feedback algorithms and alternative feedback methods can improve the outcomes as well as how comfortable the surgeons feel with both operating and learning the surgery.