Force-Sensing Forceps for Cochlear Implant Surgery

Paper Seminar Report

EN 601.656 Computer Integrated Surgery II

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Project Summary

During cochlear implant surgery, an electrode is inserted into the human cochlea. During this process, the cochlea is subject to a significant likelihood for trauma, 17.6% (Hoskison, 2017). Several studies have measured the insertion force ex-vivo on a cochlear model using 6 DOF force sensors, and among them Seta at el, 2017, identifies the traumatic insertion force to be around 60 mN. Such tiny force is well below the surgeon's tactile sensation. However, currently there are no methods for guidance, feedback, or assisting with the insertion of the electrode, and the entire process is entirely reliant on surgeon dexterity. The goal of this project, therefore, is to develop a 3DOF force-sensing forceps that can be used intraoperatively to assist the surgeon with atraumatic insertion for the electrode. Unlike previous studies, this tool has its advantage as a hand-held tool that can measure forces intraoperatively *in vivo*, and also has a potential to be robot assisted to provide feedback to the surgeon.

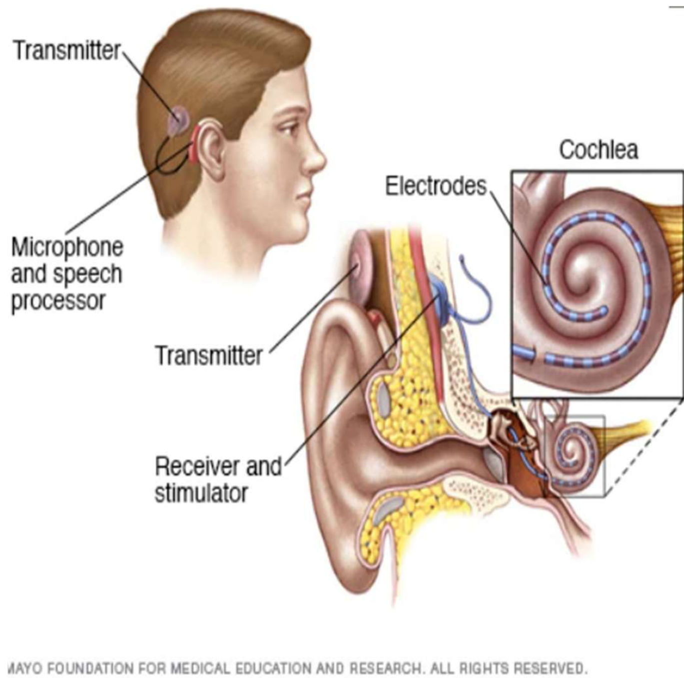

Figure 1. Cochlear Implant

Paper Selection

Design of 3-DOF force sensing Micro-Forceps for Robot Assisted Vitreoretinal Surgery (Handa et al, 2013) was chosen for its relevance to the project. Although the forceps developed in the paper is for vitreoretinal surgery, the design constraints are very similar to our purposes, including measurement of mN forces and 3 degrees of freedom force sensing ability. The paper also provides a good outline of the overall design process that can be referenced for this study.

Summary & Key Result

The summary of the paper is the design of 3-DOF force sensing forceps for vitreoretinal surgery. Key results include a full CAD model with an extensive Finite Element Analysis (FEA). Through simulation, the paper performs dimensional analysis and validates its 3DOF force sensing capability.

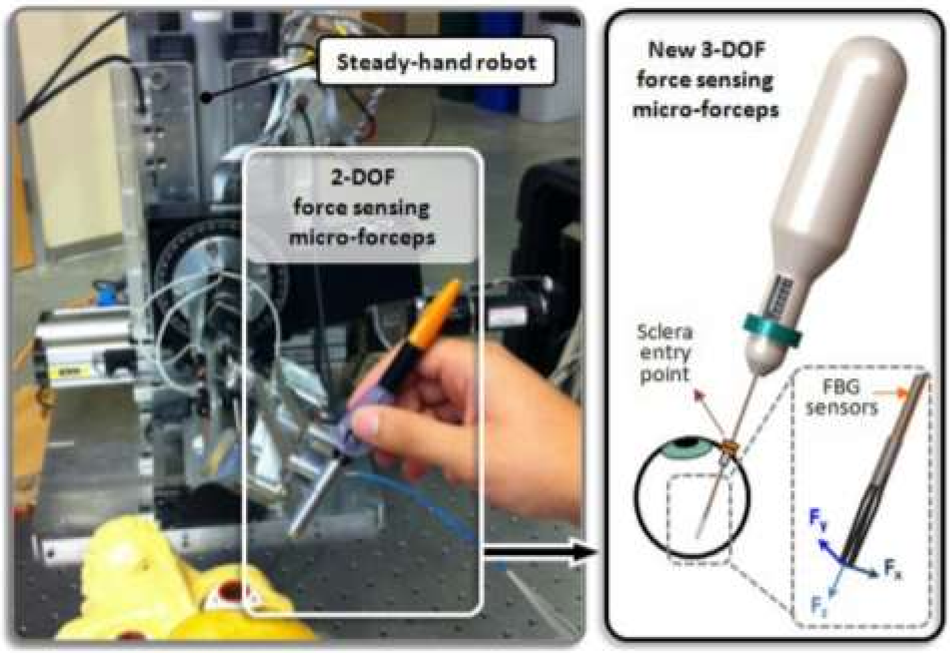

Figure 2. 3 DOF Force sensing forceps developed in the paper

Paper: Background

The forceps developed in the study is required to meet multiple constraints. First, during vitreoretinal surgery, trauma occurs at 7.5 mN force, so the forceps need to be able to measure sub-mN forces. Second, the forceps has to pass through a 20 G trocar, limiting its diameter to 0.8 mm in outer diameter. The jaw of the forceps is introduced into the eye, and the average diameter of human eyeball is 24 mm, limiting the jaw length to 14 mm. Finally, the forceps need to be biocompatible: sterilizable and reusable.

Paper: Force Sensing

To meet the design constraints, Fiber Briggs Grating sensors was chosen for its small size and excellent high resolution. 3 FBG sensors were applied in the outer tube of the forceps, and 1 FBG sensor was applied to the inner tube, each measuring strain from transverse loading at the tip and axial respectively. The FBG sensors applied in the outer tube measured strictly lateral force and was not affected by axial force. This was demonstrated in an FEA study, and the graph is shown below.

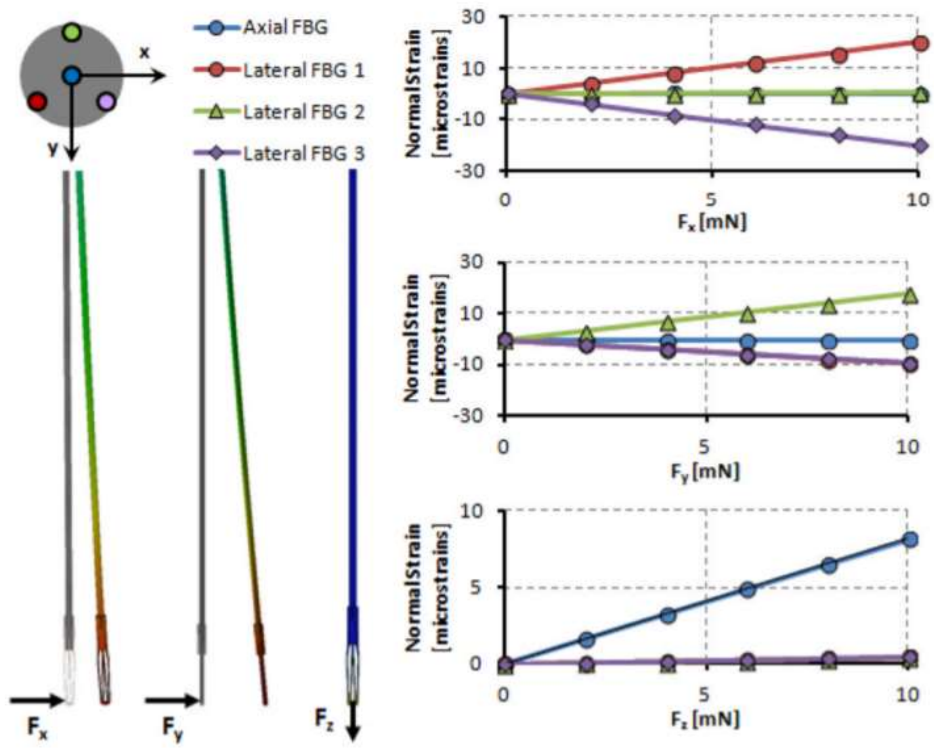

Figure 3. Normalized strain on 4 FBGS when directional loading is applied. From top to bottom, lateral x, lateral y, and axial z.

Paper: Actuation

Because the forces of interest are introduced after the forceps grasp the tissue, it is advantageous to have 0 strain on the FBGs when the forceps is closed. Hence, a normally closed jaws design was chosen.

The outer side of the jaw is connected to the outer tube, while the inner part is continued as an axis through the outer tube. The actuation is achieved by the sliding motion between these two concentric tubes. This motion is achieved by sliding an actuation ring that is preloaded with a spring, whose pre-tension can be adjusted to control the actuation force.

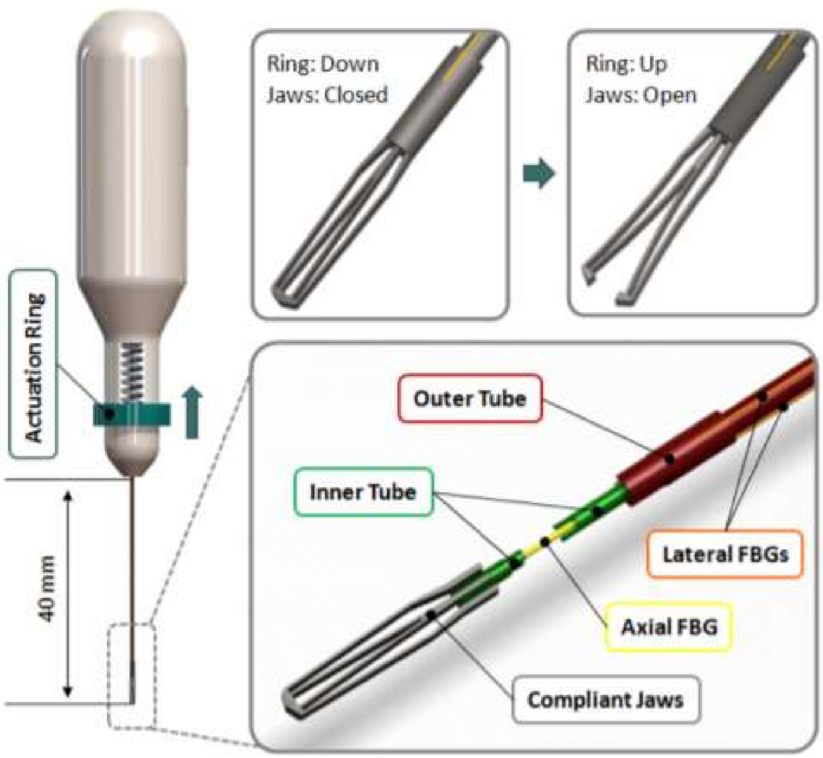

Figure 4. Actuation mechanism

Paper: Optimization

The goal of optimization study was to observe change in actuation force based on change of jaw dimensions. The desirable here is maximizing sensitivity, while maintaining the decoupling of axial and transverse force. To achieve this, the actuation force must be minimized to reduce the noise in strain measurement. The actuation force, however, is directly translated to grasping force. A good amount of grasping force is also desired to facilitate with grasping and manipulation of the forceps, and the paper determines the lower bound to be 20 mN.

In addition, the forceps geometry is limited by the resolution of the manufacturing method, which the paper chose as laser cutting. The lifespan of the forceps based on its geometry should also be calculated.

Paper: Simulation

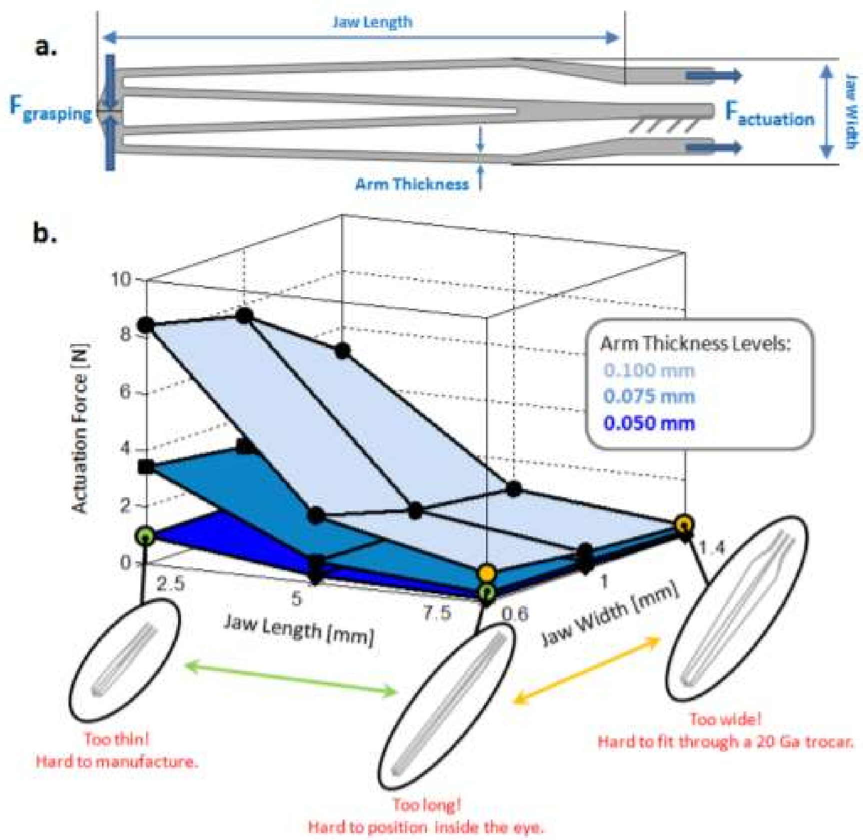

Figure 5. Change in actuation force based on varying arm thickness, jaw length, and jaw width

Optimization was performed using an extensive FEA simulation, with varying arm thickness, jaw length, and jaw width to calculate the actuation force. The figure above illustrates that actuation force is minimized when the jaw is thin, which intuitively makes sense. Moreover, changing the arm thickness is observed to be the most significant factor increasing the actuation force; hence, this should be minimized.

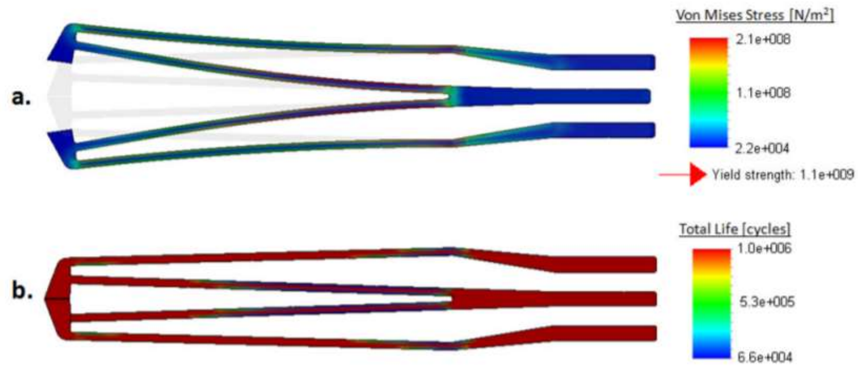

Figure 6. Jaw flexure lifespan study

The figure above also shows FEA simulated to calculate the jaw life span, which the paper reports as 60,000 cycles of actuation.

<u>Paper: Critique</u>

The paper provides a very good design with ample explanations and justifications for their design choices using simulations, especially proving its 3 DOF sensing ability. However, the paper is missing its final choice of jaw dimensions. Also, while the paper aimed to minimize the affect of actuation force on the strain of FBG, they do not actually observe its affect or validate that the affect is trivial. Intuitively, the actuation force will exert some stress in an axial direction, which will negate the axial loading at the tip. A study with both actuation force and axial-transverse loading exerted on the forceps should be performed to observe this behavior.

The paper is also missing how the jaw flexure lifespan study was performed, or what dimensions of the jaws were used to perform such study. A clearly defined set of parameters and study environment should be explicitly stated.

Furthermore, the study relies solely on simulations. A study using physical prototype and an eye model could be a very good next step. Prototyping can often reveal more design challenges and necessary adjustments to the design, which will inevitably affect the sensitivity. A plan for calibration and testing method may also be a good next step.

Project: Relevance

The design requirements for both forceps is very similar with minor difference. Both designs need to measure forces in the magnitudes of mN, and must have 3 DOF sensing ability. However, because the forceps used for cochlear implant surgery do not actually enter the inner ear cavity, they do not have such a small size constraint that the forceps in the paper does. The design should still be relatively small to provide the surgeon with least obstruction to their view to the surgical site.

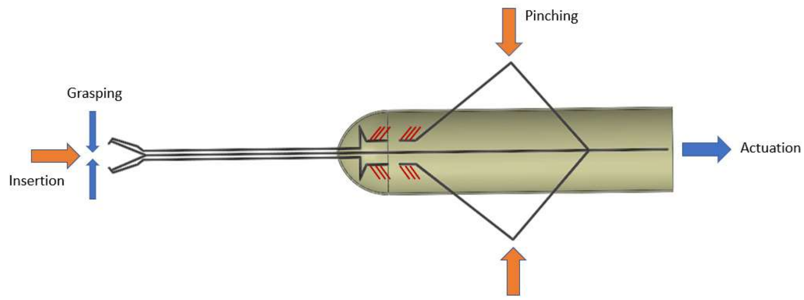

Figure 7. Actuation mechanism for cochlear implant surgery forceps

The actuation method is different for both designs. While the forceps in the study uses a spring-loaded ring as an actuation mechanism, it is desirable that the forceps used for cochlear surgery preserve the pinching motion. However, use of spring may be advantageous to introduce a controllable pre-tension. Because the force we are interested in is also introduced after full grasping, a normally closed conformation may also be advantageous. However, during cochlear implant surgery, the electrode is inserted in a feeding motion which requires repetition of actuation and releasing of the forceps. Hence, a normally closed jaws as opposed to commercially normally open jaws may introduce some inconvenience or discomfort to the surgeon, which needs to be addressed before proceeding with normally closed design.

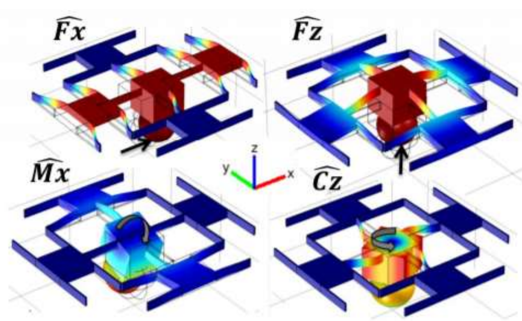

Figure 8. MEMS 6 DOF force measurement cruciform design (Billot et al., 2015)

The force sensing method is also slightly different, although the general schematic is similar. Instead of relying on the strain of the concentric tubes, we propose to implement a cruciform design that will amplify the lateral strain. However, the same optimization study measuring the grasping force in the paper should also be performed while optimizing the dimensions of the cruciform.

References

- Billot, Margot, et al. "Multi-Axis MEMS Force Sensor for Measuring Friction Components Involved in Dexterous Micromanipulation: Design and Optimisation." *International Journal of Nanomanufacturing*, vol. 11, no. 3/4, 2015, p. 161., doi:10.1504/ijnm.2015.071924.
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