Proceedings of the 34th Israeli Conference of Mechanical Engineering
Faculty of Mechanical Engineering, Technion I.I.T
Haifa, November 22-23 2016

The Hand-Held Force Magnifier & One-Dimensional Haptic Rendering Using an Audio Speaker

Avi Marcovici[1], Randy Lee[2], George Stetten[2]

[1]Faculty of Mechanical Engineering, Ort Braude College, avi.marcovici@gmail.com (A.M.)
[2]Bioengineering Department, University of Pittsburgh, 302 Benedum Hall, Pittsburgh, PA 15261, USA; ralee9@gmail.com (R.L.); stetten@pitt.edu (G.S.)

ABSTRACT

The following work deals with the haptic problem, which resulting from the loss of tactile sense during delicate microsurgeries. One of the developments that solve this problem is the Hand-Held Force Magnifier (HHFM). The research presents a conceptual design of a quick change of tools to the HHFM third prototype and a development of a new prototype, the HHFM-4. The fourth HHFM prototype will replace the surgical scalpel, allowing haptic feedback from two axes and a Quick Release brace. In addition, the work presents the development of a One-Dimensional Haptic Renderer, based on an audio loudspeaker, which is an experimental platform made to examine both third and fourth HHFM prototypes. The One-Dimensional Haptic Renderer can resemble the interaction with delicate tissues during microsurgery.

INTRODUCTION

The study presents a research and development of two projects related to the microsurgery and the science of psychophysics. Psychophysics is a branch of psychology which examines the relationship between physical stimuli and their effect on the brain's sensory response. Currently, during delicate eye surgeries, surgeons receive only visual feedback provided by microscopes. For example, during cataract surgeries, despite a high success rate, surgeons are often unable to perceive many of the forces associated with the needle penetration into the eye. Such a lack of perception can increase the risk of injury during surgery and can even cause blindness to the patient in severe cases. To increase surgeon's perception in the operating room, a device known as the HHFM was designed and developed by Mr. Randy Lee (supervised by Prof. Stetten) in the Visualization and Image Analysis (VIA) Laboratory at the University of Pittsburgh (Pittsburgh, PA) [1]. The HHFM is a novel surgical tool that can be used to measure tissue forces at the tool tip and apply magnified forces to a user's hand. The use of this device, can provide surgeons with the ability to receive haptic feedback from soft tissues which human nerves are unable to feel.

Figure 1: Model-3 HHFM shown in operator's hand [1]

1. A. CONCEPTUAL DESIGN: HHFM–3 QUICK CHANGE OF TOOLS

The first part of this project focused on improving previous prototype of the HHFM. The HHFM was designed mainly for cataract surgeries. Therefore, the front end of the device includes a thin tool tip which performs a capsulorhexis procedure. Capsulorhexis is a cataract surgery stage where the surgeon carefully peels away, in a smooth circular pattern, the few micron thick membrane, which constrains the lens from its anterior, or front, side (see Figure 1) [2]. The capsulorhexis is the most difficult part of the surgery because of the complexity of the maneuver. In capsulorhexis, the tool is typically a needle whose tip was bent backwards, to create a pick-like tool. With this tool, the surgeon can peel away the thin membrane.

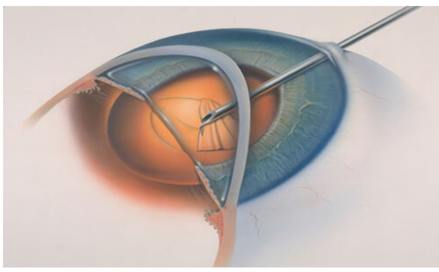

Figure 2: The capsulorhexis procedure - the surgeon produces a central circular tare in the membrane [2]

In order to adapt the HHFM to different procedures or tools, three distinct tool tip replacing mechanisms were designed for the HHFM's third prototype. After a comparison between the three models, the third model was chosen and 3D printed (see Figure 3).

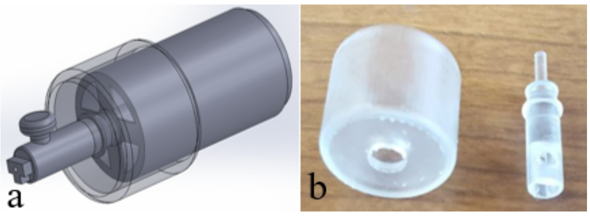

Figure 3: The chosen model of the HHFM quick change of tools mechanism: (a) SolidWorks design and (b) 3D printed

B. DESIGN THE MODEL–4 OF THE HHFM

While the HHFM Model-3 worked well as a single axis force feedback tool, it was decided to proceed to a 2-DOF prototype, the Model-4. The fourth HHFM prototype was developed for one-handed use and to be used as surgical scalpel, allowing haptic feedback from two axes and a Quick Release brace. As part of the development process, a full-model of the instrument was constructed to design the device for production. The design included the structure of a scalpel in order to provide the surgeons feeling of a surgical scalpel as opposed to a heavy and uncomfortable tool. In addition, the new prototype consist strain gages to measure tissue forces at the tool tip and two relative small linear motors, a solenoid and a voice coil actuator, in order to generate the haptic feedback through two axes.

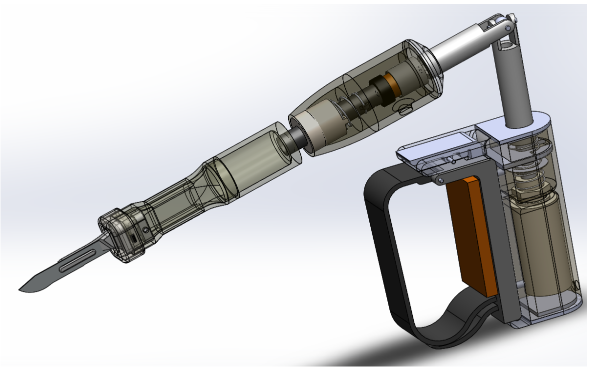

Figure 4: Transparent view of the fully-modeled HHFM-4 design

2. ONE-DIMENSIONAL HAPTIC RENDERING

In order to examine the feasibility of the HHFM as an assistive medical tool, both the third and fourth HHFM prototypes needed to be tested by a psychophysics platform. Accordingly, the second part of the project focuses on building an experimental platform known as the One-Dimensional Haptic Renderer (ODHR) [3]. The ODHR was created using an audio loudspeaker which models the properties of interacting with delicate tissues, such as the lens capsule, during microsurgery. Although the ODHR device has been designed and fabricated with only one degree of freedom (1-DOF), and has a relatively small range of displacement compared to other available haptic rendering devices, it is advantageous due to its high bandwidth, low friction, low hysteresis, low production cost and low mass capabilities. This allows for an improved simulation of delicate biological tissue puncture which consist three regions of space that can be presented as a force applied by a spring with a varied K operator. The development of the device included modeling and 3D printing a sensor housing and programming in C an external processor that control the behavior of the speaker in response to an external force.

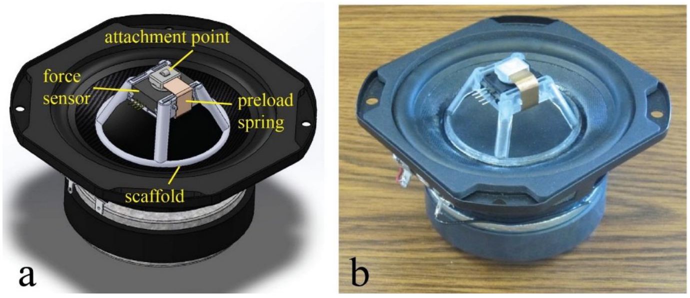

Figure 5: The ODHR device: (a) Design showing custom scaffold with supporting attachment point for user interaction, and force sensor with preload spring, allowing measurement of both push and pull forces; (b) Actual device [3]

3. CONCLUSIONS

This study highlights the need for haptic feedback on medical instruments. By implementing these feedback mechanisms as a mechatronic system, we can use engineering to assist surgeons and to reduce the risks associated with delicate operations.

REFRENCES

1. R. Lee, B. Wu, R. Klatzky, V. Shivaprabhu, J. Galeotti, S. Horvath, M. Siegel, J. S. Schuman, R. Hollis, and G. Stetten, "Hand-held force magnifier for surgical instruments: Evolution toward a clinical device," Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics), vol. 7815 LNCS, pp. 77–89, 2013.

2. M. J. Bradley Randleman, MD; Melissa Conrad Stöppler, "Cataract Surgery: Recovery and Complications," MedicineNet, Inc., 2015. [Online]. Available: http://www.medicinenet.com/cataract_surgery/article.htm. [Accessed: 14-Feb-2016].

3. Khera, R. Lee, A. Marcovici, Z. Yu, R. Klatzky, M. Siegel, S. Shroff, and G. Stetten, "One-Dimensional Haptic Rendering Using Audio Speaker with Displacement Determined by Inductance," Machines, vol. 4, no. 1, p. 9, 2016.