Robotically Assisted Cochlear Imaging

Project Proposal

Team Members: Xingchi He, Saumya Gurbani, Alperen Degirmenci

Mentors: R. Taylor, I. Iordachita

Clinical Advisor: W. Chien

Goal

The goal of this project is develop a safe procedure to guide the electrode insertion in cochlear implantation by integrating the OCT imaging with the steady-hand robot. This integration will allow for improved imaging of the cochlea, as needed for implant surgery. There will be several components of this project: a hardware adapter which allows an OCT probe (or multiple probes) to attach to the steady-hand robot, a hardware adapter which allows the electrode of the cochlear implant to attach to the steady-hand robot, and a software component which will allow the probe to interface with current software.

Background and Significance

Cochlear implant surgery is performed on patients who suffer severe hearing loss, allowing them to perceive a broader and finer tuned range of sound. The implant has two components: an external microphone to capture sound, and an embedded electrode to transmit the sound (via electric current) to the inner ear.

One of the greatest risks involved with embedding this electrode is the possibility of damaging critical tissue, such as the facial nerve, which are located in very close proximity to the target location of the implant. Damage to the facial nerve, for example, can lead to facial paralysis. Furthermore, the diameter of the scala tympani is less than 1mm, thus allowing almost no room for error during the placement of the implant.

Current procedure involves passing a flexible electrode through the round window and through the first bend of the scala tympani for placement. Pre-operative CT and MRI images are used in order to properly plan the surgery. While both of these provide a layout of the cochlea and give the surgeon a path to follow, they do not mitigate the risk of harm during the actual placement.

The integration of an Optical Coherence Tomography (OCT) probe into the electrode placement probe would allow for real time imaging during the surgery. The surgeon would be able to visualize the

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surrounding of the probe's tip and ensure that the probe will avoid striking any structural components during placement. Attaching such probes to a steady-hand robot will further mitigate the risk of damage due to hand tremor.

Currently, the hardware and software for the steady-hand robot allow five degrees of motion: translation, plus rotation about the base of the tool-attachment. The sixth degree of motion, rotation about the axis of the tool, is currently not available. Since this rotation is necessary to produce 360-degree imaging capabilities for the OCT probe, it must be developed.

Technical Summary of Approach

Our project is broken up into essentially 5 stages: First OCT Probe Design, Testing, Second OCT Probe Design, Surgical Safety Adaptations, and Bendable OCT Probe Design. The probe design stages (Stages 1 and 3) are further broken down into two sub-stages, hardware and software.

Stage 1H (hardware): In this stage, our goal is to successfully build a prototype of a side-view OCT probe adapter. We will first sketch various plausible designs for the adapter and determine, with consulting from our mentors and Dr. Chien, which is the most feasible and convenient for a surgeon to use. We will then produce a CAD model of the desired design, and send it in to the machine shop for fabrication.

Stage 1S (software): Concurrent with the hardware stage, we will also begin to work on a software package to interface our adapter with the current steady-hand robot software.

Stage 2: The second stage will consist of testing our initial prototype and software on a phantom cochlear bone. This stage is critical as it will elucidate shortcomings in our design and software implementation. Iterative changes will be made, and a second prototype will be fabricated.

Stage 3H (hardware): Once we have a side-view OCT probe adapter built, we will work on modifying the adapter to incorporate a second, front-facing OCT probe. By using both these probes, we should be able to get a complete hemispherical view of the inner ear as the probes traverse it.

Stage 3S (software): Concurrently, we will write software to help us merge together the outputs from each probe to create a 3D reconstruction of the cochlea.

Stage 4: The goal of stage four is to develop software to further aid the surgeon during the implant operation. Based off of pre-operative MRI and CT imaging, we will develop virtual fixtures that our OCT probes will be able to "see" during the surgery. We will also use this data to create safe insertion paths for the surgeon to follow. Finally, we will incorporate proximity-scaled force feedback to keep the surgeon on the delineated paths.

Stage 5: This stage is our maximal possible deliverable, with the goal to create a new OCT probe itself (not just an adapter) which can be bent around the inner ear canals and still allow enough light to pass

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so that the OCT probe can function. An alternative design would be to bend the OCT adapter at an angle, so that the adapter does not get in the field of view of the microscope.

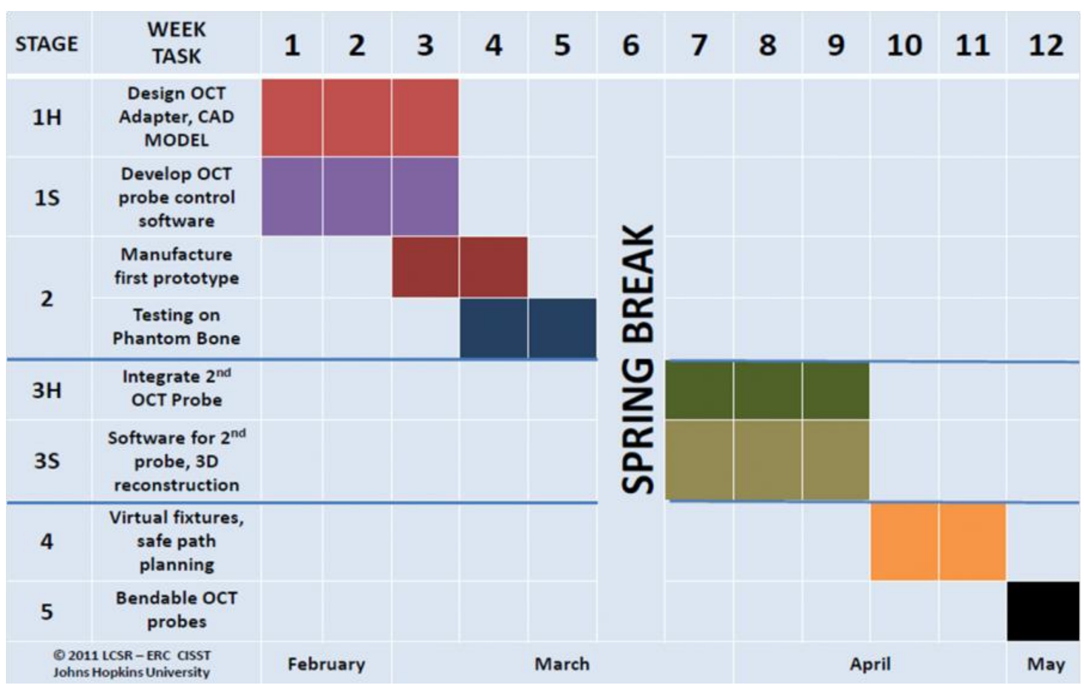
Deliverables

- **Minimal**
    - Develop a rotationally-free adaptor for OCT probe to be attached to the steady-hand robot
    - Develop a mechanism for the rotation of the OCT probe inside the cochlear canal
    - Develop software to control the rotation of OCT probe inside the cochlear canal

- **Expected**
    - Integrate a second imaging fiber into the OCT probe, directed forward, to increase maneuverability and the field-of-view
    - 3D reconstruction of the cochlear canal using the software available

- **Maximal**
    - Develop a hardware adapter which holds the electrode of the implant for insertion
    - Design a bendable OCT probe and/or bendable adapter
    - Generate virtual fixture from the 3D reconstruction of the cochlear canal
    - Suggest safe insertion paths to the surgeon
    - Provide proximity-scaled force-feedback to the surgeon

Timeline



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Assigned Responsibilities

Much of our work will be collaborative, with the three of us working together to achieve the individual goals. However, we plan to take advantage of each other's strengths and compensate for each other's weaknesses. The following is a breakdown of certain components which will be split up amongst the three of us.

Xingchi:

- Design the fixture and rotation mechanism in CAD
- Generate virtual fixture, safe insertion path planning
- Integrate front-facing OCT probe with side-view probe

Saumya:

- Software to control the OCT probe; interface with steady-hand robot
- 3D reconstruction of the cochlear canal
- Generate virtual fixture, safe insertion path planning

Alperen:

- Design the fixture and rotation mechanism in CAD
- Generate virtual fixture, safe insertion path planning
- Integrate front-facing OCT probe with side-view probe

Dependencies

1. OCT system and software
    - Obtain from Kang Zhang and Dr. Kang
2. Access to phantom bones and clinical advice
    - Dr. Chien has already provides us with one bone, and is willing to give us what we need
3. Access to steady-hand robot and the software engineers
    - Access granted.
4. $2000 budget for manufacturing OCT adapters
    - Proposing budget to Dr. Taylor
5. Access to machine shop for manufacturing prototypes.
    - Contact Rich
6. Access to a motor for testing
    - Obtain from Dr. Kang

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Management Plan

1. Weekly meeting with Dr. Chien (when he is available) to understand about the surgery from the clinical perspective.
2. Weekly meetings with each other on Tuesday and Thursday, after CIS course. This will allow to us collaborate on certain segments of the project, and access equipment in the robotorium as needed.
3. 50 man hours put into the project per week.

Reading List & Bibliography

1. "Cochlear Implants". Medical Devices - US Food and Drug Administration. http://www.fda.gov/MedicalDevices/ProductsandMedicalProcedures/ImplantsandProsthetics/CochlearImplants/default.htm. Accessed 12 February 2011.
2. Cohen, Noel L. and J. Thomas Roland Jr. "Complications of Cochlear Implant Surgery".Cochlear Implans. Ed. Susan B. Waltzman and J. Thomas Roland. Thieme Medical Pub, 2006. 126-132.
3. H.W. Pau, E. Lankenau, T. Just, and G. Hüttmann, "Imaging of Cochlear Structures by Optical Coherence Tomography (OCT). Temporal bone experiments for an OCT-guided cochleostomy technique.," Laryngo- rhino- otologie, vol. 87, Sep. 2008, pp. 641-6.
4. H.W. Pau, E. Lankenau, T. Just, D. Behrend, and G. Hüttmann, "Optical coherence tomography as an orientation guide in cochlear implant surgery?," Acta oto-laryngologica, vol. 127, Sep. 2007, pp. 907-13.
5. J.U. Kang and P. Gehlbach, "Endoscopic Functional Fourier Domain Common-Path Optical Coherence Tomography for Microsurgery," IEEE Journal of Selected Topics in Quantum Electronics, vol. 16, Jul. 2010, pp. 781-792.
6. B.J. Wong, J.F. de Boer, B.H. Park, Z. Chen, and J.S. Nelson, "Optical coherence tomography of the rat cochlea.," Journal of biomedical optics, vol. 5, Oct. 2000, pp. 367-70.
7. I. Fleming, M. Balicki, J. Koo, I. Iordachita, B. Mitchell, J. Handa, G. Hager, and R. Taylor, "Cooperative robot assistant for retinal microsurgery.," Medical image computing and computer-assisted intervention : MICCAI ... International Conference on Medical Image Computing and Computer-Assisted Intervention, vol. 11, Jan. 2008, pp. 543-50.
8. Nakabayashi, Koki et. al. "OCT Optical Probe and Optical Tomography Imaging Apparatus". US Patent Application No. 12/363,021. Filed 30 January 2009.
9. C.G. Wright, P.S. Roland, and J. Kuzma, "Advanced bionics thin lateral and Helix II electrodes: a temporal bone study.," The Laryngoscope, vol. 115, Nov. 2005, pp. 2041-5.

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