Johns Hopkins University

Project Report

Robotically Assisted Cochlear Imaging

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EN.600.446 Computer-Integrated Surgery II

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Prof. Russell Taylor

Acknowledgements

We would like to thank the following people for their support in this endeavor over the past few months.

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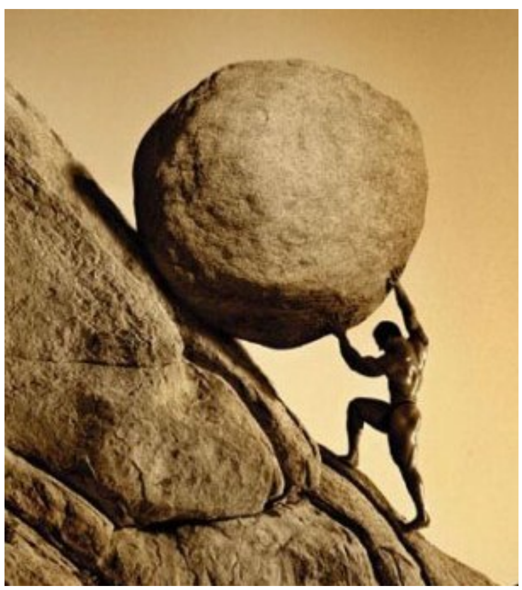
Dr. Iulian Iordachita, who mentored us through the hardware design and creation process. He provided many ideas for the borescope and OCT adapter mounts for the EyeRobot, and gave us access to the equipment necessary for prototyping these devices.

The Kang's laboratory, for providing us with equipment and tutorials on how to use their OCT system.

Marcin Balicki, for his continued guidance and support while we wrote software to interface with the EyeRobots, even late at night and on weekends.



Picture taken from: http://blog.heartofecuador.com/blog-heart-of-ecuador/tag/spiritual-reflections

Team Members: Alperen Degirmenci, Saumya Gurbani, Xingchi He

Mentors: Dr. Russell Taylor, Dr. Iulian Iordachita

Clinical Advisor: Dr. Wade Chien

Goal

The goal of this project was to design, build, and test a robotic system for assisting surgeons in cochlear implant surgeries via visual and force feedback, path planning, and semi-automation. The system utilizes a borescope integrated with the steady-hand robot. This integration allows for pre-operative safe path planning, as needed for implant surgery, visual guidance during operations, which surgeons currently lack, and accurate micro-scale control, eliminating hand tremor and increasing dexterity. This was an ambitious project with many unforeseen setbacks. Two main components of this project that were completed this semester are: (1) a hardware adaptor which integrates the borescope with the steady-hand robot, (2) another adaptor for guiding a cochlear implant into the cochlea, and (3) a software component which allows the probe to interface with the robot and other software components that were employed for feedback and safe path planning.

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 facial nerves, which are located in very close proximity to the target location of the implant. Damage to the facial nerves, 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, and making it impossible to fit any other instruments in the cochlear canal during the operation.

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.

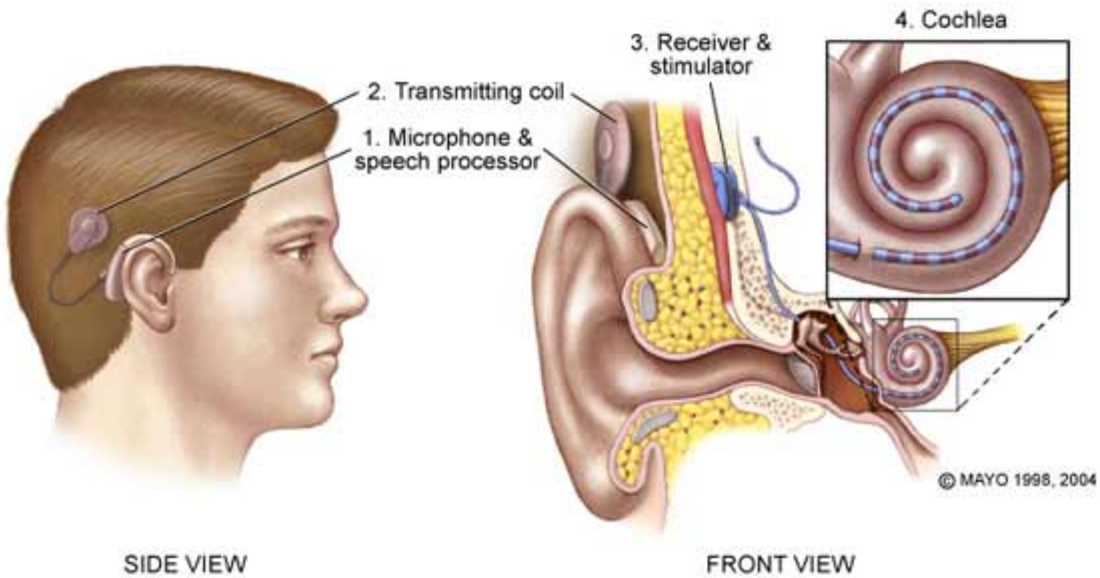


Figure 1: Representation of a cochlear implant inside the cochlea.

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.

Guiding the borescope into the cochlear canal with the help of the Eye Robot helps determine the safest path for instrument insertion. Because the borescope is attached to the same tool arm as the implant tools, a simple registration can be done between the borescope's path and the tooltip's path even though the two items are not being inserted concurrently.

Technical Summary of Approach

The technical approach taken was based on making use of the EyeRobot's Remote Center of Motion and Virtual Fixture capabilities in order to minimize the risk of damaging the cochlea by assisting surgeons in the implant insertion process. During the insertion of the borescope into the cochlea, and down to the first turn of the cochlear canal, a 3D reconstruction of the canal will be made. The 3D reconstruction using only one camera is possible because (1) the position of the borescope is known through the kinematics of the EyeRobot (assuming a rigid scope), (2) the intrinsic parameters of the borescope can be measured using a calibration toolbox, and (3) applying an optical flow algorithm provides the transformation of the image in camera coordinates. Combining these parameters, a 3D reconstruction can be done. Currently, only steps (1) and (2) are working (there are some problems with getting robot coordinates), and (3) will be implemented. More information on algorithms can be found in Appendix A and B.

The project was broken up into five essential stages: First Adapter Prototype, Second Adapter Prototype, Testing, Software Development for Safe-Path Registration, and Segmentation of

Borescope Images. The probe design stages (Stages 1 and 3) are further broken down into two sub-stages: (H) hardware and (S) software.

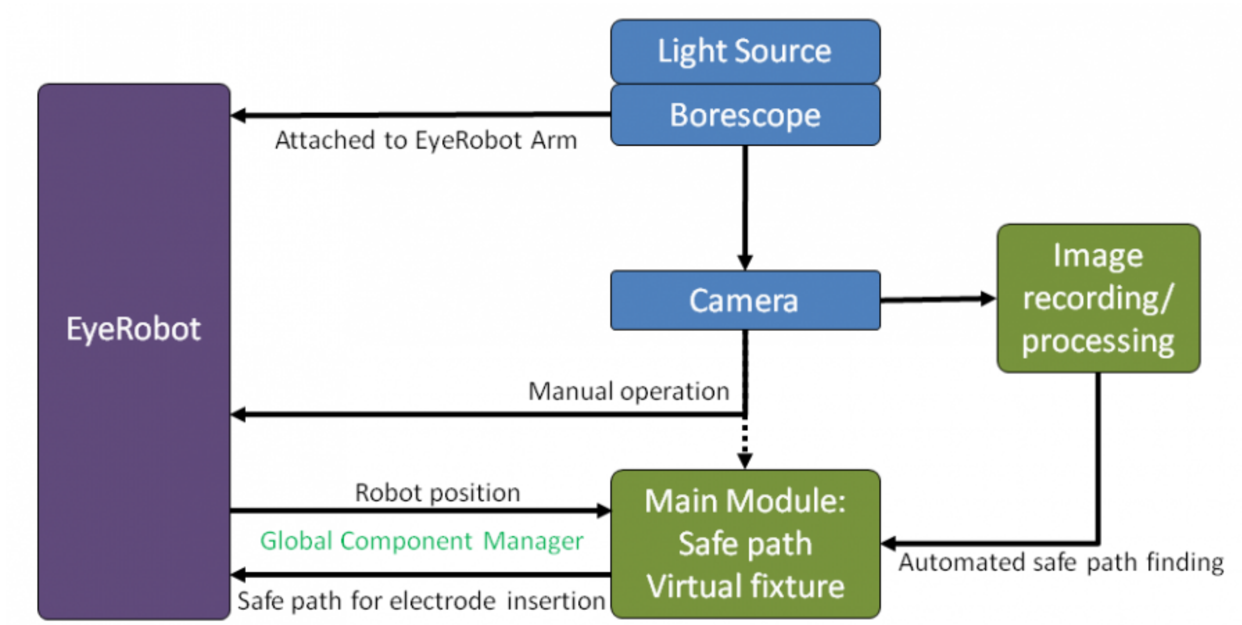


Figure 2: Work flow.

Stage 1H (hardware): In this stage, the goal was to successfully build an adapter for the borescope. Various plausible design ideas were sketched for the adapter and, with the guidance of mentors and surgical collaborator Dr. Chien, the most feasible and convenient design for a surgeon's use was determined. A CAD model of the desired design was produced using ProEngineer (see the Appendix for various designs), and was built using the µPrint Rapid Prototyping Machine.

Stage 1S (software): Concurrent with the hardware stage, software for acquiring images from the borescope through a FireWire camera was developed. This stage mainly involved understanding how the Global Component Manager and EyeRobot1 communicated, how to use the cisstStereoVision library to acquire images from a camera and record videos, and how to integrate a new component into this system.

Stage 2: The second stage consisted of testing our initial prototype and software on a phantom cochlear bone. This stage was critical as it elucidated the shortcomings in our design and software implementation. Iterative changes were made, and a second adapter was built.

Stage 3: A new component was created using the CISST Libraries in order to acquire the position of the EyeRobot tooltip, which could then be used to create a safe path for insertion of instruments into the cochlea. Currently, this process is manual, meaning that the operator has to click on a button in the GUI to register the current instrument position as a safe-path member point.

Stage 4: Code for segmenting the images acquired from the borescope was developed and integrated with the CameraViewer in the cisstStereoVision library. Segmentation can be used in combination with optical flow to create a 3D reconstruction of the cochlear canal. The reconstruction can then be used to impose virtual fixtures and do safe-path planning.

Stage 5: The intrinsic parameters of the borescope + FireWire camera system were determined using a camera calibration toolbox (DLR CalLab). These parameters are an integral part of the 3D reconstruction process; they are used to transform camera coordinates to world coordinates, make it possible to set virtual fixtures on world coordinates.

Results

An adapter with interchangeable tips for the borescope and electrode was designed and built. A manual safe-path generation program was written. Robot position can be recorded for use in 3D reconstruction. A real-time segmentation filter was created for use in 3D reconstruction. The borescope + FireWire camera intrinsic parameters were determined through calibration. The safe-path was generated by fitting a straight line through the manually registered safe path points. The maximum distance between a safe-path point and the computed safe-path line is 0.57 millimeters, spanning a cylinder with a diameter of 1.14 millimeter, which is about the average cochlear canal diameter. This is a promising result, and can be improved when the 3D reconstruction algorithm is completed.

Management Plan

Assigned Responsibilities

Much of the work was done collaboratively, with the members working together to achieve individual goals. Individual responsibilities were assigned depending on each member's strengths. The following is a breakdown of certain components

Alperen Degirmenci:

- Adapter design and prototyping
- Optical flow
- Borescope calibration

Saumya Gurbani:

- Segmentation
- Safe path GUI
- EyeRobot interfacing

- Safe path recording

Xingchi He:

- Adapter design and prototyping
- Safe path generation
- Borescope calibration

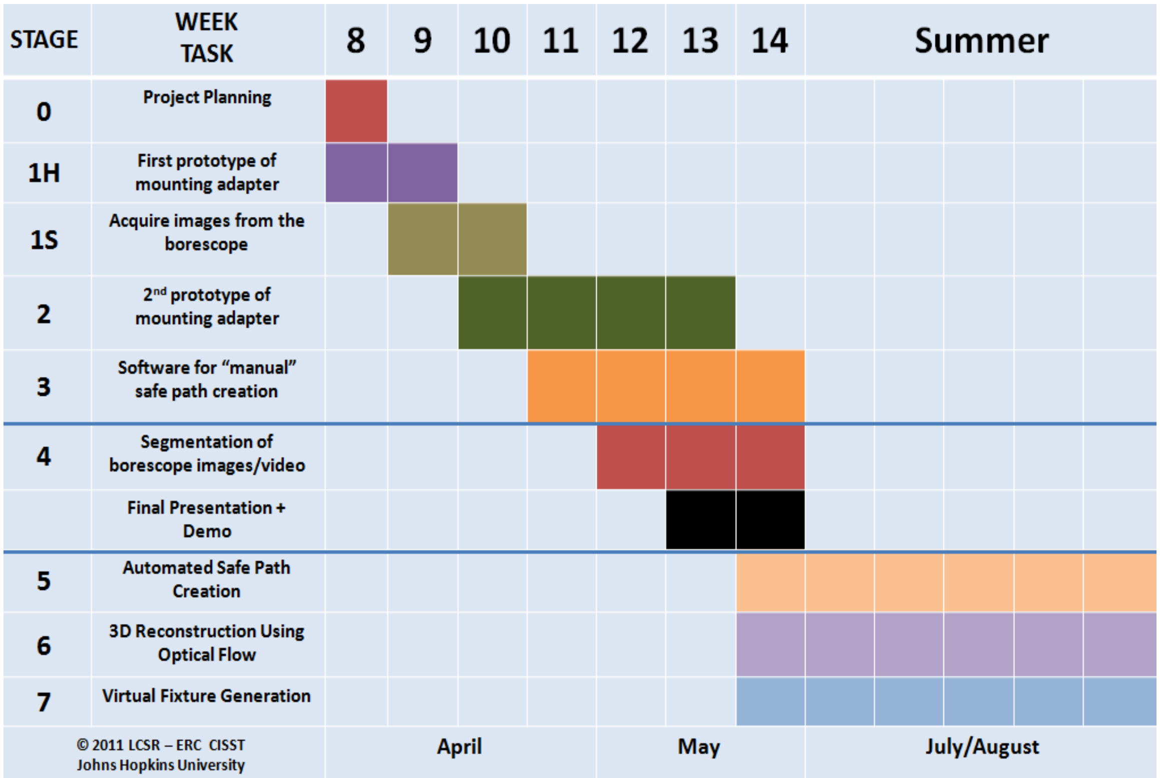
Deliverables - What was accomplished vs. planned

	Deliverable	Status
Minimum	Hardware to mount borescope system on to the EyeRobot setup	**COMPLETED 05/14/2011**
	Develop software for “manual” safe-path generation (can’t control the robot using this constraint yet)	**COMPLETED 05/17/2011**
Expected	Do camera calibration to get intrinsic parameters.	**COMPLETED 05/14/2011**
	Display a live video feed from the borescope. Apply real-time segmentation filter	**COMPLETED 05/17/2011**
	Develop software to register the borescope & safe path with subsequent surgical tools	**EXPECTED SUMMER 2011**
Maximum	Generate virtual fixtures from safe path	**EXPECTED SUMMER 2011**
	Automate the safe path generation process	**EXPECTED SUMMER 2011**
	Use optical flow to create a 3D reconstructions of the cochlea	**EXPECTED SUMMER 2011**

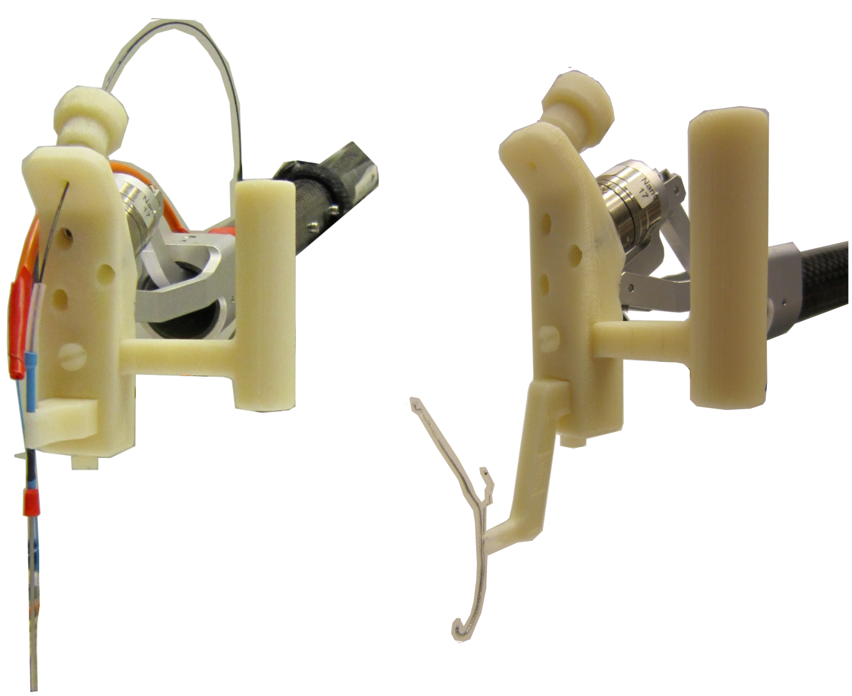
It can be seen that the minimum and most expected deliverables were completed.

Appendix

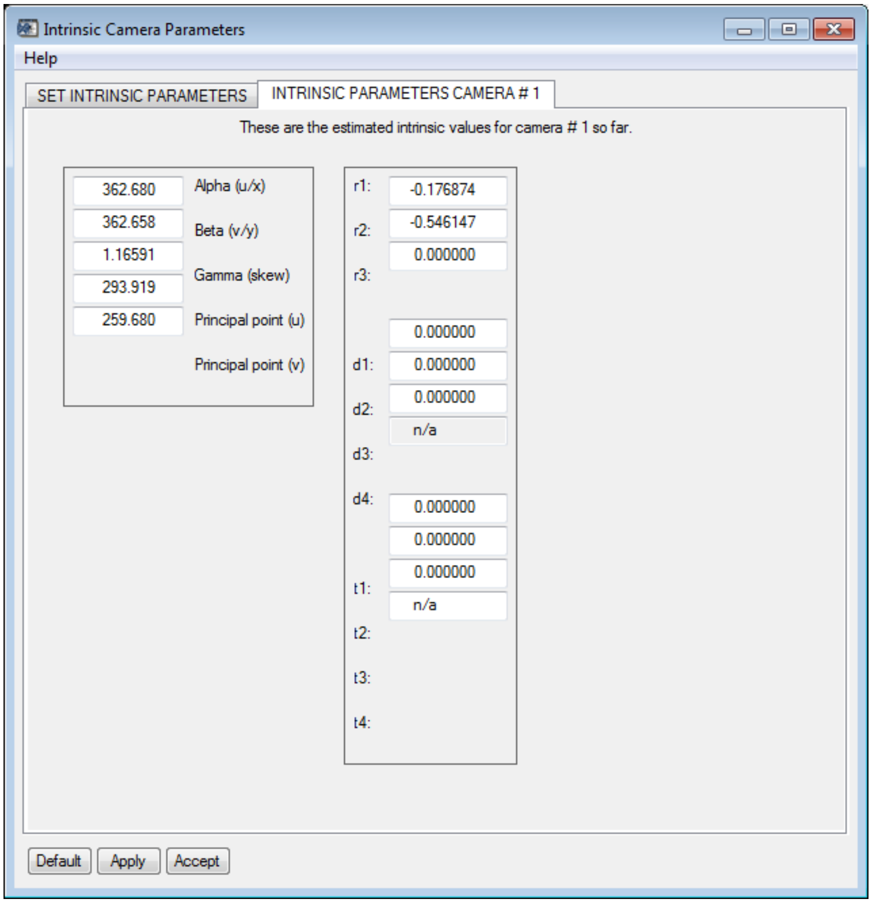
Appendix 1 - Timeline



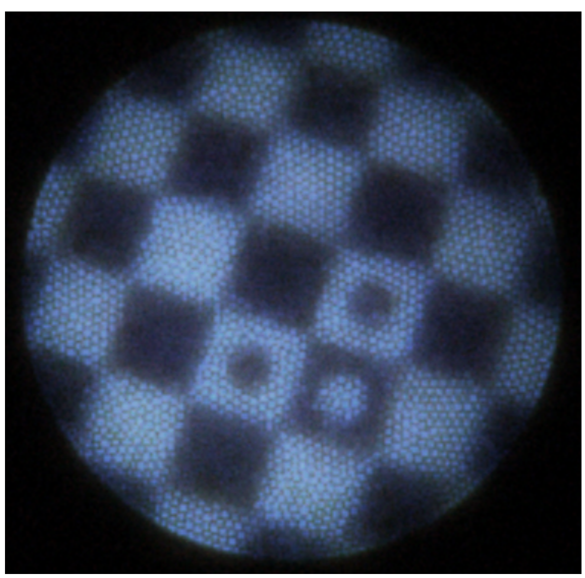
Appendix 2 – The Adapter Created for Attaching the Borescope (left) and Electrode (right) to EyeRobot1



Appendix 3 – Intrinsic Parameters for the Borescope+FireWire Camera System Calculated by DLR CalDe Calibration Toolbox



Appendix 4 –Calibration Grid Picture Taken Using the Borescope+FireWire Camera System



Appendix 5 - Reading List & Bibliography

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