Assessment of Intra-Operative OCT Imaging in a Simulated Micro-Surgical Task

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1 Summary

We aim to assess the efficacy of intra-operative OCT (Optical Coherence Tomography) imaging as an aid in vitrioretinal surgery, in particular for peeling epiretinal membranes (ERM). We intend to investigate this using a simulated micro-surgical task. Secondarily, we seek to improve the existing user interface of the OCT system in order to advance the system towards potential clinical use.

2 Motivation

Vitreoretinal surgery is technically demanding for surgeons, and is made especially challenging due to factors such as:

1. difficulty visualizing surgical targets
2. small size and delicate nature of tissues
3. voluntary and involuntary movement of the patient's eye
4. hand tremor and lack of force feedback

The OCT-integrated pick paired with the JHU EyeRobot platform attempts to address many of these factors. Specifically, the OCT system can be used to provide high-resolution spatial information and tissue depth perception. The driving application of this feature is the ability to locate the edges of epiretinal membranes for removal. These are very small delicate membranes that need to peeled from the retina, but are clear and very difficult to locate. Intra-operative OCT imaging can greatly facilitate the localization of these membranes, and incorporation of OCT imaging with an assistive robot can address issues like accuracy, hand tremor and safety.

3 Background

A Optical Coherence Tomography

OCT provides micron-scale images of anatomical structures within a given tissue. Broadband light passes down a single optical fiber, gets reflected by tissue layers and interacts with itself. The reflected light is fed to a spectrometer, which performs Fourier analysis to return depth information on the anatomical features. The depth image at a single point is an Axial or A-mode image. Taking a continuous scan and combining the sequence of A-mode images produces a distorted cross-sectional B-mode scans.

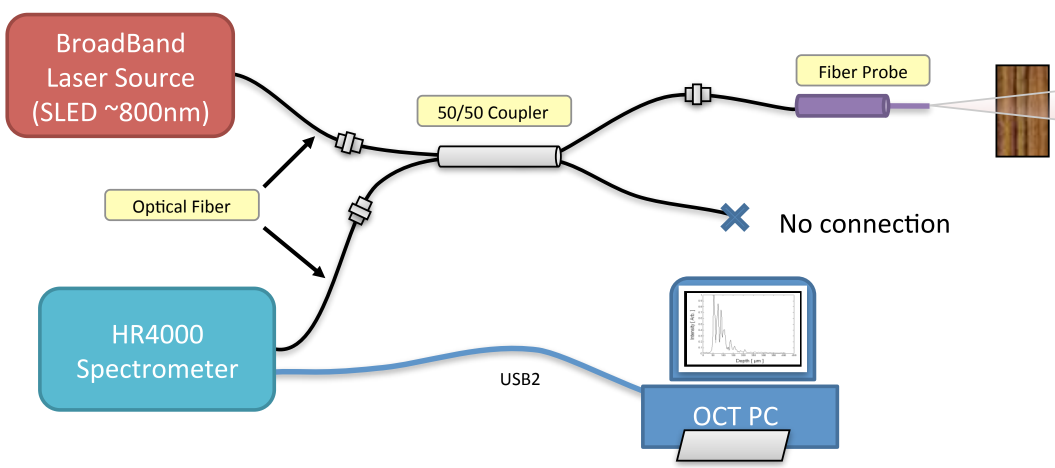

Figure 1: OCT System. M. Balicki et al.

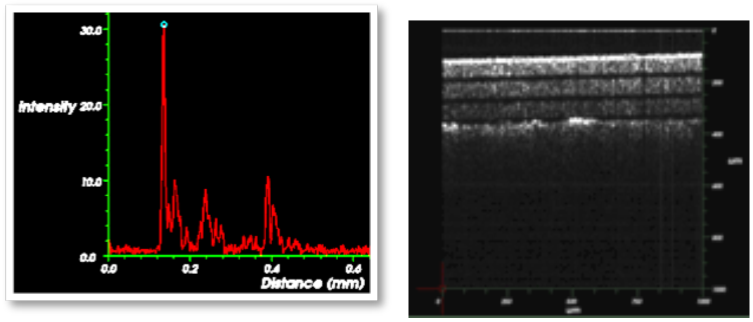

Figure 2: A-mode data (left) at many instances combine to form a B-scan (right). M. Balicki et al.

B Fiber Integrated Surgical Pick

By incorporating sensors directly into ophthalmic instruments it is possible to assess the structures ahead of or in contact with the instrument. In the case of the fiber-integrated surgical pick, surgeons can image using the same tool that they would use to remove ERMs, instead of changing tools and re-imaging frequently.

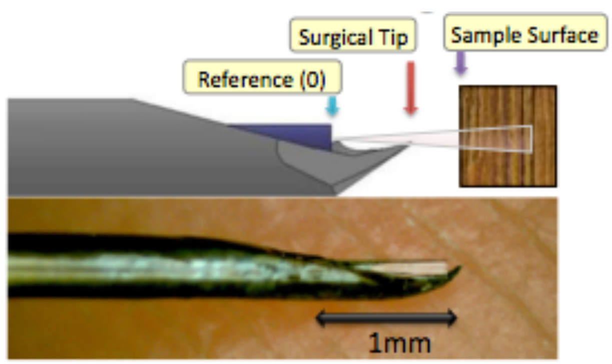

Figure 3: M. Balicki et al.

C Visual Tracking and Annotation

The stereo video microscope is registered with the position of the intraoperative OCT imaging tool, and the video feed is annotated with the paths of the tool scans. This enables surgeons to return to locations on the retina that show anatomical features of interest in the OCT scan.

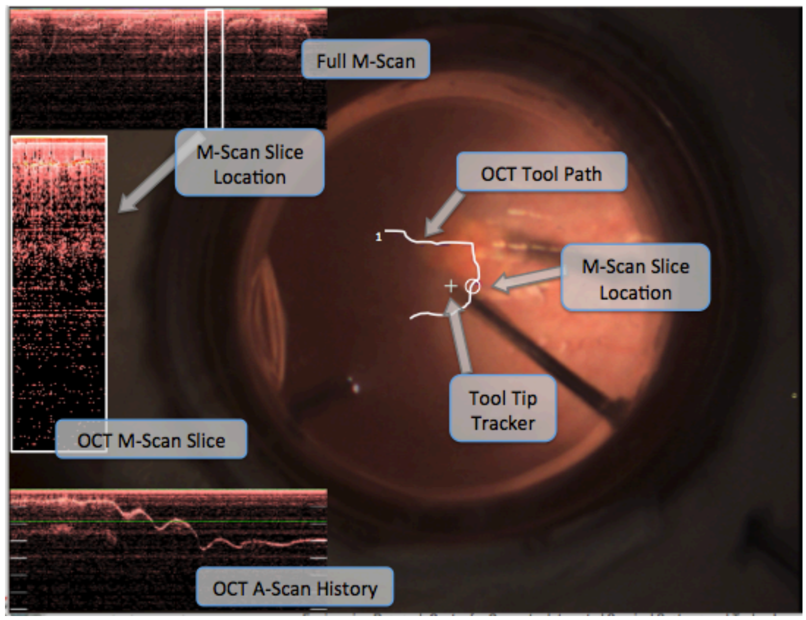

Figure 4: Display with OCT scan information overlay. M. Balicki et al.

D Integration with Assistive Robots

While the OCT imaging pick can be used freehand by providing, for instance, auditory feedback to the surgeon, it can also be used as imaging feedback for active assistant robot like the SteadyHand. This presents many benefits like reduced hand tremor and increased accuracy (through movement attenuation and scaling).

4 Areas for improvement

- User interfacing/GUI
  - allow user to select an area of the OCT image to highlight the corresponding position in the overlaid scan path on the retina
  - color enhancement

  - annotation of anatomical landmarks

- Smart OCT processing
  - Correct for time-space differences:
    The existing M-scans show depth versus time, such that if the OCT probe is held still, the resulting OCT image contains redundant information. A related effect is that the OCT image varies depending on the speed at which the probe is moved over the path. However, it is preferable to display depth data versus path distance, so that redundancy is avoided and the position of features on the M-scan can be intuitively related to distance along a scan path. This can be implemented by converting the depth-time images to depth-space images, using information from the stereo video recording. Another solution could involve using an assistive robot to move the OCT pick at a constant speed.
  - Automatic scanning:
    As an extension of robot-assisted scanning, it could be useful to instruct the robot to scan a path that is dense over a small area, providing more detailed information about that patch of retina.

5 Specific Goals

- Build a phantom
- Design a micro-surgical task
- Obtain IRB approval for task
- Conduct subject trials
- Perform statistical analysis of data from experiments
- Overlay OCT mScan paths on stereocamera view of operating area
- Implement mScan dewarping

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6 Technical Approach

A Experimental Validation of mScan for Locating ERM Edges

A.1 Phantom Design

In order to test the efficacy of the mScan-OCT system for detecting ERM edges, there is the need for a realistic phantom eye, in which the retina surface has regions of scar tissue. In particular, this scar tissue must have the following properties:

- transparent
- non-reflective
- thin

The ERM regions should be effectively invisible to the naked eye, and also difficult to locate with stereomicroscopy, which could be achieved by the use of a material with similar or identical properties to he material of which the retina surface is made.

A.2 Experimental Task Design and Data Analysis

The purpose of the experimental task is to evaluate whether using OCT-system-generated mScans improves the success rate of finding ERM edges with the properties described above. In order to simulate intraoperative conditions as closely as possible, we will attend vitreoretinal surgeries on both humans and on rabbits to better appreciate the challenges faced by surgeons. We will also consult them for suggestions on the type of tasks our experiment could include. This may involve supplying participants with a radial pattern of ”pre-operative” mScans from the test retinas, instructions to find as many edges within an allocated time, progressively more difficult retina samples, and/or the use of the EyeRobot in conjunction with the OCT probe versus freehand operation of the probe. The statistical significance of the outcome will be assessed using a test suitable to the specific experimental design, the number of trials and study participants.

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B GUI and User Interface

The existing OCT system returns the position of the OCT probe tip versus time, while the mScan contains depth information versus time. By combining the information contained in these two modalities, a feature could plausibly be developed in which an interesting section of an mScan can be mapped to a position in stereovideo. The visual rendering of this information in the operating view will be improved, taking into account the feedback from the eye surgeons we will consult. We will also investigate encoding an automatic scan of the retina, providing high-resolution OCT information over a small region of tissue.

7 Deliverables

- Minimum
  - Phantom
  - IRB approval
  - Subject experiment
  - Refined mScan user interface
- Expected
  - Functional demo of GUI
  - Results from executed experiments
  - Statistical analysis of results
  - OCT image enhancement
- Maximum
  - Automatic scanning
  - Time-space differences correction
  - Publication
  - Robot integration

8 Management Plan

- Weekly meetings with mentor
- Assessment of progress and timeline update
- Wiki maintenance
- We will collaborate on each task and share responsibility equally
- Possible use of Redmine

9 Dependencies

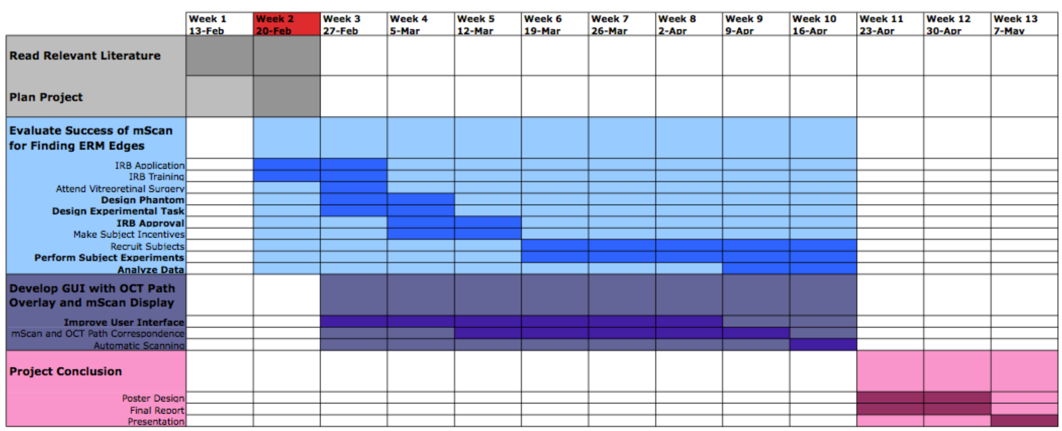
Dependency	Solution	Status	Fallback Plan
Access to Robotorium	Apply	Resolved	
OCT System and Software	Schedule time for use	Resolve by DATE	Re-schedule
Marcin	Schedule weekly meetings	Resolved	
Materials and resources for phantom	Get access and funding	Resolve by DATE	Fundraise
IRB approval	Submit application	Resolve by 03/14	Re-apply with necessary changes
Attend Vitreoretinal surgery	Ask Marcin for help scheduling	Unresolved	Discuss VR surgery with surgeons
Subject Recruitment	Fliers, Today's announcements, etc.	Resolve by 03/21	Increase incentives, try different forms of advertisement
Subject Incentive Funding	Apply for funding for T-shirts, gift cards, etc.	Resolve by 03/21	Fundraise

10 Milestones

- Design of micro-surgical task that simulates ERM peeling
- Working phantom

- IRB approval
- Completion of advertisement and incentive for subject recruitment
- Completion subject trials
- Statistical analysis of data from subject trials
- OCT enhancements
  - Color enhancement
  - Annotation of anatomical landmark
  - GUI improvement
  - Time-space correction
- Successful annotation of selected landmark on overlaid scan path
- Implementation of time-space mScan dewarping

11 Timeline



12 Reading List

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- "Common-path Fourier-domain Optical Coherence Tomography with a Fiber Optic Probe Integrated Into a Surgical Needle" Jae-Ho Han, Marcin Balicki, Kang Zhang, Jae-Ho Han, Marcin Balicki, Kang Zhang, Xuan Liu, James Handa, Russell Taylor, and Jin U. Kang; Proceedings of CLEO Conference, May 2009

- "Micro-Force Sensing in Robot Assisted Membrane Peeling for Vitreoretinal Surgery" Marcin Balicki, Ali Uneri1, Iulian Iordachita, James Handa, Peter Gehlbach, Russell Taylor. Proceedings of the MICCAI Conference, 2010.

- "Automatic online spectral calibration of Fourier-domain OCT for robot-assisted vitreoretinal surgery" Xuan Liu, Marcin Balicki, Russell H. Taylor, and Jin U. Kang. , in SPIE Advanced Biomedical and Clinical Diagnostic Systems IX,25 January 2011.

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- "Biopsy site re-localisation based on the computation of epipolar lines from two previous endoscopic images." Allain B, Hu M, Lovat LB, Cook R, Ourselin S, Hawkes D. Centre for Medical Image Computing, University College London

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