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

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Mentors:
Marcin Balicki
Professor Russell Taylor

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1 Technical Summary

A Background

Vitreoretinal conditions such as retinal scarring and macular degeneration require surgical interventions of a difficult nature. Surgeons are faced with the three main challenges of visualizing surgical targets, compensating for patient eye movement and surgeon hand tremor, and operating on extremely delicate tissues without tactile feedback. In our work, we consider specifically the location and removal of epiretinal membranes (ERMs), which are ... These are often extremely difficult to discern from healthy retinal tissue, and peeling requires the detection of the ERM edges. Currently, it is common practice to take pre-operative scans of the retina in a grid or NSEW-NE-SE-SW-NW pattern in the region where the ERM is believed to be located, in the hopes that one of these scan paths will cross an ERM edge. While this provides some assistance to the surgeon, the ERM is still difficult to find. Furthermore, the pre-operative scans become outdated if the retinal topology

is changed, for instance if during ERM peeling only part of a membrane is removed.

B Problem Scenario

Recently, microsurgical robotic assistants have been developed to address these challenges. They provide features such as hand tremor cancellation and haptic feedback, as well a live visual feed from a stereomicroscope. The use of intraoperative optical coherence tomography (OCT) imaging is being developed for further intraoperative imaging capabilities. This allows for real-time updated imaging information during the surgical procedure. This has great potential for vitreoretinal surgery, provided surgeons find the microsurgial assistant workstation to be useful.

Our project aimed to assess and improve this "usefulness". To evaluate the usefulness of the existing system, a microsurgical task was developed to simulate the detection of an epiretinal membrane. The degree of success in performing the task was quantified using metrics based on measurements taken during the experiment. Secondly, to improve the usefulness of the system, the OCT probe was processed in various ways to make it easier for surgeons to interpret it.

C Simulated Microsurgical Task

C.1 Approach

The setup consists of an eye phantom mounted on an adjustable platforms, with two probes inserted into it via trocars. One probe is a fixed light source held in a stand, while the other is the probe tool held in the SteadyHand robot. The retina is visualized through the microscope and also displayed in 3D stereovideo.

The experimental task is divided into two segments–intraoperative OCT assisted vs unassisted. In the unassisted segment, ERM edges are located by close inspection of the microscope/stereo image. In the assisted segment, there are additional overlays on the stereo image to display OCT scans, scan paths and correspondences between points on the scan path and sections of the OCT scans. Each segment requires the subject to locate ERMs in

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3 to 5 retinal phantoms. For each phantom, the subject is provided with pre-operative OCT images in a radial pattern along with a fundus image depicting the location of each scan. The subject is given between 2 and 5 minutes with each phantom. The OCT tool tip is used as a pointer to demarcate as much of the ERM edge as possible, using at least 5 points. Further, when a point is selected, it is overlayed on the display with a bounding circle within which no more points may be selected.

To evaluate the participant's success rate at marking out the ERM, a distance metric is computed by calculating the shortest distance from each point to the true ERM edge. Other metrics, such as time taken to mark 5 points, distance travelled while searching for points, etc are also considered. The true location of the membrane is computed by obtaining a C-scan over the area containing the ERM, projecting the 3D image down to get a 2D image, and registering this with the shot containing the subject's marked points using anatomical landmarks, namely the blood vessels.

There were several resources that had to be developed before the experiment could be conducted. To simulate ERM membranes on a retina, several retinal phantoms were made as detailed in Appendix A. For the experiment, the ERMs had to be transparent and non-reflective, such that when the retinal phantom is filled with water the membranes are not obviously visible. There was also a need for a distinct pattern on the retina to act as a fiducial for the registration between the "true" membrane edges and the experimental participants' final screen. Pre-operative OCT scans of the experimental phantoms were also necessary. Furthermore, the registration between the 2D projected image and the displayed image had to be developed.

C.2 Significance

Developing a means to concretely quantify the degree to which a new technology facilitates surgery is relevant for multiple reasons, the most salient of which is the fact it can expedite the technology's transition from laboratory to operating room. This ensures that the public enjoys its benefits sooner. In the particular case of the Intraoperative OCT imaging system, being able to ascertain numerically the degree to which it increases ERM location accuracy and reduces location time can facilitate the system's approval for public usage, and help make vitrioretinal surgeries shorter and more effective.

Additionally, this type of experiment can serve to increase funding for similar technologies, advancing our knowledge and improving surgical technologies for the benefit of all.

D User Interface

This section details the OCT scan processing developed during the course of this project. The main concern dealt with here is that the raw Mscan is not an anatomically correct cross section of the retina along the scan path, which would be helpful to the surgeon. The reasons for this are twofold. First, the Mscan is composed of successsive Ascan images strung together. This means that the sampling of a point on the retina and its resulting representation in the scan depends on the number of Ascans taken there, or the amount of time the OCT tool spends there. In order to obtain an anatomically correct cross section, the OCT tool tip would have to be moved at a constant speed along the scan path, which is unreasonable to expect when using a handheld probe. Secondly, the Mscan is not constrained in the direction normal to the scan surface. As a result, the Mscan may give the impression of an irregular surface when in actuality the probe is imaging from different heights away from the surface.

A second issue concerned the need to discard redundant Ascans from OCT images. This addresses the fact that the OCT probe samples at a very high frequency such that for typical scan paths and scan velocities, the stereocamera resolution cannot distinguish the positions of adjacent Ascans. Furthermore, OCT probes actually oversample the scan path, meaning that a large proportion of Ascans can be discarded.

D.1 Approach

Time-Space Distortion Correction

This method is based on the premise that the width of a section of the OCT image should be proportional to distance travelled by the probe in the trajectory followed while scanning. It makes use of the fact that the imaging probe is tracked via stereo video system, and that the time is an equal variable: the time at which a the probe was located on a point on the imaged trajectory corresponds to a time during which an Ascan was taken

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in the OCT image.
In order to obtain an approximation of an anatomically correct OCT image the trajectory followed by the probe is divided into small segments. The OCT image is partitioned into segments corresponding to the same time interval. For each segment, the segment length (trajectory) to total trajectory length ratio is computed. This ratio is then used to scale the corresponding OCT image segment using image processing tools available in MATLAB.

Redundant Data Removal

The raw Mscan is processed by assuming that spatially adjacent A-scans will contain similar or nearly identical information and will likely be redundant. The first Ascan is selected as a reference and each successive Ascan is compared with the reference by computing a similarity coefficient. Ascans with a similarity coefficient above a threshold are discarded until an Ascan below this threshold is found. This Ascan is added to the set of Ascans that form the reduced image, and it is also updated to be the new reference.

D.2 Results

Time-Space Distortion Correction

The following are theoretical results obtained through randomly generating points and times to corresponding Ascans.

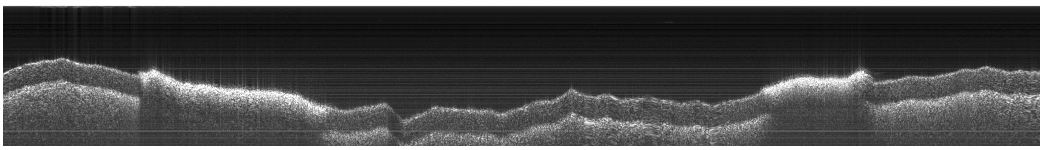

Figure 1: Unprocessed Mscan image

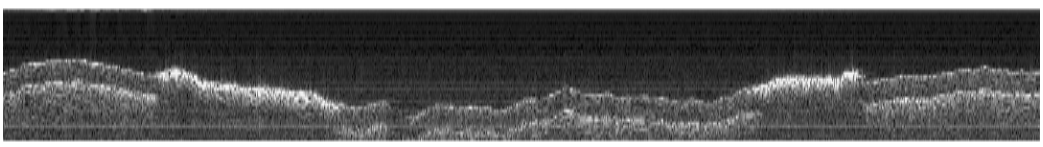

Figure 2: Corrected Mscan image

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This method should prove to be more efficient when the material being scanned is very homogeneous and the similarity coefficient method proves faulty. In the limit as the trajectory segment length gets smaller and smaller, the approximation and the results should improve.

Redundant Data Removal

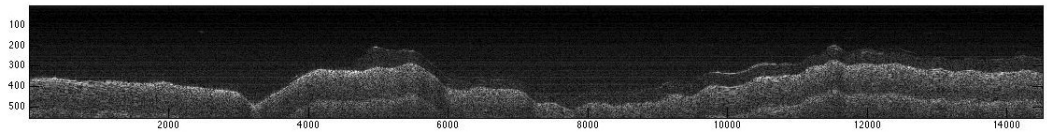

Figure 3: Unprocessed Mscan image

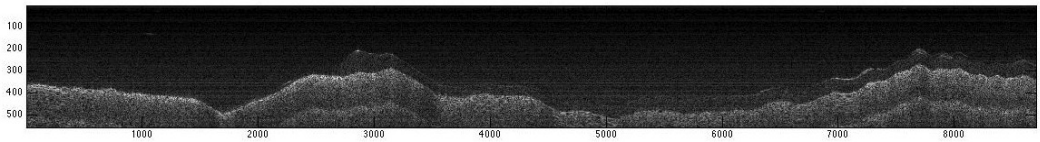

Figure 4: Threshold 0.9

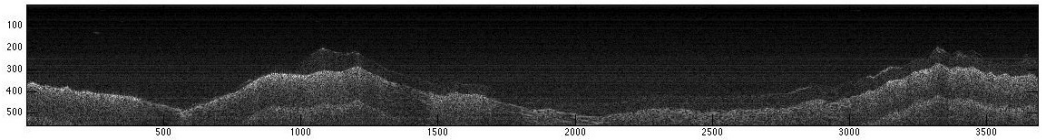

Figure 5: Threshold 0.85

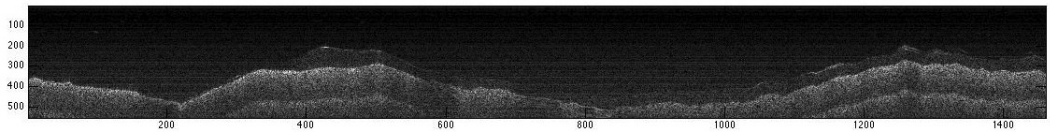

Figure 6: Threshold 0.8

The correlation coefficient algorithm worked well with sample surfaces that were highly to moderately irregular. The processed images were quite

close to the original Mscans but were made of a smaller number of Ascans. In highly uniform regions of the surface, the algorithm mistook the similar adjacent Ascans to be oversamplings of the same point, resulting in over-compressed sections of the image.

D.3 Significance

The time-space distortion correction achieves our aim of producing anatomically correct cross sectional images. This is useful to the surgeon since there is a direct correlation between the distance along a scan path and the distance along the OCT scan. Furthermore, this type of correction allows OCT data to be more easily incorporated into imaging applications. For instance, in generating the 3D cross-section images it can be further assured that the velocity of the robot at different points in the scan do not affect the final image.

The correlation coefficient algorithm can be used for a variety of purposes, including reducing data. Additionally, it could be extended to implement a Z-axis correction. This might be achieved by applying the algorithm to the lower pixels of each A-scan (assumed to be the gradually curving base layers of the surface), shifting the comparison A-scans vertically to find the shift that correlates most with the reference and realigning all the A-scans.

2 Management Summary

A Distribution of Labors

For the bulk of the project, Andrea and Amrita worked together on all aspects of the work. The experimental planning and the manufacture of phantoms was done by Amrita and Andrea, while the robot motion coding, point selection GUI and other developments with the SteadyHand-OCT system were implemented by Marcin. The time-space distortion correction algorithm was discussed jointly between Marcin, Amrita and Andrea, and was implemented by Andrea. The correlation-coefficient based Mscan processing was implemented by Amrita.

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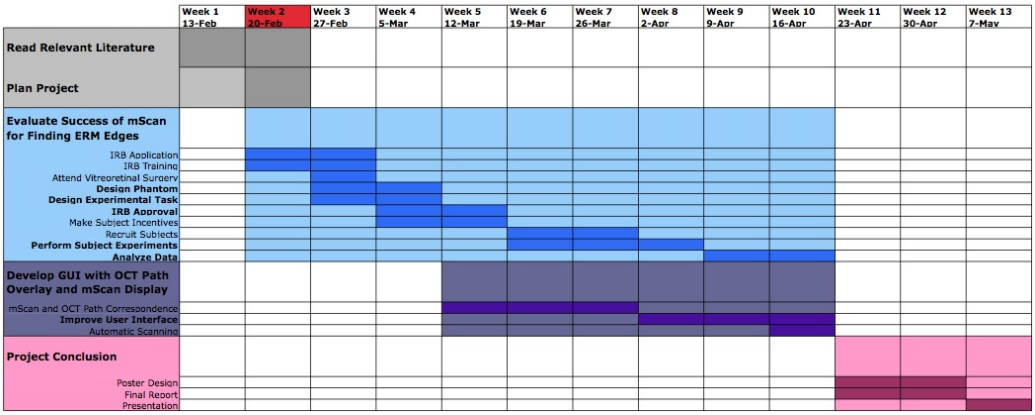

Figure 7: Initial Timeline

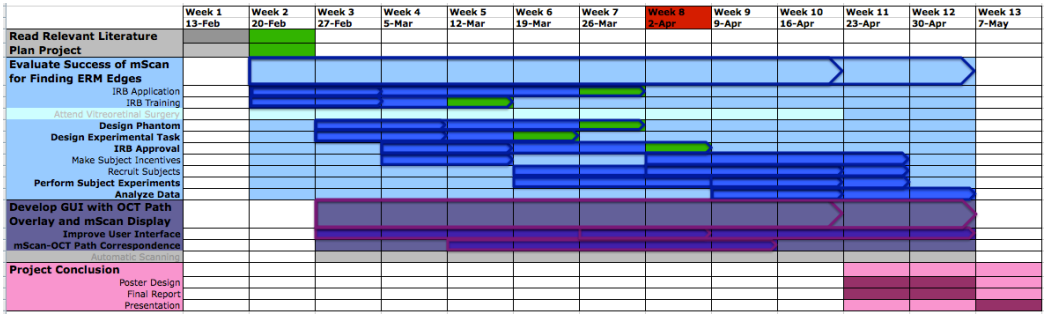

Figure 8: Checkpoint Timeline

B Project Progress

Our main delays at this point were caused by several issues relating to the IRB application. Firstly, it was some time before we achieved a successful phantom retina with ERMs. Since the experimental task designed would depend heavily on the properties of our phantom, this meant that the experimental plan was only finalized once the phantoms were successfully designed. Furthermore, writing the IRB application took longer than anticipated because we were unfamiliar with the format for applying for the Application for Ammendments to the Microsurgical Assistant Workstation project. Dr. Taylor was indispensable to the attainment of IRB approval, after which the second, revised timeline was charted.

Once we were cleared to move forward with subject trials, we met with some more setbacks in arranging the experiment as planned. We needed pre-operative OCT scans of the phantom retinas. Originally we had planned to have these made using the same device used clinically. It took some time to arrange to use this machine, and subsequently the results were not satisfactory for use in the subject trials. Instead, we decided to use the OCT setup in the robotorium to generate our own pre-operative scans. This required the development of new code (by Marcin) to instruct the robot to move the OCT tool in a straight line between two specified points on the retina while remaining at a specified distance from the curved surface. At the conclusion of this course, we are now prepared to manually generate our own pre-operative scans and to proceed to subject trials.

Final Status of Milestones

1. ***Design of micro-surgical task that simulates ERM peeling***
   Planned Date: 3/12/12
   Completion Date: 3/21/12
   Status: Done!

2. ***Working phantom***
   Planned Date: 3/12/12
   Completion Date: 4/1/12
   Status: Done!

3. ***IRB approval***
   Planned Date: 3/19/12
   Completion Date: 4/4/12
   Status: Done!

4. ***Completion of advertisement and incentive for subject recruitment***
   Planned Date: 3/19/12
   Completion Date: 4/11/12
   Status: Done!

5. ***Completion subject trials***
   Planned Date: 4/16/12
   Expected Date:6/25/12
   Status: In progress; to be continued

6. ***Statistical analysis of data from subject trials***
   Planned Date: 4/16/12
   Expected Date:6/30/12
   Status: In progress; to be continued

7. ***OCT enhancements (Color enhancements, GUI improvements)***
   Planned Date: 4/9/12
   Expected Date: 7/15/12
   Status: Not yet begun; relegated to future work

8. ***Implementation of time-space distortion correction***
   Planned Date: 4/9/12
   Completion Date: 5/7/12
   Status: Done!

C Next Steps

As indicated in the above milestones the subject trials will be conducted in the next few weeks and the subsequent statistical analyses will be performed. In particular, the analyses will focus on two aspects of ERM edge detection: accuracy and time. The null hypotheses will propose that the mean distance-error and mean time to outline an edge will be the same for OCT-assisted and unassisted procedures. The alternative hypotheses will propose that the OCT-assisted procedures will have a lower mean distance-error and a lower mean time.
Further enhancements to OCT processing and the user interface could also be developed. These include:

- Z-axis correction in M-scans. This would allow even scans taken with a freehand OCT probe to return a useful cross-section along the scan path. Vertical translations of the tool tip would not result in misleading jumps in the OCT image.

- Calibrating robot safety boundary based on smooth surface trend rather than local surface features. This would prevent the robot from jumping up and down when it encounters sharp irregularities on the surface that should ideally be displayed on the OCT scan.

- Color enhancements to the OCT image to make important features more visible.

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D Lessons Learned

We learned a great deal regarding the planning and execution of subject experiments. We came in with the notion that the planning stages would take place, after which a proposal could be submitted for IRB approval while preparations would be made. However, at all stages of the process there needs to be concurrent development of materials and resources for the experiment. Successes (or failures) in developing hardware, materials, code and functionalities determined what could be done for the experiment. Furthermore, the process of writing a proposal was a learning experience. We had to distill the most important elements of our experimental plan and detail those, while leaving room for minor adjustments and planning alternative solutions to potential setbacks.

3 Appendices

A Phantom Instructions

Retinal Phantom

Both latex base and colored latex paints are required. The latter are mixed to obtain a brownish paint, or color as desired for the retina. A steel ball is attached with hot glue to some surface that allows for convenient dipping, standing and runoff collection.

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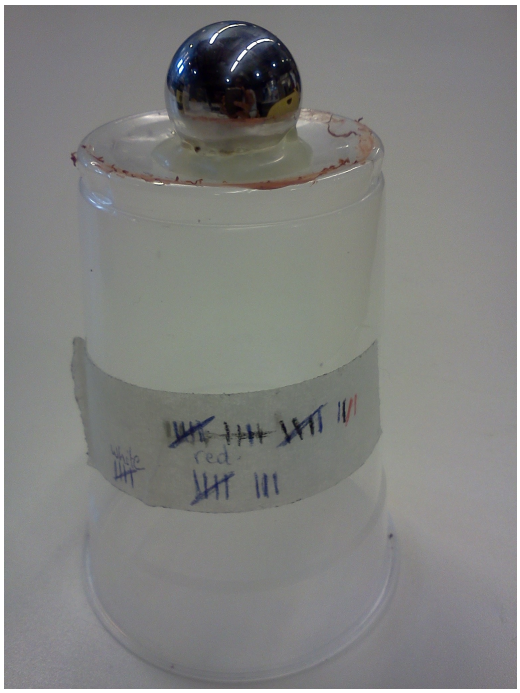

First the ball is dipped into the latex paint base and then allowed to dry over 10 to 15 minutes. Two such layers are done before drawing on the vessels using a fine tipped pen. The drawn on vessels were allowed to dry for 24 hours, then dabbed with tissue paper to avoid ink bleeding in subsequent dippings.



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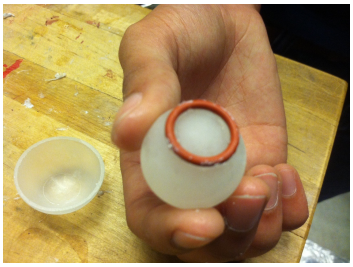
Once the ink is dry, yellow latex paint is dabbed at the top to form a fovea. Once the fovea has dried, a final layer of latex paint base is added. Finally, six layers of colored latex paint are added, once again allowing time for drying between layers. The phantom is peeled off the ball and the inner and outer surfaces are rubbed with a small amount of SORTA-Clear® 18 Part B to prevent sticking. To create the ERMs, the retinal phantom is inverted to expose the vesseled side and a razorblade is used to apply a thin patch of silicone adhesive. The phantom is returned to normal shape, taking care not to smudge the silicone adhesive, and this is allowed to dry for 5 to 10 minutes.

Eyeball Phantom

Silicone adhesive is used to stick an O-ring to a plastic inner ball. In order to ensure that the eyeball phantom is not too thin on the O-ring side, the adhesive layer is applied generously.

Once the adhesive has dried and the O-ring is firmly attached to the plastic inner ball, the other side of the O-ring is once again layered generously with the adhesive. This is then inverted and stuck to the bottom hemisphere of the outer mould.

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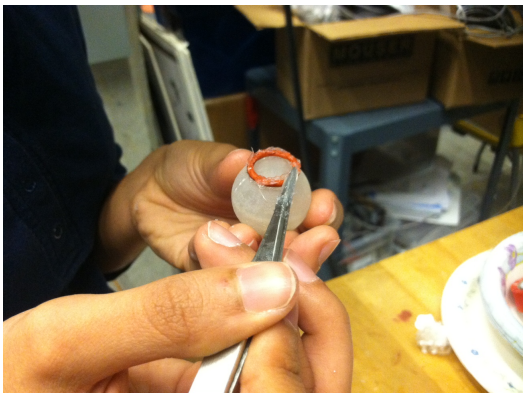


A mixture is made using Smooth-On SORTA-Clear® 18 translucent Silicone Mold Rubber as well as Smooth-On SILC PIG white silicone pigment. Parts A and B of SORTA-Clear are prepared in a 10:1 ratio by weight as per the instructions. Next, a minimal amount of white pigment is added to the SORTA-Clear mixture to obtain a white, viscous paste (described as similar to "marshmallow fluff"). Note that adding too much pigment results in the phantom being too sticky. This mixture is kept in a vacuum for about 5 minutes to reduce bubbles.

The inner surfaces of the two hemispheres of the outer plastic mould are sprayed lightly with Mann Release Technologies Ease Release 200. While we did not incorporate this step in the making of our phantoms, it should enable

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easier removal of the dried phantoms from the moulds. The mixture is then drawn into a syringe and used to fill the bottom hemisphere of the plastic casing, in the spaces between the inner plastic ball and the outer plastic casing. Care is taken to avoid leaving empty bubbles. Next, the top hemisphere of the outer casing is secured in place using tape. The syringe is used to continue filling the empty space in the mould via the hole at the top. This is allowed to dry for 24 hours.

The outer casing is removed and the O-ring carefully removed. The phantom is stretched to removed the inner plastic ball, and finally the O-ring is glued

back in place.

B IRB Materials

JOHNS HOPKINS
U N I V E R S I T Y

Homewood Institutional Review Board
3400 N. Charles Street - AMR2, Rm007
Baltimore MD 21218-2685
410-516-6580 _ http://web.jhu.edu/Homewood-IRB/

Michael McCloskey
Chair

April 3, 2012

Russell Taylor, PhD
Computer Science
Hackerman 127

Re: HIRB No. 2008095 / **Microsurgical Assistant System**

The Homewood IRB has reviewed an amendment to this research project (*to add new experiment, recruitment docs, and questionnaire; revised generic consent for larger study; add new team members Corredor, Gupta & Balicki*), and is satisfied that there is no change to risk status.

IRB approval of the research, including this amendment, is still valid until **4/02/2013**. The research may not continue past this date without re-approval by the IRB. An application for continuing review must be submitted to the Homewood IRB six weeks prior to expiration of the current approval. No changes may be made to the protocol or the consent form without the approval of the Board. Please keep in mind, it is your responsibility to inform the Board of any adverse consequences to subjects that occur in the course of the study.

Please keep a copy of this letter for future reference. Thank you for contacting the Homewood IRB about this research and for providing the requested information to make this determination. Your cooperation is greatly appreciated.

If you have any questions, please do not hesitate to contact the HIRB at (410) 516-6580 or HIRB@jhu.edu.

Homewood IRB

APPROVAL IS GRANTED UNDER THE TERMS OF **FWA00005834** FEDERAL-WIDE ASSURANCE OF COMPLIANCE WITH DHHS REGULATIONS FOR PROTECTION OF HUMAN RESEARCH SUBJECTS

INTRAOPERATIVE OCT MEMBRANE EDGE DETECTION

Instructions for participant

If you agree to participate in this study, you will be asked to do the following:

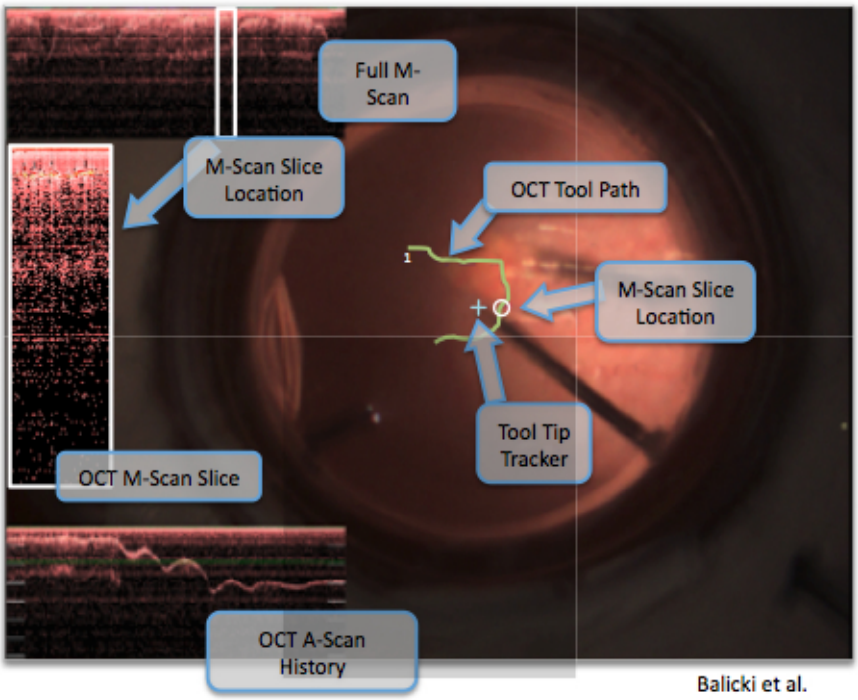
The experiment will be conducted in one session spanning no more than 90 minutes. First, we will explain the procedure of epiretinal membrane (ERM) edge detection and the risks associated with this study. Subsequently, if you agree to participate as a subject, you will be asked to sign the consent form. We will guide you through the experimental task with the aid of a demonstration.

The experiment supervisor will arrange the experimental apparatus beforehand. It will consist of an eye phantom mounted on an adjustable platform. Two probes are inserted into the eye phantom via miniature trocars—one for the light source and the other for the pipette tool. These will be held either freehand or with a steady hand robot, and the operating area can be visualized either through the microscope or on the 3D stereo display.

The experiment will be divided into two segments, separated by a 10 to 15 minute break to minimize learning effects and fatigue. You may also take breaks during the experiment if you feel the need. One segment will use the microsurgical assistant system to detect the ERMs while the other segment will use the conventional method. You may be asked to start with the microsurgical assistant system or with the conventional method.

For each segment, you will be given a series of 3 to 5 phantom eyes in which the retinas have ERMs. You will also be provided with a set of "pre-operative" OCT scans taken in a radial pattern on the retina to provide a sparse map of the retinal topography. This is similar to the traditional surgical approach in which surgeons use pre-operative scans to attempt to identify the most promising areas for investigation in surgery. For each of phantom, you will be given between 2 and 5 minutes to demarcate as much of the ERM edge as you can, using at least 5 points.

Johns Hopkins University IRB Approved HOMEWOOD



In the conventional approach segment, you will be asked to locate ERM edges by looking closely at the surface. When you find an edge, you can press a pedal to mark the point on the visualization system. The point will be surrounded by a circle inside which you will not be allowed to select any more points. For the OCT-assisted segment, your visualization system will include additional overlaid displays data from the OCT probe. You will be able to see a continuous stream of the imaged surface structure at the instantaneous position of the probe. You can command the system to store scans, and you will also be able to display the scan path on the retina, as well as the OCT image collected over that path. Lastly, you will be able to select a slice on the OCT image to display the corresponding point on the highlighted scan path, and vice versa.

Your success at finding ERM membrane structures using the two methods will be compared. For each point you select we will compute the closest distance to the actual location of the membrane, and then calculate the average distance of your points from the true path. A video and audio recording of each attempt will be taken through the microscope—only the tools and phantom eye will be visible. After the experiment is complete, you will be asked to fill out a short questionnaire regarding your experience.

Volunteers Needed to Test Intra-operative OCT Imaging System

We are looking for volunteers to participate in a research study that involves testing an Intraoperative Optical Coherence Tomography imaging system in simulated microsurgical trials.
Participants will be asked to locate simulated epiretinal membranes in
realistic eye phantoms with and without the aid of intraoperative OCT imaging.

Sessions will last no longer than 90 minutes.

Johns Hopkins University IRB Approved 4/03/2012 HOMEWOOD IRB

All participants will have the opportunity to evaluate innovative medical technology

Participants must be JHU or JHMI students or employees and must be at least 18 years of age.
If you are interested in participating, please contact us via email at

oct.erm@jhu.edu

Principal Investigator: Dr. Russell Taylor
JHU Homewood IRB Protocol Number: 2008095

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EMAIL SCRIPT

Subject line: Volunteers Needed to Test Intra-operative OCT Imaging System

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Participants must be JHU or JHMI students or employees and must be at least 18 years of age.

If you are interested in participating, please contact us via email at **oct.erm@jhu.edu**

Principal Investigator: Dr. Russell Taylor

JHU Homewood IRB Protocol Number: 2008095

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Johns Hopkins University
Homewood Institutional Review Board (HIRB)

Informed Consent Form

Title:	**A Microsurgery Assistant System**
Principal Investigator:	Russell H. Taylor, PhD Director, CISST ERC
Date:	3/28/12 12:02 PM

PURPOSE OF RESEARCH STUDY:

The study is designed to investigate the impact of the microsurgical assistant system and its components in improving human performance of microsurgical tasks. Three retinal microsurgery tasks will be used as testbed applications: A) epiretinal membrane peeling; B) internal limiting membrane peeling; and C) retinal vein cannulation. Within these testbeds, subjects may be asked to perform an entire procedure (cannulation, grasping or peeling of a membrane) one or more times using conventional instrumentation and/or using the assistive capabilities of the system.

Subjects also may be asked to perform individual sub-steps of a task or simulated task (identifying targets, placing instruments on targets, grasping or moving tissue or objects, inserting needles, initiating or controlling a tear) multiple times. Broadly, we will perform these kinds of assessment: 1) specific technical metrics associated with particular technology; and 2) measurement of general surgical task performance under various experimental conditions.

This study is funded through NIH award #BRP 1 R01 EB 007969.

HOMEWOOD IRB

PROCEDURES:

If you agree to participate in this study, we will ask you to perform individual sub-steps of a task or simulated task multiple times, as described on the accompanying instruction sheet, both with and without the use of components of our system. We will use the system to acquire video and other sensor data while you perform the procedures and then use statistical methods to assess the effectiveness of our system.

Also, you will be asked to fill out a short questionnaire regarding your experience.

RISKS/DISCOMFORTS:

The risks involved in this study are minimal, since data will be recorded using non-invasive procedures. You will be interacting with microscopes and equipment encountered in conventional retinal surgery. The principal risk is fatigue. We will minimize this risk by i) adjusting your position and the microscope to maximize comfort to the extent possible; ii) limiting the duration of individual test sessions; iii) providing for a rest period between repetition; and iv) permitting you

to pause or terminate the procedure at any time. In addition, the surgical tools used for some procedures may be extremely sharp. Although you will not be asked to touch the sharp parts of the tool, care should be taken in handling them, just as you would any other sharp object.. If you wish to wear latex or latex-free gloves during the procedure, we will provide them to you. Also some of the experimental phantoms in some experiments may include latex material. Although we do not anticipate that you will come into direct contact with the phantoms, you should inform us if you have any latex allergies. This will not preclude you from participating in the study, but in this case, you should wear latex-free gloves.

BENEFITS:

Potential benefits to the subjects and others: There are no direct benefits to you from participating in this study. This study may benefit society if the results lead to a better understanding of ways to improve existing human limitations in microsurgery, promoting better and more consistent outcomes as well as enabling novel surgical interventions that are not currently possible.

Importance of the knowledge to be gained: Testing and evaluation of human performance using the microsurgical surgical assistant technology and systems that are the subjects of this research are essential elements in determining its value in improving surgical performance. Also, this information is an essential element in guiding the development and further improvement of these systems.

Johns Hopkins University
IRB Approved
3/28/2012
Expires

VOLUNTARY PARTICIPATION AND RIGHT TO WITHDRAW:

Your participation in this study is entirely voluntary: You choose whether to participate. If you decide not to participate, there are no penalties, and you will not lose any benefits to which you would otherwise be entitled.

If you choose to participate in the study, you can stop your participation at any time, without any penalty or loss of benefits. If you want to withdraw from the study, please inform the study director or the student coordinator responsible for your testing day.

There may be circumstances under which we would wish to have you come back to repeat part or all of the study. If these circumstances arise we would contact you, and you would be free to agree to return or to decline participation at that time.

CIRCUMSTANCES THAT COULD LEAD US TO END YOUR PARTICIPATION:

Under certain circumstances we may decide to end your participation before you have completed the study. Specifically, we may stop your participation if you are unable to perform the physical requirements of this study. There may also be other circumstances that would lead us to end your participation.

If we end your participation before you have completed the study, we will still provide you with a gift of nominal value, similar to what you would receive if you had completed the study.

CONFIDENTIALITY:

Any study records that identify you will be kept confidential to the extent possible by law. The

records from your participation may be reviewed by people responsible for making sure that research is done properly, including members of the Johns Hopkins University Homewood Institutional Review Board and officials from government agencies such as the National Institutes of Health and the Office for Human Research Protections. (All of these people are required to keep your identity confidential.) Otherwise, records that identify you will be available only to people working on the study and having a need to know your identity, unless you give permission for other people to see the records.

You will be assigned a unique identifier code. Acquired experimental data will be separated from your name and contact information, so that the only linkage between your identification and the acquired data is the assigned identifier code. The only personal data that will be used in data analysis is the experience level of the subject (graduate student year, residency/fellowship year, attending surgeon status, past experience in using robotic equipment, past experience and expertise in microsurgery). Only statistical summaries and otherwise anonymous data (e.g., non-identifiable photographs, audio, or video sequences of procedures) will be published.

Your contact information will be kept should the need arise to contact you in the future. This information will be kept secure on a password-protected workstation or in hard copy in a locked file drawer and will only be available to the Principal Investigator (Dr. Taylor) and his administrative assistants.

Johns Hopkins University IRB Approved 03/2012 Homewood IRB

COMPENSATION:

You will receive a gift of nominal value for participating in this study.

IF YOU HAVE QUESTIONS OR CONCERNS:

You can ask questions about this research study now or at any time during the study, by talking to the researcher(s) working with you or by calling:

Russell Taylor, PhD (JHU School of Engineering) – cell: 443-838-9729; office 410-516-6299

If you have questions about your rights as a research participant or feel that you have not been treated fairly, please call the Homewood Institutional Review Board at Johns Hopkins University at (410) 516-6580.

SIGNATURES

NOT VALID WITHOUT IRB CERTIFICATION STAMP

Do not sign after the expiration date of: 4/02/2013

WHAT YOUR SIGNATURE MEANS:

Your signature below means that you understand the information in this consent form. Your signature also means that you agree to participate in the study.

By signing this consent form, you have not waived any legal rights you otherwise would have as a participant in a research study.

FOR PARTICIPANTS CAPABLE OF GIVING CONSENT:

Participant's Signature **Date**

Signature of Person Obtaining Consent **Date**

Amrita Gupta: agupta48@jhu.edu
Andrea Corredor: acorred1@jhu.edu

C Mscan Time-Space Distortion Correction Code

```
clear;
close all;
%Time interval scaling


%Generate 3D points that are part of the trajectory followed while imaging
%This will likely be changed to reading points off of some file, as each
%point has a time at which it was taken possibly create an object that
%houses both
numPoints = 1000;
upper = [500 500 500];
lower = [-100 -100 -100];
finalT = 100; %Also total time, as this assumes start time = 0
[Points, times] = generatePoints(numPoints,lower,upper,finalT);


%Compute approximate length of imaged trajectory
[total_length,DeltaD] = lengthTrajectory(Points);

%Compute DeltaT
DeltaT = zeros(numPoints-1,1);
for i=1:numPoints-1
   DeltaT(i) = times(i+1) - times(i);
end

%DeltaD contains length invertals
%DeltaT contains time intervals

%Load image
image = imread('MScans2012-03-01_15-37-43-MScanHighRes.png','PNG');

% discard repeated data
image = double(image(:,:,1));

[image_height,image_length] = size(image);
```

Amrita Gupta: agupta48@jhu.edu
Andrea Corredor: acorred1@jhu.edu

```
%Select image fragments
%In this case, randomly partition the image by assigning a column (Ascan)
%to a time (# Ascans > #seconds)

time_ascan = zeros(numPoints,1);
time_ascan(1,1) = 1; time_ascan(numPoints,1) = image_length;
temp = randperm(image_length-1)+1;
time_ascan(2:numPoints-1) = temp(1:numPoints-2);
time_ascan = sort(time_ascan);

Temp = cell(numPoints-1,1);

for i=1:numPoints-1
    scale_factor = DeltaD(i)/total_length;
    J = image(:,time_ascan(i):(time_ascan(i+1)-1));
    Temp{i,1} = imresize(J,[image_height round(scale_factor*image_length)]);
end

CI = cell2mat(Temp');
[~,sizeCI] = size(CI);

%Output altered image
imshow(CI,[])

function [Points, times] = generatePoints(num,lower,upper,ft)
%Generates 3D points that are part of the trajectory followed while imaging
%num - number of points to be generated
%lower - vector with the lower bound in space for all dimensions
%upper - vector with the upper bound in space for all dimensions
%ft - final time, assumes times starts at zero
%Points - matrix with each point a column vector

Points = zeros(3,num);
times = sort(ft*rand(num,1));

%X
Points(1,:) = lower(1) + (upper(1) - lower(1))*rand(num,1);
```

```
%Y
Points(2,:) = lower(2) + (upper(2) - lower(2))*rand(num,1);

%Z
Points(3,:) = lower(3) + (upper(3) - lower(3))*rand(num,1);

end

function [length,DeltaD] = lengthTrajectory(Points)
%Computes the total length of an imaged trajectory by approximating the
%distance between each points as a straight line

[~,num] = size(Points);
Points = Points';
DeltaD = zeros(num-1,1);

for i=1:num-1
     DeltaD(i) = pdist(Points(i:i+1,:));
end

length = sum(DeltaD);

end
```

D Redundant Data Removal Code

```
I = imread('MScans2012-03-01_15-19-09-MScanHighRes.png');

% discard repeated data
I = double(I(:,:,1));

mu = mean(I,1);
stdev = std(I,0,1);
I_rel = I - ones(size(I))*diag(mu);

threshold = 0.85; %some random value%
Aref = I_rel(:,1); nref = 1; nscans = 1;
```

```
Astore = zeros(size(I)); Astore(:,1) = I(:,1);

for n = 1:length(I_rel(1,:))
    Acomp = I_rel(:,n);
    sigref = stdev(nref);
    sigcomp = stdev(n);

    rho = dot(Acomp,Aref)/(length(Aref)*sigref*sigcomp);
    if rho > threshold
        % do nothing
    else
        nscans = nscans + 1;
        Astore(:,nscans) = I(:,n);
        Aref = Acomp;
        nref = n;
    end
end

figure; image(Astore(:,1:nscans)); colormap(gray(256));
```

E References

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