Group 5 Project Proposal
Prototype of a Micro-Surgical Tool Tracker

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1 Project Summary

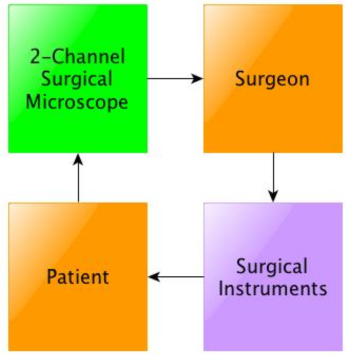
Computer and robot assisted eye surgery has great potential to address common problems encountered in many eye surgery tasks including poor visualization, lack of force sensing, hand tremor, and accessibility. Positional feedback of the instruments relative to the eye can be used to prevent undesirable collisions, improve remote center of motion interaction, and possibly automate tasks like insertion of instruments into trocars. The goal of this project is to create a prototype of a device that provides real-time 3D tracking of the eye and instruments relative to each other during surgical procedures.

2 Relevance and Importance

The current state-of-the-art techniques for ophthalmic surgery involve a surgeon looking through a 2-channel surgical microscope and using surgical instruments (see Figure 1). However, there are some obvious disadvantages to this method. The surgery is not very precise, accurate or stable. Also, the surgeons natural hand tremor has the potential to damage eye tissue and cause cataracts [3]. And since the microscope provides an amplified view of the eye, it narrows the surgeons field of view. This can lead to poor decision-making and poor interpretation of the qualitative data [3]. Finally, there is a lack of information provided to the operating room staff that is present to support the surgeon. According to a study conducted in 2009, ophthalmic surgery has the highest rate of incorrect procedures within the operating room [1].

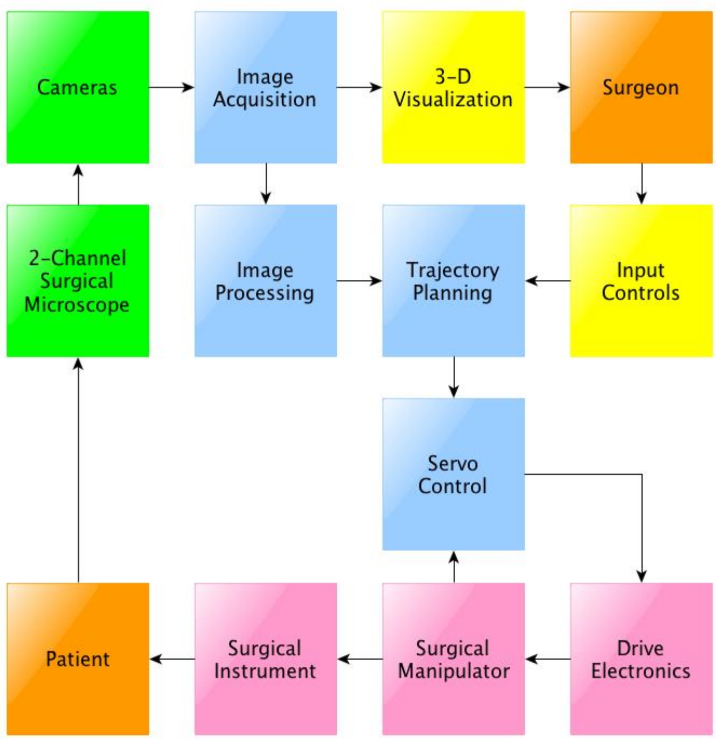
Researchers have turned their attention to integrating robotics for use in surgical methods. This has a more complicated process (see Figure 2). Robot-assisted surgery has increased precision, accuracy, and stability, and is capable of reducing hand tremor. Furthermore certain processes can me automated, and the surgeon does not have to be in the

Figure 1: Block diagram of current ophthalmic surgery [3].



same room as the patient when utilizing teleoperation. However, there are some limitations that prevent this from use in clinical practice. Most notably, robot-assisted surgery has not resolved the problem of surgeons making poor decisions and interpreting the qualitative data poorly. It is also expensive to buy and maintain robots, there arent many robots available, there is a possibility of robot malfunctions, and gaining patient trust can be difficult.

Figure 2: Block diagram of robot-assisted surgery [3].



With the aid of an optical tracker that provides positional feedback, it is possible to improve the surgeons decision-making and interpretation of data. One suggestion for an optical tracking system is to attach a camera to the surgeons microscope. This approach cannot account for obfuscation due to equipment and surgeons hands, can interfere with the function of the microscope, and provides suboptimal resolution due to the distance from the surgical site and approach angle. Other solutions rely on the magnetic field, which can be affected by metal in the surgical field, and also has suboptimal accuracy for microsurgical applications.

Instead, we propose an alternative optical tracking system that can be placed around the patient's eye without interfering the necessary intraocular surgical procedures. The system provides surgeons with positional feedback of instruments in relation to the eye. Specifically, tool position is desirable to ensure iso-centric rotation of instruments into the trocars, automate insertions of instruments into the trocars, prevent unintentional collisions with other instruments and anatomy, and prevent excessive stress on the sclera. Our aims are to provide the following:

- Integrate a tracking system architecture with the mask placed directly on the patient
- Combine multiple imaging for tracking tools
- Provide visual feedback (a 3-D display) to the surgeon
- Utilize redundancy to reduce line-of-sight problems
- Utilize fiducial markers on tools for identification
- Evaluate tracking accuracy of a static tool
- Evaluate tracking accuracy of a dynamic tool
- Evaluate tracking accuracy under varying illumination and occlusion

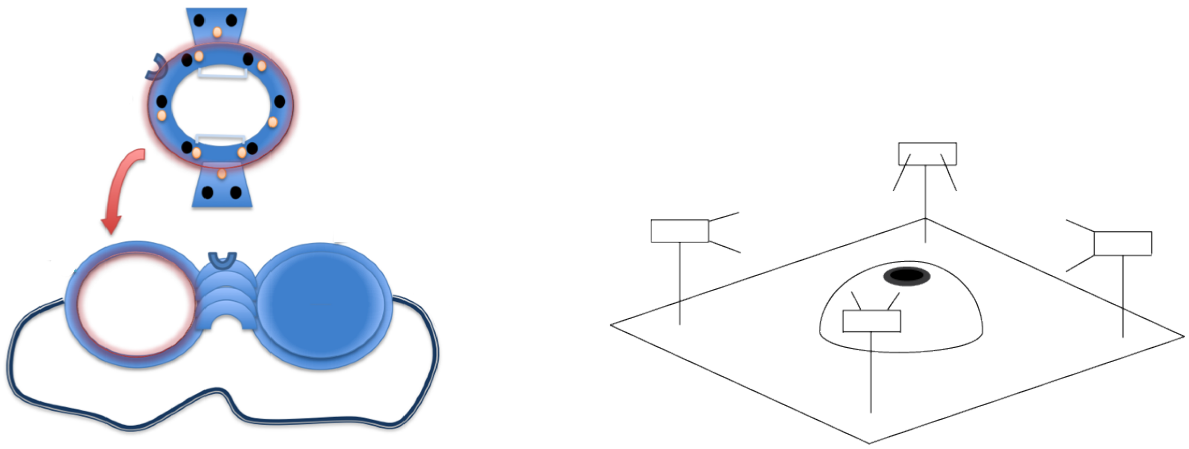
Ultimately, this system will help monitor surgical protocols, assess surgical skill, and improve safety of ophthalmic procedures. For example, lubricant must be added to the eye during eye surgery to keep the eye moist. Utilizing an optical tracker, the system could check that the gel is added every four minutes. The tracking system could also be modified to identify incompatible tools and provide warnings to the surgeon. Furthermore, there is a way to identify the best movements for eye surgery. By assessing and improving surgical skill, this optical tracker has the potential to increase the efficiency of surgeons. Finally, collision warnings could be implemented to prevent surgeons from damaging eye tissue and hitting the lens, which can cause cataracts. This goggle device could also be adapted for other microsurgeries, such as for cochlear implantation.

3 Technical Approach

Phase One: Research

First, an evaluation of the clinical eye surgery environment will be conducted through hospital visits, videos of ophthalmic surgeries, and a survey of literature in order to determine device constraints on orientation and position of the equipment. Once the constraints for our prototype are approved, we will evaluate current off-the-shelf RGB and infrared cameras to optimize focal length, field of view, camera synchronization, shutter speed, resolution, and cost. Separately, we will research standard multi-camera calibration methods, segmentation methods, tracking algorithms and necessary equipment for different camera systems. This information will be used to design the tracking system pipeline and three tests to confirm successful implementation. In parallel, we will determine the number and type of markers to be placed on tools for easy tracking. At the end of this phase, we will have a layout of the device and the tracking system design. A conceptual diagram of the prototype is shown in Figure 3A.

Figure 3: A) Conceptual design of prototype. B) Initial prototype design.



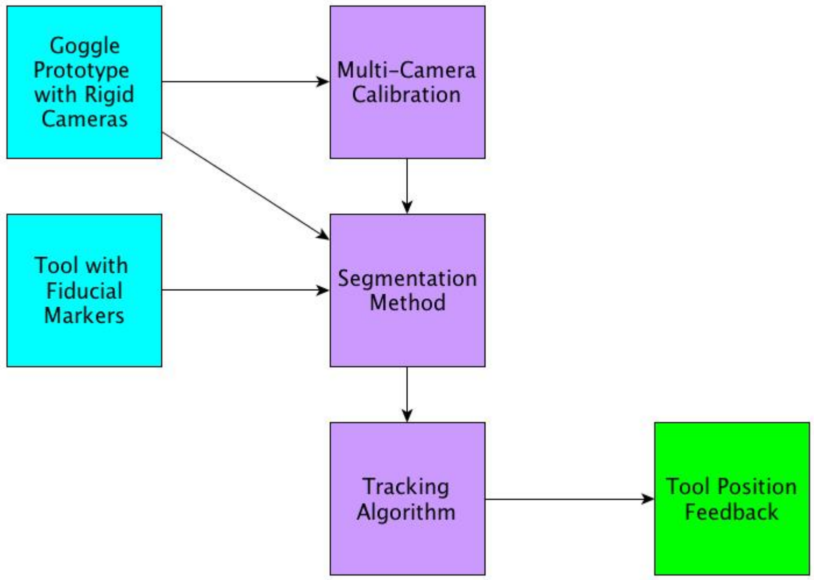
Phase Two: Design and Build

Taking into account the capabilities of the cameras, we will design a scaled blueprint of the face. This will be used to create a simple model of the eye with rigidly attached cameras for our initial prototype shown in Figure 3B. Later, the skull and nose will be added to the phantom so that the final device may rest on the bridge of the nose. Separately, we will implement multi-camera calibration and design a mini-test to confirm success. Specifically, we will prepare one tool with appropriate fiducial markers, and use the initial prototype to perform an offline multi-camera calibration test. Next, utilize computer aided design to design the goggle prototype to hold the cameras and any other features. Once the design is approved, we will rapid prototype the goggles and attach it to the phantom. At the same time, implement segmentation and tracking algorithms. Test the validity of the implementations using tests designed in the previous phase. The complete microsurgical tracker will follow the system described in Figure 4.

Phase Three: Evaluation

In order to evaluate the success of our prototype, we will design a simple experiment to test the accuracy of our tracking system for a stationary tool, as well as to measure the accuracy of a tool in motion. We will also look into tracking accuracy with respect to varied camera occlusion and illumination. The static tool and varied illumination and occlusion tests will be run. If time permits, we will bring the system online and track a tool in real time.

Figure 4: Block Diagram of Micro-Surgical Tracker System.



4 Deliverables

Minimum Planned Completion: 3/18

- CAD of the prototype
- Blueprint of phantom
- Specifications for the cameras, light sources, and other equipment
- Calibration scheme
- Segmentation and tracking scheme

Expected Planned Completion: 4/26

- A scaled (2-3 times larger than life) prototype of the device
- A scaled (2-3 times larger than life) phantom
- Complete model with fiducial trackers, cameras, device, and phantom
- Successful offline multi-camera calibration
- Successful offline segmentation and tracking algorithm

Maximum Planned Completion: 5/14

- Life-size prototype
- Life-size phantom
- Successful real-time segmentation and tracking algorithm
- Evaluation of static tracking accuracy
- Evaluation of dynamic tracking accuracy
- Evaluation of accuracy under varying circumstances such as occlusion and lighting
- Generate tracking confidence based on coverage and correlation of features

5 Milestones

Date	Milestones	Responsibility
3/11	Offline Tracking System Design (Sue)	-Calibration Scheme -Segmentation Scheme -Tracking Scheme
3/18	Design of Prototype and Phantom (Yejin)	-Conceptual design of Eye and Face -CAD of the prototype
4/1	Build Phantom (Yejin)	-Build and attach eye to platform -Build and attach skull and nose to platform
4/1	Calibration Implementation (Sue)	-Implement single camera/multi camera calibration -Run test to verify success
4/8	Prototype of Device (Yejin)	-Rapid prototype goggle device -Rigidly attach cameras -Attach miscellaneous fixtures
4/15	Test of Segmentation (Sue)	-Implement Segmentation Method -Run test to verify success
4/29	Test of Tracking Implementation (Sue)	-Implement tracking algorithm -Run test to verify success
5/13	Evaluation of Micro-Surgical Tracker (Yejin)	-Static tool coordinate accuracy -Dynamic tool coordinate accuracy -Miscellaneous accuracy

See attached gantt chart for a more detailed list of key dates and assigned responsibilities.

6 Dependencies

The consequences of not resolving these dependencies typically result in a delay in the original plan, which is described in Gantt chart. Specifically, without observing ophthalmic surgery, the design of the prototype may be less ideal. Without the mentor's expertise, implementing a tracking system for our prototype will take longer. Particularly, the expertise from Balazs Vagvolgyi is important to utilize CISST and other off-the-shell libraries. Furthermore, without the access to a Steady Hand Eye Robot, we will not be able to perform an evaluation of our final device. This robot is essential for obtaining the exact position of an object, which can then be compared to the positional feedback from the tracking system. Moreover, if the materials purchased are not compatible with each other, our schedule will be postponed to reconsider equipment options and purchase new materials. If the equipment, particularly the cameras, are delivered late, the development of the prototype will also be delayed. The calibration of the cameras and testing of the implementation depends upon the initial prototype being set up. Finally, if the budget is not approved by Dr. Taylor and we do not receive funding, our options for equipment for the device will be very limited. Look at Figure 5 for proposed solutions and key dates.

Figure 5: Table of project dependencies.

Dependency	Proposed Solution	Due Date	Consequence
Ophthalmic Surgery Observation	Schedule through Marcin Balicki Acquire videos online	2/25 3/4	Less ideal prototype design
Access to Expertise	Weekly mentor meetings Survey literature	2/14 3/11	Longer time to implement program
CISST Libraries	Training with Balazs Vagvolgyi If not, custom libraries as needed	3/4	Cannot use the library
Other Off-the-shelf Libraries	Research and plan accordingly Back-up plan: Implement on our own	3/11	Cannot use the library
Access to Steady Hand Eye Robot	Get initial plan approved Schedule through Marcin Balicki	3/11 4/8	Cannot perform accurate evaluation
Equipment	Evaluate constraints Purchase off-the-shelf components (OTC)	3/4 3/11	Postpone the calibration and the test of the implementation
Funding	Propose budget plan to Dr. Taylor	3/4	Project equipment is limited

7 Management Plan

We have made plans to meet weekly with either Marcin Balicki or Balazs Vagvolgyi. Bi-weekly team meetings have been scheduled Monday and Wednesday evenings. We will spend approximately 30 hours per week on this project. Yejin Kim is in charge of prototype development and funding. Sue Kulason is in charge of the tracking system, wiki-page, and communication.

References

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Computer Integrated Surgery II: Surgical Tool Tracking Prototype

Feb 12, 2013

Gantt Chart

Name	Begin date	End date
Project Proposal	2/11/13	2/17/13
Determine Seminar Topic	2/11/13	2/17/13
Phase 1	2/19/13	3/12/13
Research Multi-Camera Calibration	2/19/13	2/24/13
Research Segmentation Methods	2/25/13	3/3/13
Research Tracking Algorithm	2/25/13	3/3/13
Create Off-line Calibration to Tracking	3/4/13	3/10/13
Determine Constraints on Prototype	2/19/13	2/24/13
Determine Optimal Equipment	2/25/13	3/3/13
Write Budget Proposal	2/25/13	3/3/13
Order Equipment and Supplies for Phant...	3/4/13	3/12/13
Create Blueprint of Anatomy (Eye and Fa...	3/4/13	3/10/13
Seminar Presentation	3/11/13	3/11/13
Checkpoint Presentation	3/31/13	3/31/13
Milestone 1: Off-line Tracking System Pipeli...	3/11/13	3/11/13
Milestone 2: Prototype and Phantom Design	3/15/13	3/15/13
Phase 2	3/11/13	5/5/13
Implement Calibration Scheme	3/11/13	3/16/13
Build Phantom Eye (part of initial prototy...	3/11/13	3/16/13
Adjust Calibration Scheme as needed	3/24/13	3/30/13
Complete Initial Prototype (attach camer...	3/25/13	3/31/13
Run Implementtion Tests	4/1/13	4/7/13
Implement Segmentation Scheme	4/8/13	4/21/13
Run Segmentation Tests	4/8/13	4/14/13
Adjust Segmentation Scheme as needed	4/8/13	4/14/13
Implment Tracking Scheme	4/22/13	5/5/13
Run Tracking Tests	4/22/13	4/28/13
Adjust Tracking Scheme as needed	4/22/13	4/28/13
Conceptualize Final Prototype	3/11/13	3/16/13
CAD of Final Prototype	3/25/13	4/7/13
Build Phantom of Face	3/24/13	3/30/13
Rapid Prototype	4/8/13	4/14/13
Adjust CAD	4/15/13	4/21/13
Finalize Device	4/15/13	4/21/13
Design Evaluation Experiments	4/22/13	4/28/13
Add any extra features to prototype	4/22/13	4/28/13
Milestone 3: Successful Test of Calibration I...	4/1/13	4/1/13
Milestone 4: Prototype of Device	4/8/13	4/8/13
Phase 3	4/29/13	5/12/13
Put system online	4/29/13	5/5/13
Run static tests	4/29/13	5/5/13
Run dynamic tests	5/6/13	5/12/13
Compile Results	5/6/13	5/12/13
Milestone 5: Successful Test of Segmentation...	4/15/13	4/15/13
Milestone 6: Successful Test of Tracking Imp...	4/29/13	4/29/13
Milestone 7: Evaluation of Micro-Surgical Tra...	5/13/13	5/13/13
Final Report	5/13/13	5/13/13
Poster Presentation	5/13/13	5/13/13