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

According to a study conducted in 2009, ophthalmic surgery have the highest rate of incorrect procedures within the operating room than any other surgical specialty [1]. These common surgeries often utilize techniques such as robot-assisted instruments and optical tracking, which have dramatically improved accuracy in the past decade. However, the success of ophthalmic surgeries with these state-of-the-art techniques is limited. Surgeons currently rely on microscopes that amplify the scale of the eye and limit field of view, which can lead to misinterpretation of qualitative data and undesirable collision that can damage the eye [3]. As such, researchers have turned their attention to integrate robotics in surgical methods. Progress in the field of ophthalmic surgery has been slowed by the lack of an optical system that can track eye surgery in an accurate and unobtrusive fashion. Traditional optical tracking systems that attach to a surgeon's microscope cannot account for obfuscation due to equipment and surgeons' hands, interfere with the function of the microscope, may interfere with the function of the microscope, and have 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 has suboptimal accuracy for microsurgical applications.

We propose an alternative to the standard optical tracking system that can be placed around the 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 and range-finding technologies 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 and estimating distance
- A device that sits directly on the anatomy
- A device that does not rely on the magnetic field
- Evaluate tracking accuracy of a static tool
- Evaluate tracking accuracy of a dynamic tool
- Evaluate tracking accuracy under varying illumination and occlusion

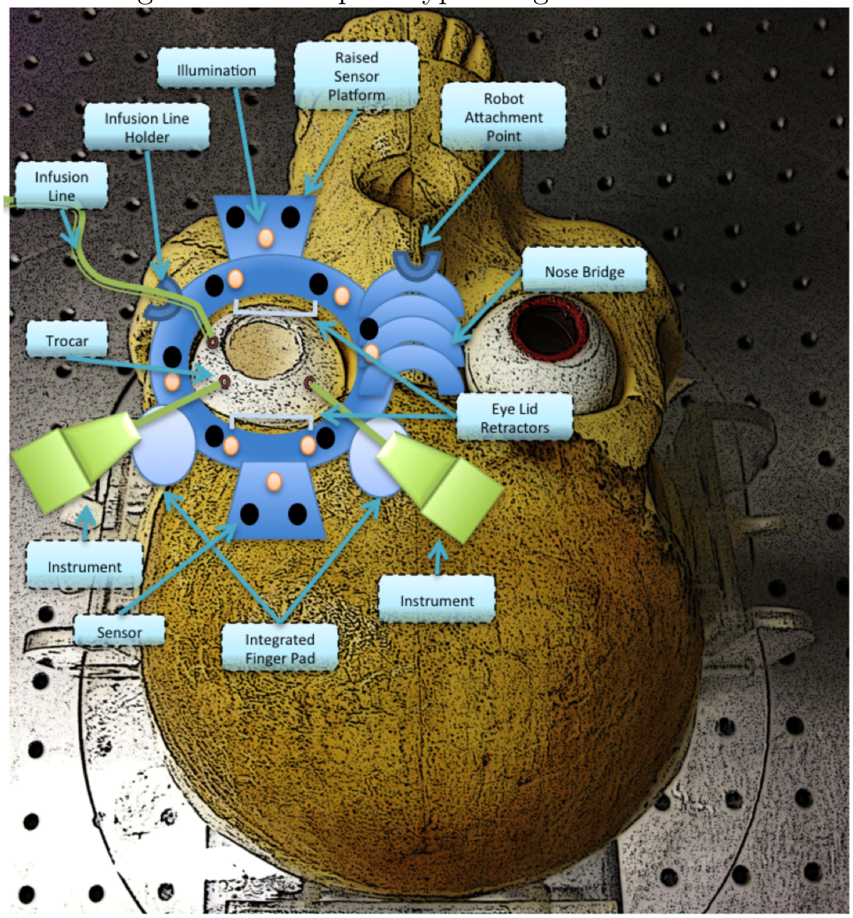
Ultimately, the system is expected to ensure safety and provide higher care to patients by minimizing any tissue damages, shortening the duration of a surgery, and increasing the efficiency for the surgeon. With this technology, the tracking system can be expanded for use in surgical skill assessment, give real-time visualization of the eye environment for staff, provide warnings of possible tool collisions with lens and other structures, and alert the surgeon of incompatible tools. It can also be used to monitor surgical protocols for timely, accurate sequences. For example, when Geniosol must be applied every 4 minutes. Furthermore, the device structure can be modified to adapt to other anatomical features, such as for cochlear implantation.

3 Technical Approach

Phase One: Research

First, an evaluation of clinical eye-surgery environments will be conducted through hospital visits, videos of ophthalmic surgeries, and a survey of literature 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, and cost. Separately, we will research standard multi-camera calibration methods and necessary equipment for different camera systems. Next, we will determine the number and type of markers to be placed on tools for easy tracking. An initial diagram of the prototype is shown in Figure 1.

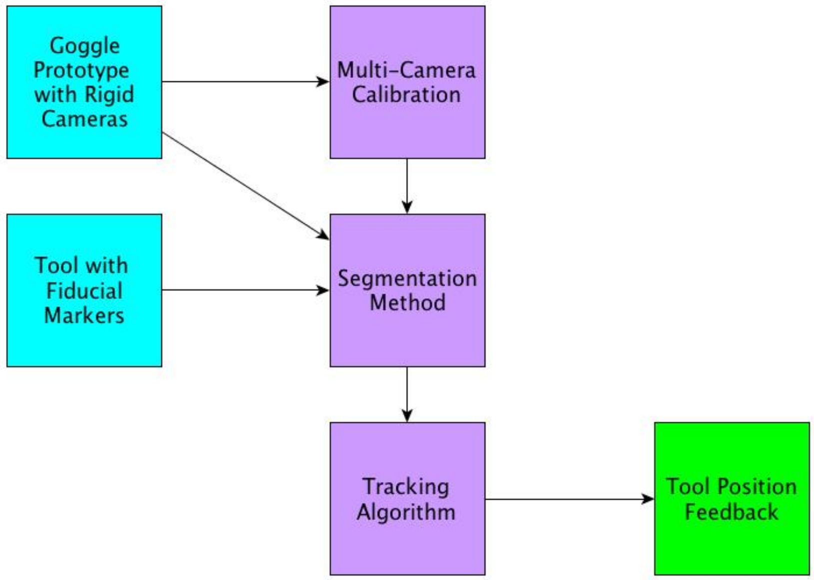
Figure 1: Initial prototype design of the device.



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. 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, research and implement segmentation and tracking algorithms. Design a mini-test to confirm coordinates of an object can be obtained accurately offline. The complete micro-surgical tracker will follow the system described in Figure 2. If time permits, we will bring the system online and track a tool in real time.

Figure 2: Block Diagram of Micro-Surgical Tracker System.



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. If time permits, we will also look into tracking accuracy with respect to varied camera occlusion and illumination.

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

Offline Tracking System Pipeline due 3/11

- Calibration Scheme
- Segmentation Scheme
- Tracking Scheme

Design of Prototype and Phantom due 3/18

- Blueprint of Eye and Face
- Computer Aided Design of Goggles

Build Phantom due 4/1

- Build and Attach Eye to Grid
- Build and Attach Skull and Nose to Grid

Test of Calibration Implementation due 4/1

- Implement Single Camera Calibration
- Implement Multi-Camera Calibration
- Run test to Verify Success

Prototype of Device due 4/8

- Rapid Prototype Goggle Device
- Rigidly Attach Cameras
- Attach Miscellaneous Fixtures

Test of Segmentation Implementation due 4/15

- Implement Segmentation Method
- Run Test to Verify Success

Test of Tracking Implementation due 4/29

- Implement Tracking Algorithm
- Run Test to Verify Success

Evaluation of Micro-Surgical Tracker due 5/13

- Static Tool Coordinate Accuracy
- Dynamic Tool Coordinate Accuracy
- Miscellaneous Accuracy (Illumination, Obfuscation)

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

6 Dependencies

Dependency	**Proposed Solution**	**Due Date**
Ophthalmic Surgery Observation	Schedule through Marcin Balicki Acquire videos online	2/25 3/4
Funding	Propose budget plan to Dr. Taylor	3/4
Access to Expertise	Weekly mentor meetings Survey literature	2/14 3/4
Camera System	Evaluate constraints Purchase off-the-shelf parts	3/4 3/11
CISST Libraries	Training through Balazs Vagvolgyi	3/4
Other Libraries	Research and plan accordingly	3/11
Eye and Skull Phantom	Build	4/8
Access to Steady Hand Eye Robot	Get initial plan approved Schedule through Marcin Balicki	3/11 4/8

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