

**Title:** 3D Tool Tracking in the Presence of Microscope Motion

**Topic:** Tool Tremor, Camera Stabilization, Tool Tracking

**Goal:** The goal of this project is to measure ground truth tool tremor data, develop a computer vision algorithm to track the tool tip and compute tool tremor from stereo video.

**Team:** Molly O'Brien

**Mentors:** Austin Reiter, Russ Taylor

**Relevance/ Importance:**

Tool tracking is important in the operating room and the in the laboratory. Accurate tool tracking is required to enforce safety barriers in microsurgery. Microsurgery is challenging because surgeons need to navigate through and operate on delicate, critical structures. An example of a challenging microsurgery is a mastoidectomy where the surgeon drills out part of the bone behind the ear. Mastoidectomies are performed to clear out diseased tissue or get access to the inner ear. In mastoidectomies, the surgeon needs to drill within 1mm of the facial nerve. If the facial nerve is cut, half of the patient's face is paralyzed for life. To make microsurgical procedures safer, my lab wants to introduce surgical robots that enforce safety barriers with respect to the patient to keep the robot from damaging critical structures. To achieve this, the robot's position with respect to the patient must be known with submillimeter accuracy. Existing tracking systems can track patient and robot motion with 1.5mm-3mm accuracy; this is unacceptable in microsurgery [1]. To solve this problem, I propose tracking the tool relative to the patient using the stereo microscope. A challenge with visual tool tracking is that the microscope moves during the video. To accurately track the tool motion in the world, I need to track the tool motion seen through the video and the camera motion.

Accurate tool tracking is also relevant in the lab. A major advantage of surgical robots is that they reduce hand tremor. My lab is interested in quantifying robot tool tremor and comparing it to human tool tremor to assess how much a robot can improve surgical manipulation. To assess tool tremor, I need to accurately record tool motion of hand-held and robot-held tools and perform frequency analysis on the motion.

**Technical Approach**

There are four technical components of this project:

- 1) Record ground truth data
- 2) Compute microscope motion
- 3) Find tool tip in image
- 4) Motion analysis

Record ground truth data:

First I will record optical tracking data and stereo microscope video of hand-held and robot-held tool motion. The optical tracking data will be my ground truth tremor data. Later in the project I will test my computer vision tracking algorithm on the microscope data and compare my results with the ground truth data. To record the optical tracking data, I will set up

an optical tracking system available in the lab and attach a marker to a surgical tool. I will record hand-held and robot-held motion data. The microscope video will show suturing of a chicken phantom held in a custom holder. This holder will be stationary during the video and have easily detected feature points. The feature points will be used to compute camera motion.

### Compute Microscope Motion

I will compute the rigid transformation of the camera from frame to frame in the microscope video. The camera transformations will be used to remove the effect of camera motion from the tool motion. Each frame in the microscope video will consist of a stereo image pair. The fiducial points on the chicken holder will be detected in the stereo images and used as the feature points. I will calibrate the microscope and use the calibration results to triangulate the 3D location in camera coordinates of the feature points. Since the points detected in each frame are from a rigid object, there should be a rigid transformation that relates the 3D point clouds generated from two frames. I will use ICP to find the best rigid transformation between background points in consecutive frames. The rigid transformation between two frames gives the camera motion between the frames. Applying the inverse of the camera motion transformation to points triangulated from the microscope video will remove the effect of camera motion.

### Tool Tracking

The goal of the tool tracking algorithm is to triangulate the 3D tool tip position in each video frame. First I will detect the tool tip in the left and right images of each stereo pair. Then I will triangulate the 3D tool tip position for each frame of the video. To detect the tool tip in each image I plan on implementing an algorithm like [2]. In [2] Allen et al. do color segmentation on input images to find the tool shaft. Next, they find the tool contours, and then search along the tool to find the tip. I will experiment with the tool segmentation to find a good tool mask in our setup with our surgical tool.

After the tool tip has been found in the individual images I will use the detected locations in each stereo pair to triangulate a 3D tool tip position. This will generate a 3D tool tip location in each video frame. The camera motion found between frames will be used to transform the detected tool tips into the coordinate frame of the first image:

${}^m t_n$  : the tool tip detected in frame  $n$ , in coordinates of frame  $m$

${}^N t_N$  : the tool tip detected in frame  $N$ , in coordinates of frame  $N$   
(results of feature point triangulation)

${}^{m-1} F_m$  : the camera motion transformation between frame  $m - 1$  and  $m$

$${}^0 t_N = {}^0 F_1 * {}^1 F_2 * \dots * {}^{N-1} F_N * {}^N t_N$$

This will remove the effect of camera motion from the tool motion.

### Motion Analysis

Once the tool tip positions are in the same coordinate frame I will perform the Fast Fourier Transform (FFT) on the tool trajectory. The FFT will show what frequencies of motion are present in the tool motion. Lower frequencies will show deliberate movement and higher frequencies will show the tool tremor. I will perform frequency analysis on the optical tracking

data and the tracking results from my microscope tracking algorithm. I expect that small errors in the tool tip detection in the microscope images will introduce some high frequency error in the motion frequencies detected. I will explore if there exists some filter  $H(\omega)$  that extracts the ground truth tool motion frequencies from the frequencies detected from the microscope video.

**Deliverables:**

Min

- A system capable of measuring tool movement (using existing optical tracking system)
- Optical tracking data of hand-held and robot-held motion
- Frequency results from tracked tool movement (using existing optical tracking system)
- An algorithm to triangulate 3D points from stereo video and track background motion (with fiducial points)

Expected

- A tool tracking algorithm using microscope video as the input
- Frequency analysis of the tool tip motion detected from a microscope video

Max

- An algorithm to extract ground truth tool tip motion and tremor from microscope video tracking results
- Comparison of hand-held and robot-held tool tremor

**Schedule:**

| Date  | Milestone  | Outcome for each step:  |
|-------|--|---|
| 03/15 | <b>Record Ground Truth Data</b><br><i>Minimum Deliverable</i>  | <ul style="list-style-type: none"> <li>• Recorded OT data</li> <li>• Microscope video</li> <li>• Frequency analysis of OT data</li> </ul>                                     |
| 02/22 | Pick optical tracking system   | <ul style="list-style-type: none"> <li>• System selected</li> <li>• System located in lab</li> <li>• Someone identified to train me to use it</li> </ul>                      |
| 03/08 | Add markers to tool  | <ul style="list-style-type: none"> <li>• Tool selected</li> <li>• Marker selected</li> <li>• Permission obtained to modify tool</li> <li>• Marker attached to tool</li> </ul> |
| 03/10 | Set up system  | <ul style="list-style-type: none"> <li>• Location selected</li> <li>• OT system set up in lab</li> <li>• Plan for experiment setup</li> </ul>                                 |
| 03/10 | Record tracking data and microscope video with <ul style="list-style-type: none"> <li>• Hand-held tool motion</li> <li>• Robot-held tool motion</li> </ul> | <ul style="list-style-type: none"> <li>• Access to robot for experiment obtained</li> <li>• Optical tracking data</li> <li>• Microscope video</li> </ul>                      |
| 03/15 | Frequency analysis of optical tracking data  | <ul style="list-style-type: none"> <li>• Motion magnitude at each frequency</li> </ul>  |

|       |  |   |
|-------|--|---|
| 03/01 | <b>Compute Background Motion</b><br><i>Minimum Deliverable</i>               | <ul style="list-style-type: none"> <li>Algorithm to triangulate 3D points from stereo image pair</li> <li>Algorithm to find 3D rigid transformation between stereo image pair</li> </ul>                                |
| 02/17 | Triangulate background 3D points   | <ul style="list-style-type: none"> <li>Algorithm to triangulate 3D points from stereo image pair</li> </ul>   |
| 03/01 | Compute camera rigid transformation between frames                           | <ul style="list-style-type: none"> <li>Algorithm to find 3D rigid transformation between stereo image pair</li> </ul>   |
| 05/03 | <b>Implement Video Tracking Algorithm</b><br><i>Expected Deliverable</i>     | <ul style="list-style-type: none"> <li>Algorithm to detect tool tip in image</li> </ul>   |
| 03/29 | Color Segmentation   | <ul style="list-style-type: none"> <li>Binary map with tool shaft as white, the rest of the image black</li> </ul>  |
| 04/12 | Extract tool connected component, tool contours                              | <ul style="list-style-type: none"> <li>Binary map with tool shaft as one white connected component, the rest of the image black</li> <li>Equations for lines along tool shaft in image</li> </ul>                       |
| 04/26 | Compute tool tip location  | <ul style="list-style-type: none"> <li>Pixel location of tool tip</li> </ul>  |
| 05/03 | Frequency analysis of video tracking data                                    | <ul style="list-style-type: none"> <li>Frequency analysis of microscope tracking data</li> </ul>  |
| 05/12 | <b>Frequency Investigation</b><br><i>Maximum Deliverable</i>                 | <ul style="list-style-type: none"> <li>A filter to extract ground truth tool tremor results from microscope tracking results</li> <li>Discussion of difference between robot-held and hand-held tool motion.</li> </ul> |
| 05/05 | Compare tracking frequency results from optical tracker and video tracking   | <ul style="list-style-type: none"> <li>A filter to extract ground truth tool tremor results from microscope tracking results</li> </ul>   |
| 05/12 | Compare tracking frequency results from hand-held and robot-held tool motion | <ul style="list-style-type: none"> <li>Discussion of difference between robot-held and hand-held tool motion.</li> </ul>  |

*Schedule Discussion:*

The schedule listed above is an aggressive plan. I may run into the following delays during this project:

- Recording ground truth data: There may be a time conflict using robot or trouble getting the optical system set up and working. If this happens I can simply record the ground truth data later than planned. The camera and tool tracking steps do not rely on the optical tracking or the specific video content. This will not push back the other steps in my schedule.
- Tool tip tracking: I may have trouble with the technical implementation of the tool tip tracking. If this happens my contingency plan is to paint the tool tip and track the color more easily in the microscope.

**Dependencies :**

| <b>Dependency</b>   | <b>Resolution Plan</b>  | <b>Status</b>      |
|---|---|--------------------|
| Access to microscope and video capture computer                                   | I will coordinate with Dr. Taylor and lab.  | <i>Resolved</i>    |
| Chicken holding phantom   | Enlist other members of the lab to help me. Abinav and Olivia have volunteered to help. We will meet this week to discuss the project.                      | <i>In progress</i> |
| Access to robot   | Determine when robot will be needed. Coordinate with Dr. Taylor and lab.  | <i>Pending</i>     |
| Access to tools   | Coordinate with Dr. Taylor and lab. Obtain permission to add an optical marker to a tool.   | <i>Pending</i>     |
| Access to optical tracking system. Help from Dr. Kazanzides or Paul to use system | Coordinate with Dr. Taylor and lab. Contact Dr. Kazanzides or Paul Wilkening. (Paul will be setting up the Atracsys OT System shortly for another project.) | <i>Pending</i>     |

**Management Plan:**

During the semester I will have weekly meetings with Dr. Taylor and Dr. Reiter.

**Reading List:**

- Camera motion calc
  - S. Leonard, A. Reiter, A. Sinha, M. Ishii, R. Taylor, and G. Hager, “Image-Based Navigation for Functional Endoscopic Sinus Surgery Using Structure From Motion,” in *SPIE*, San Diego, 2016.
- Tool tracking
  - B. Allen, F. Kasper, G. Nataneli, E. Dutson, and P. Faloutos, “Visual Tracking of Laparoscopic Instruments in Standard Training Environments,” in *MMVR*, Newport Beach 2011.
  - R. Sznitman, K. Ali, R. Richa, R. Taylor, G. Hager, and P. Fua, “Data-driven visual tracking in retinal microsurgery. In Medical Image Computing and Computer-Assisted Intervention,” in *MICCAI*, Nice 2012.
  - Loubna Bouarfa, Oytun Akman, Armin Schneider, Pieter P. Jonker and Jenny Dankelman (2012) In-vivo real-time tracking of surgical instruments in endoscopic video, *Minimally Invasive Therapy & Allied Technologies*, 21:3, 129-134, DOI: 10.3109/13645706.2011.580764
  - W. Zhao, C. Hasser, W. Nowlin, and B. Hoffman, “Methods and systems for robotic instrument tool tracking with adaptive fusion of kinematics information and image information,” U.S. Patent 8108072 B2, Jan 31, 2012.

- A. Cano, F. Gaya, P. Lamata, P. Sanchez-Gonzalez, and E. Gomez, "Laparoscopic Tool Tracking Method for Augmented Reality Surgical Applications," in *LNCS*, vol. 5104, pp. 191-196, 2008.

**References:**

- [1] P. Grunert, K. Darabi, J. Espinosa, and R. Filippi, "Computer-aided navigation in neurosurgery," *Neurosurgical Review*, vol. 26, no. 2, pp. 73-99, 2003.
- [2] B. Allen, F. Kasper, G. Nataneli, E. Dutson, and P. Faloutos, "Visual Tracking of Laparoscopic Instruments in Standard Training Environments," in *MMVR*, Newport Beach 2011.