3D Tool Tracking in the Presence of Microscope Motion

Team:

Molly O'Brien

PhD Student

mobrie38@jhu.edu

Mentors:

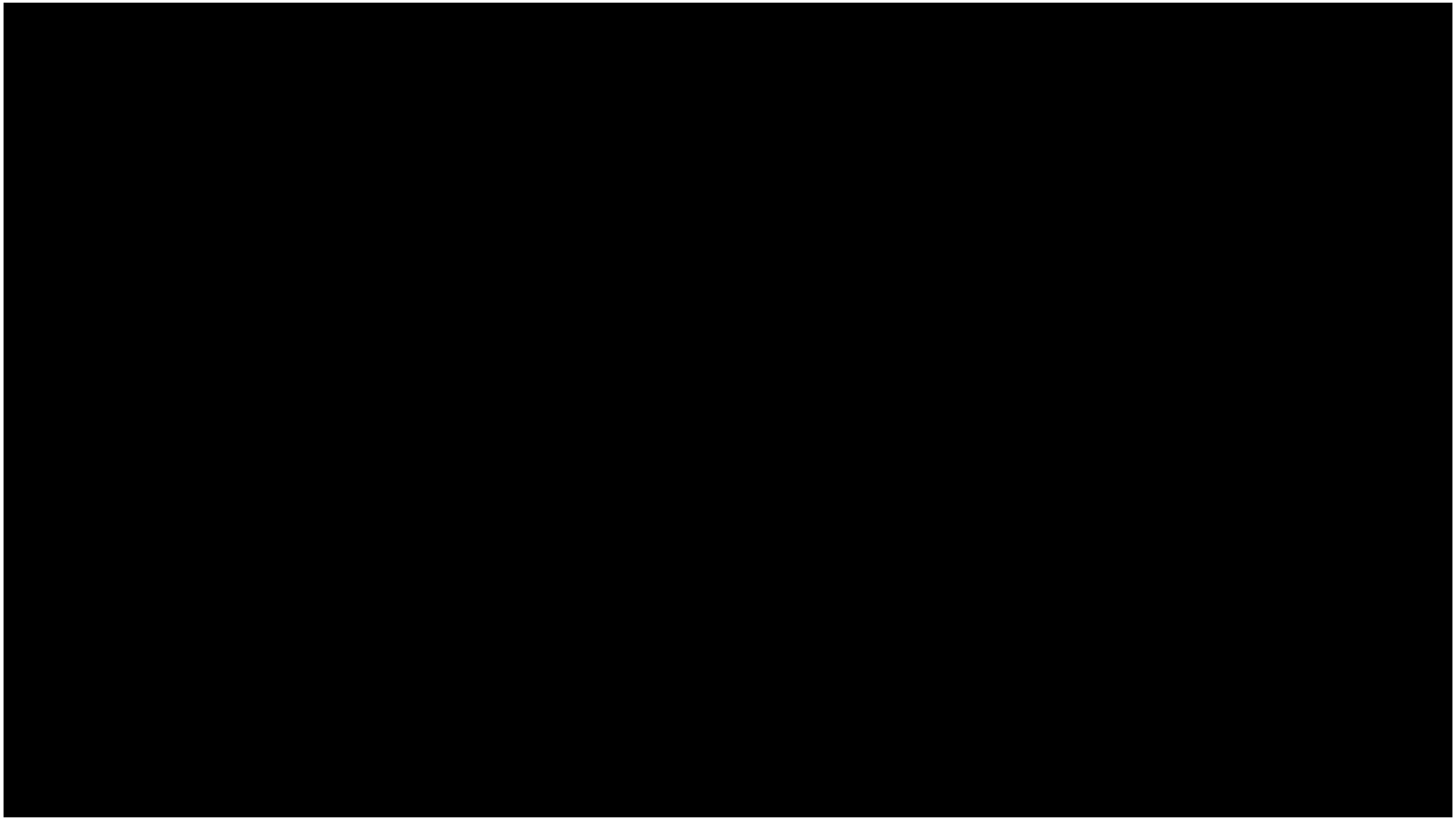
Dr. Austin Reiter,

Dr. Russell Taylor

JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

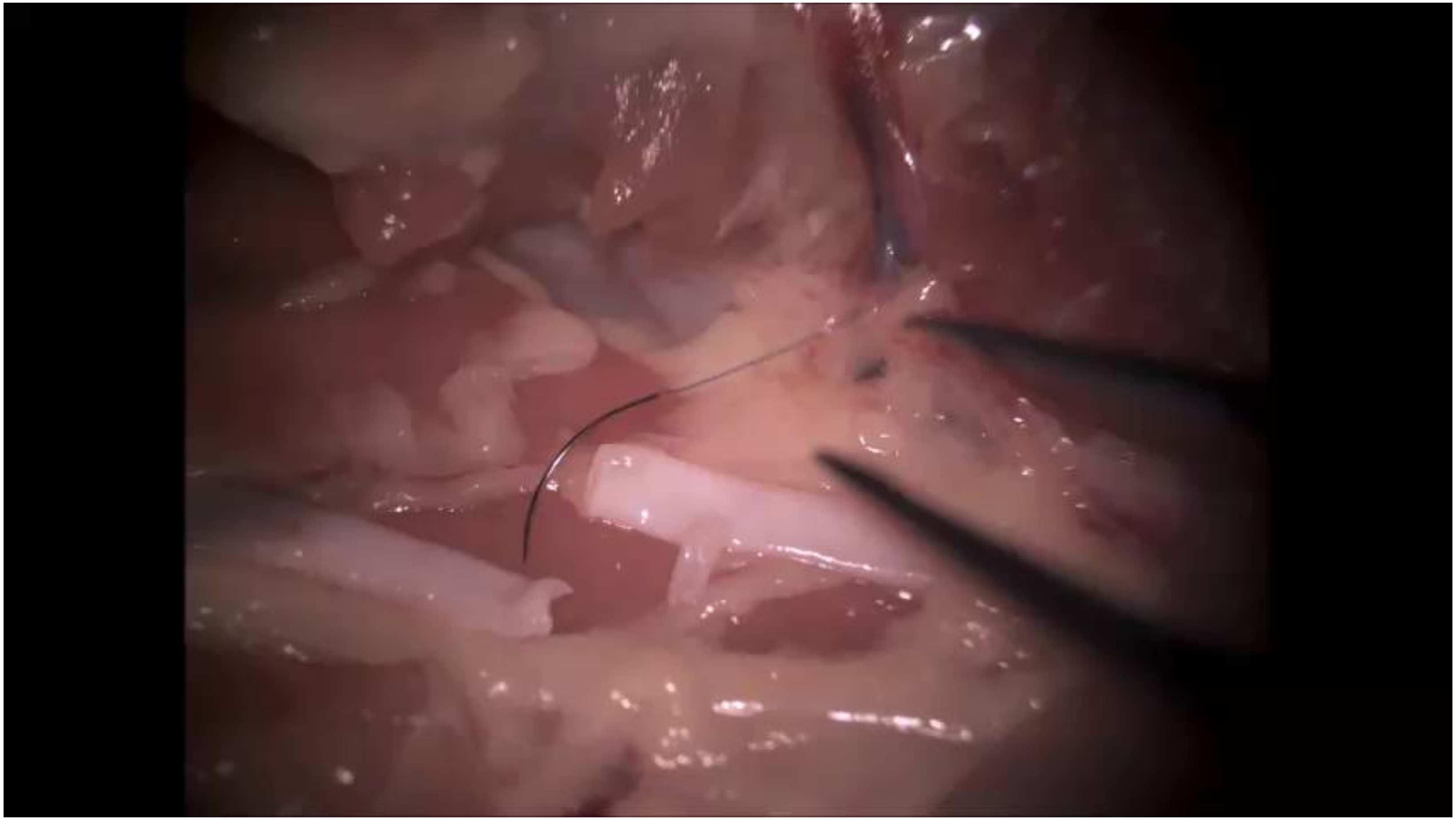
Clinical Motivation: In the operating room

Mastoidectomy: a microsurgical procedure



https://www.youtube.com/watch?v=HXTEFoFJ9iA&t=617s

Clinical Motivation: In the lab



Proposed Solution

Implement Optical Tool Tracking

- Attach optical marker to tool
- Record stereo video of tool
- Compute marker position
- Perform frequency analysis of tool motion

Camera Motion Tracking

- Extract background feature points from left and right frame
- Stereo matching
- Triangulate background 3D point cloud
- Perform ICP to find 3D camera motion between frames

Video Tool Tracking

- Implement tool tracking
- Frequency analysis
- Test against ground truth results

Motion Analysis

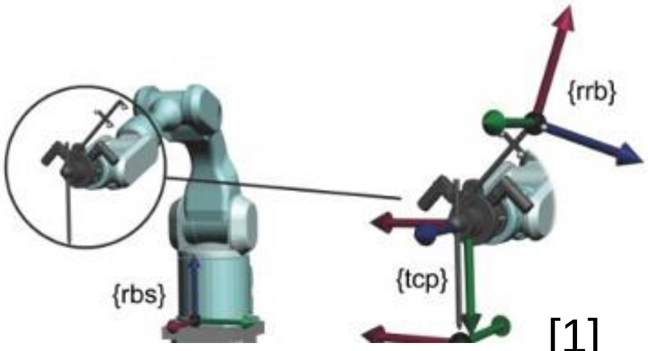
- Compare frequency analysis from optical tool tracking and video tool tracking-> Can ground truth tremor be recovered from imperfect video tracking?
- Compare frequency analysis of hand-held tools and robot-held tools

Technical Approach

Implement Optical Tool Tracking

- Attach optical marker to tool
- Record stereo video of tool
- Compute marker position
- Perform frequency analysis of tool motion

- Existing technology
- Get ground truth tool tracking data



[1]

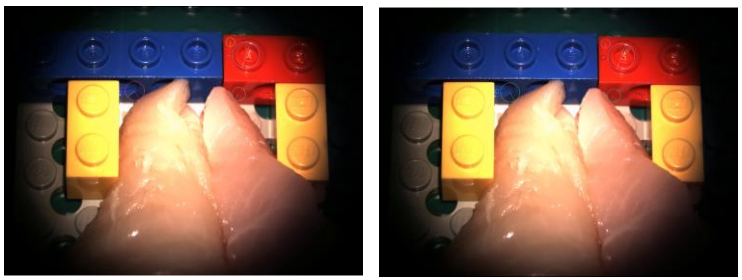
Technical Approach

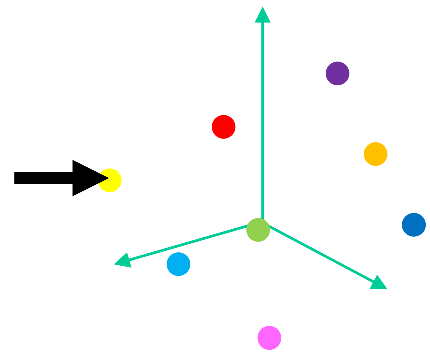
Camera Motion Tracking

- Extract background feature points from left and right frame
- Stereo matching
- Triangulate background 3D point cloud
- Perform ICP to find 3D camera motion between frames

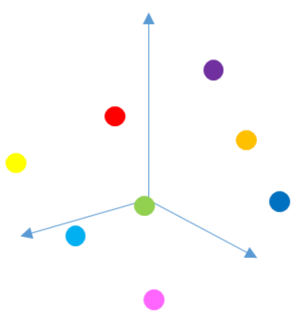
For each video frame

Stereo Image Pair

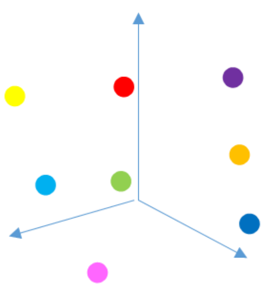




3D fiducial point locations

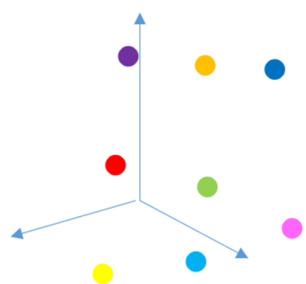


Frame 1



Frame 2

...



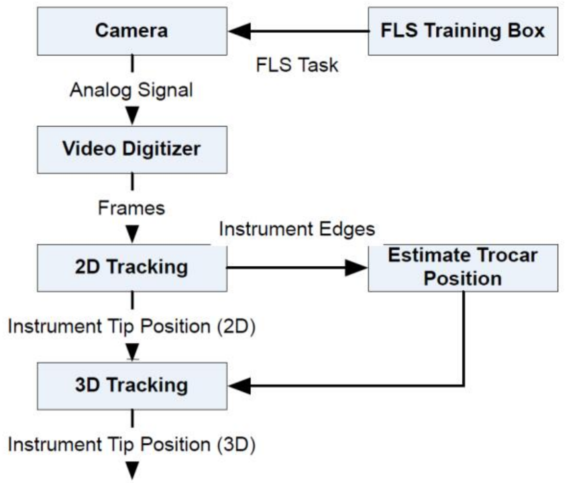
Frame N

ICP: Compute fiducial transformation between each frame → 3D Microscope Motion between each frame

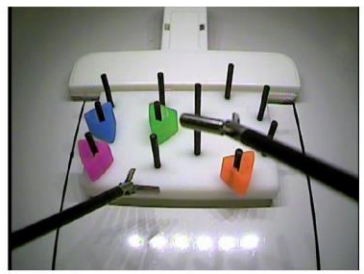
Technical Approach

Video Tool Tracking

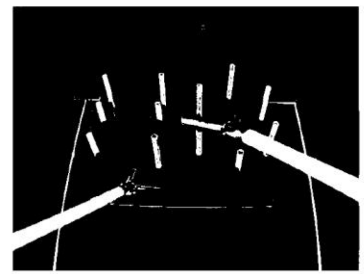
- Implement tool tracking
- Frequency analysis
- Test against ground truth results



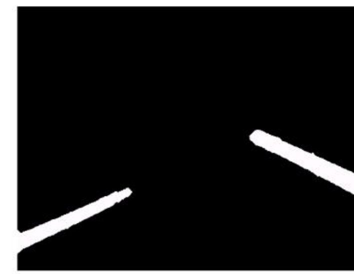
(a) Overview of the process showing data flow.



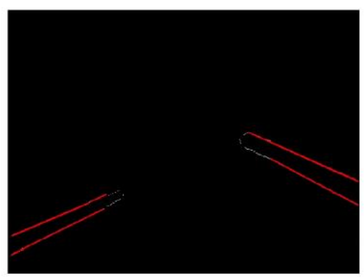
(a) Unmodified frame from the FLS camera during a training task.



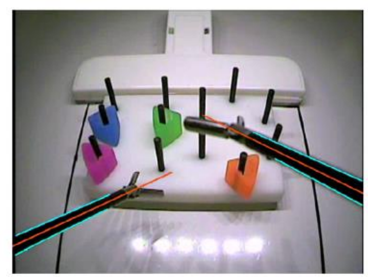
(b) Binary probability map of black regions.



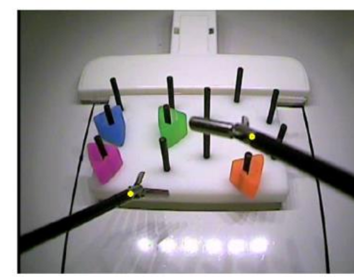
(c) Binary mask with isolated instruments.



(d) Extracted lateral contours of instruments.



(e) Instrument direction estimated using line-fitting.



(f) Tracked position in 2D.

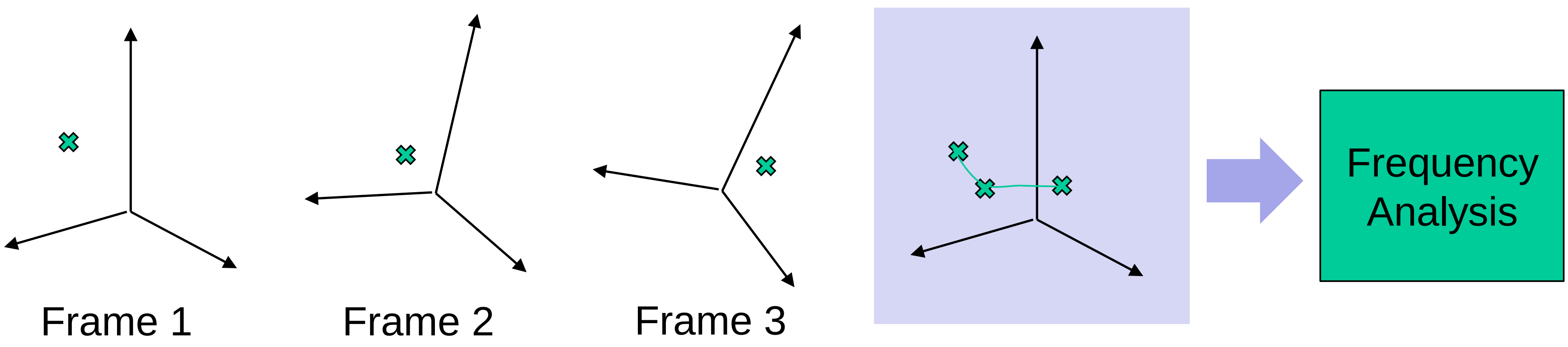
[2] B. Allen, F. Kasper, G. Nataneli, E. Dutson, and P. Faloutos, "Visual Tracking of Laparoscopic Instruments in Standard Training Environments," in *MMVR,* Newport Beach 2011.

Technical Approach

Motion Analysis

- Compare frequency analysis from optical tool tracking and video tool tracking-> Can ground truth tremor be recovered from imperfect video tracking?
- Compare frequency analysis of hand-held tools and robot-held tools

Tool tip detections:



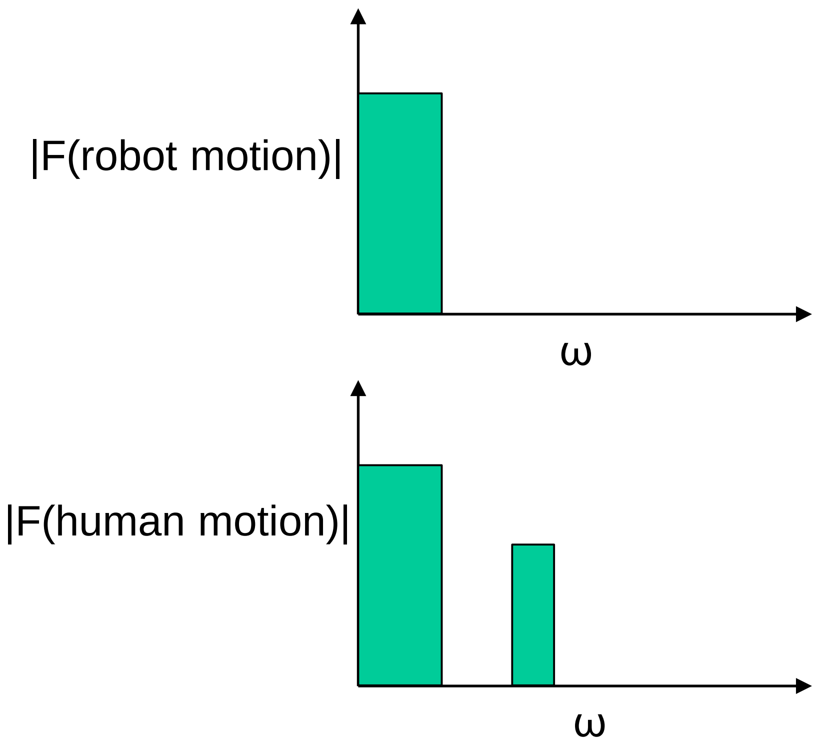
Tool tip positions in one coordinate frame

Technical Approach

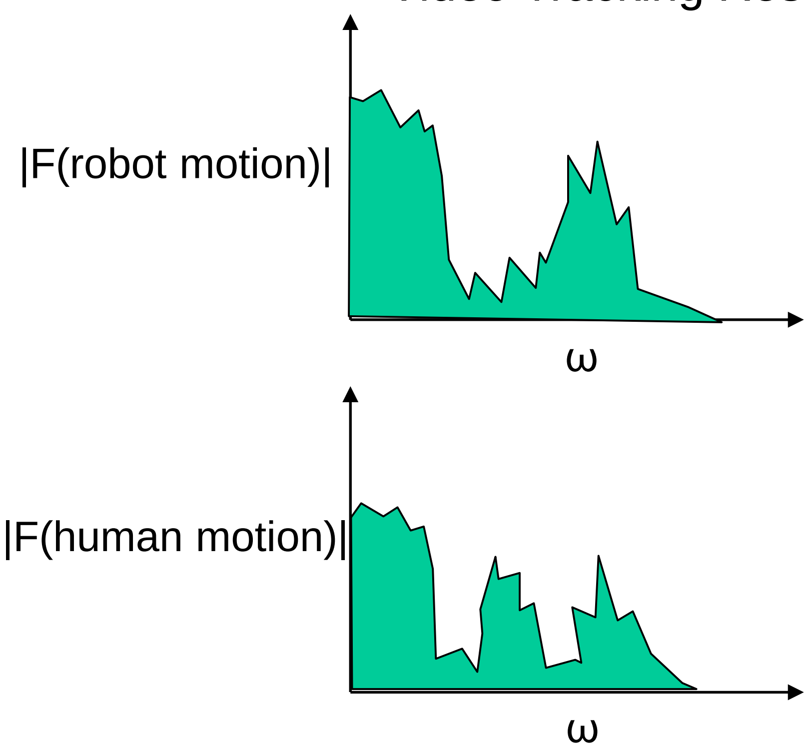
Motion Analysis

- Compare frequency analysis from optical tool tracking and video tool tracking-> Can ground truth tremor be recovered from imperfect video tracking?
- Compare frequency analysis of hand-held tools and robot-held tools

Ground Truth Results



Video Tracking Results



Deliverables

Deliverables	
Min	A system capable of measuring tool movement (using existing tracking system)
	Frequency results from tracked tool movement (using existing tracking system)
	Algorithm to triangulate 3D points from stereo video and track background motion (with fiducial points)
Expected	Tool tracking algorithm using microscope video
	Frequency analysis of the tool tip motion from a stereo video
Max	Algorithm to get accurate tool tip motion and tremor from microscope video
	Comparison of hand-held and robot-held tool tremor

Dependencies

Dependency	Proposed Solution	Status
Access to microscope and video capture computer	Coordinate with Dr. Taylor and lab	*Resolved*
Chicken holding phantom	Enlist other members of the lab to help me	*In progress*
Access to robot	Determine when robot will be needed. Coordinate with Dr. Taylor and lab	*Pending*
Access to tools	Coordinate with Dr. Taylor and lab	*Resolved*
Access to optical tracking system	Coordinate with Dr. Taylor and lab	*Pending*

Management Plan

Weekly meetings with Dr. Taylor and Dr. Reiter

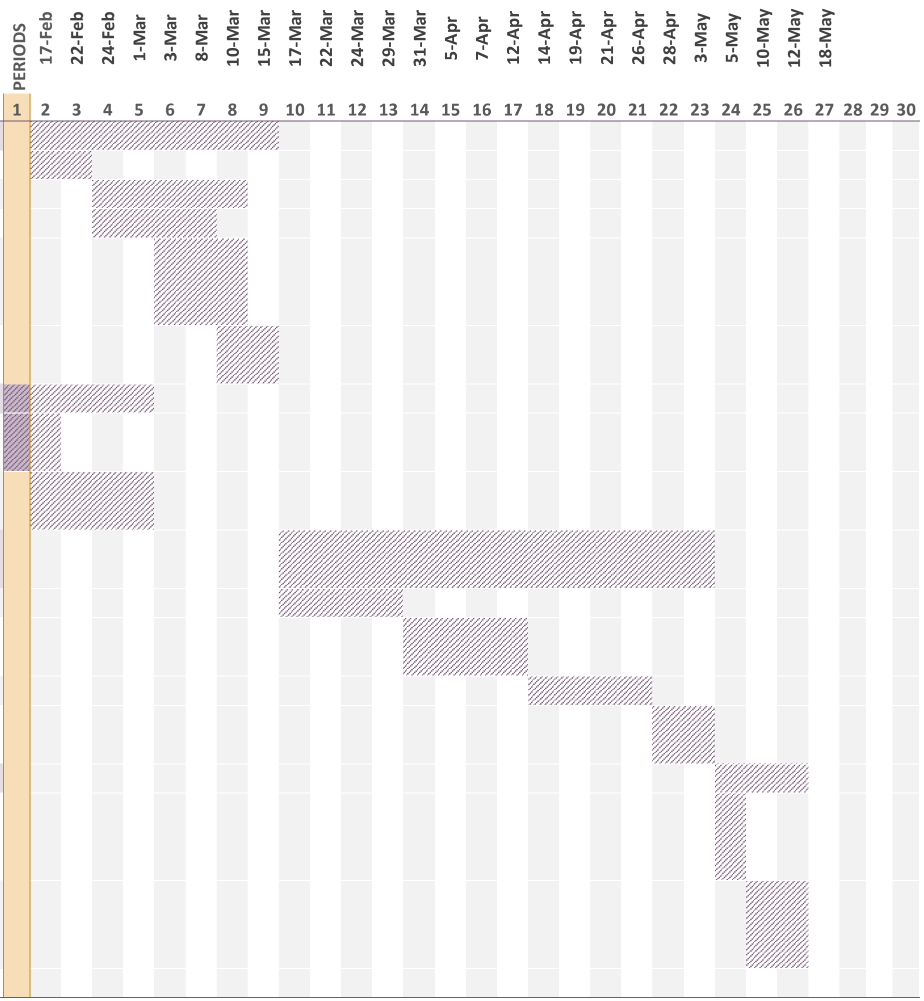
Schedule

3D Tool Tracking Project Planner

Select a period to highlight at right. A legend describing the charting follows.

Period Highlight: 1 — Plan Duration — Actual Star — % Complete — Actual (beyond plan) — % Complete (

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Get ground truth data	2	8			
Pick optical tracking system	2	2			
Set up system	4	5			
Add markers to tool	4	4			
Record tracking data and microscope video (with hand-held and robot-held tools)	6	3			
Frequency Analysis of optical tracking data	8	2			
Compute background motion	1	5	1		
Triangulate background 3D points	1	2	1		
Compute camera rotation between frames	2	4			
Implement video tracking algorithm	10	14			
Color segmentation	10	4			
Extract tool connected component, contours	14	4			
Compute tool tip location	18	4			
Frequency Analysis of video tracking data	22	2			
Frequency Investigation	24	3			
Compare tracking results from optical tracker and video tracker	24	1			
Create an algorithm to extract accurate tool motion from imperfect video tracking	25	2			



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] Hans-Christian Schneider and Juergen Wahrburg (2010). Simulation Model for the Dynamics Analysis of a Surgical Assistance Robot, Robot Surgery, Seung Hyuk Baik (Ed.), InTech

[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.

Questions???