Automatic Calibration of Mosquito Dissection System for the Production of Malaria Vaccine

Checkpoint Presentation

Team members: Miles Liu

Mentors: Balazs Vagvolgyi, Anna Goodridge

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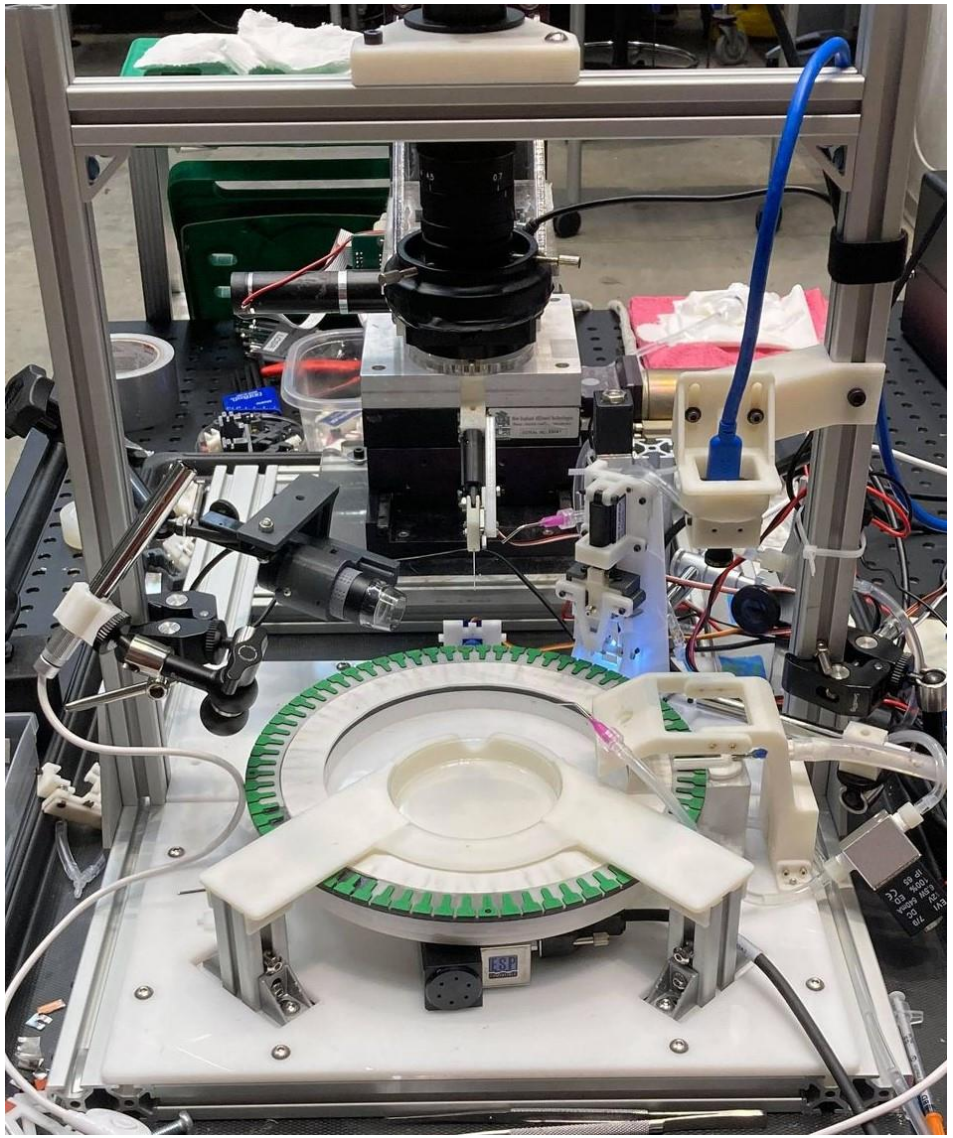
Computer Integrated Surgery II

Project Summary

- Part of a larger project to develop a robot platform to automate mosquito salivary gland extraction for malaria vaccine production
- Robot requires frequent, high precision calibrations to perform accurate mosquito microdissection

- **Goal**: Streamline robot calibration routines

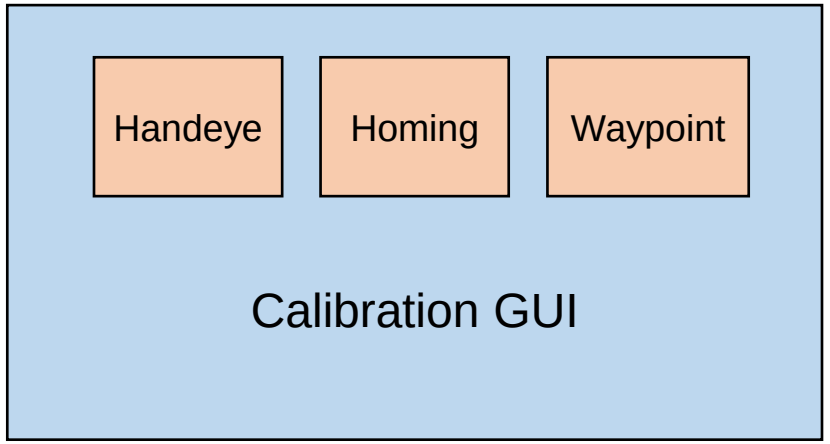


Main Project Tasks

- A main calibration GUI to facilitate the entire robot calibration workflow
  - To be used by developers and robot operators

- Three main subcomponents:
  - Robot homing
  - Robot path/waypoint calibration
  - Camera-robot handeye calibration

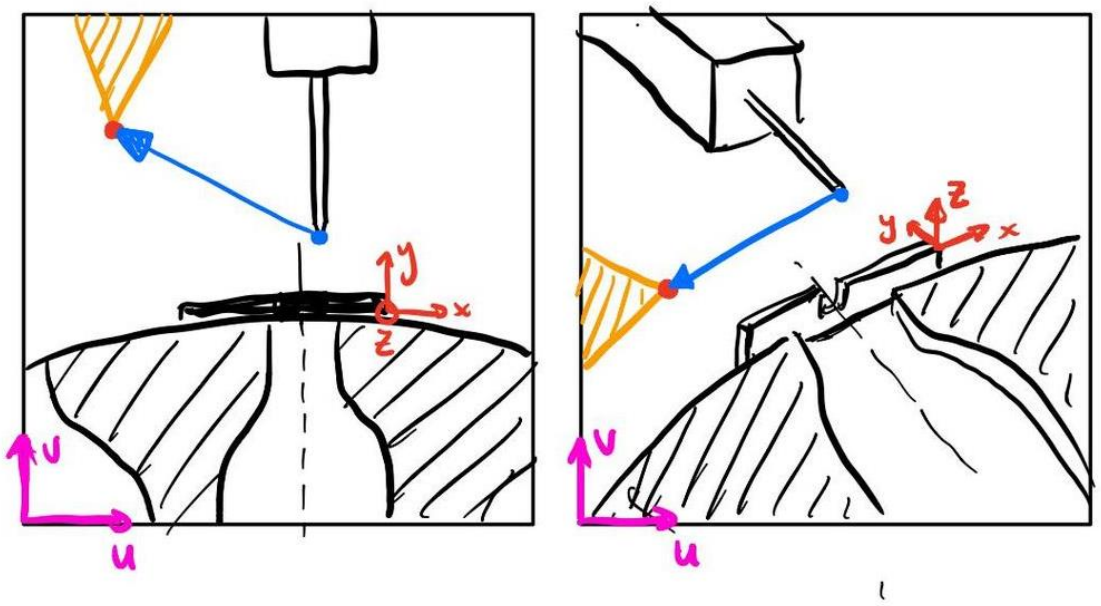
- **Progress summary**: Each subcomponent is nearing completion. Yet to make significant progress on integrating everything together



Robot Homing - Progress

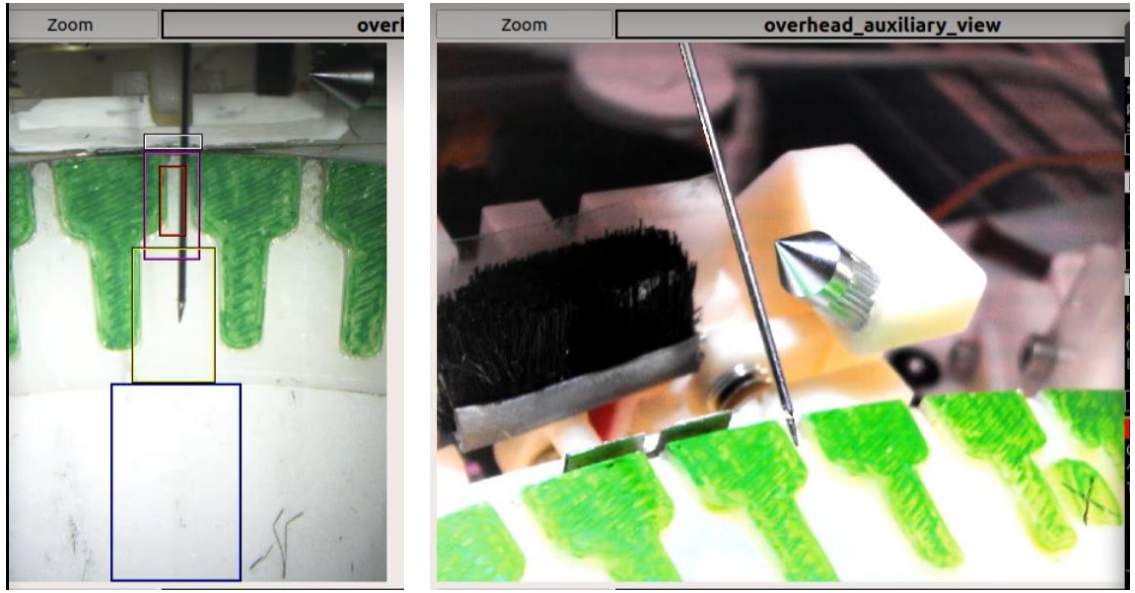
- **Approach:** Use visual servoing to home the robot tooltip to a fixed 3D “home position” with two cameras (two 2D projections)

- Servoing algorithm implemented:
  - Find the pixel location of the target point in both images
  - Do small motions along each robot axis, find the tooltip pixel location on both images, pair (Δu, Δv) with robot (Δx, Δy, Δz)
  - Find local Jacobian J, optimize for robot path to target point
  - Repeat until converged

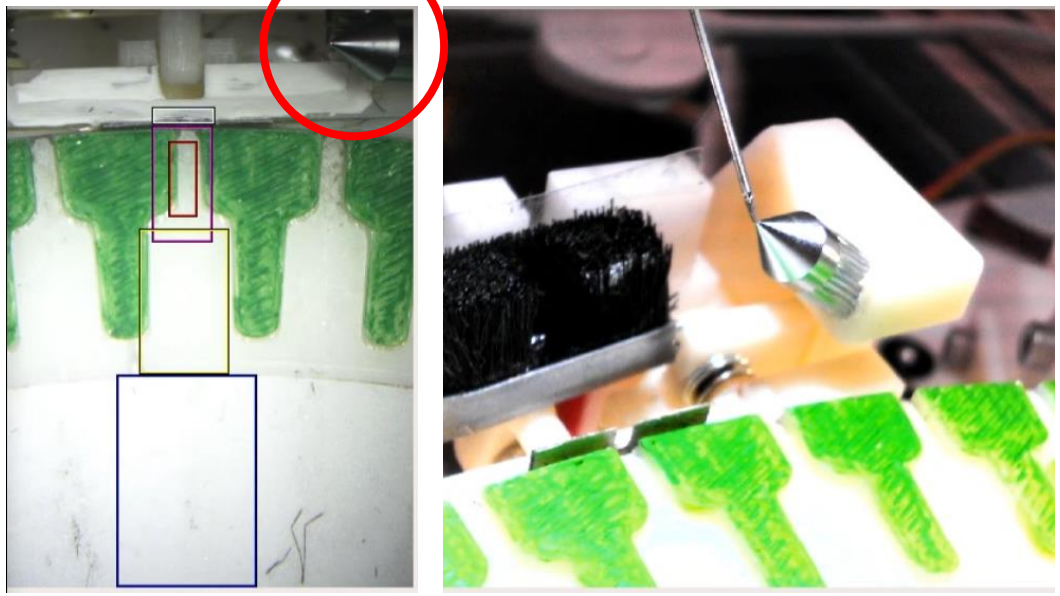


Robot Homing - Progress

Start



End



Robot Homing – Issues

- Prototype homing procedure not accurate enough
  - Need further investigation on the acceptable accuracy range
  - Related to robot controller PID tuning

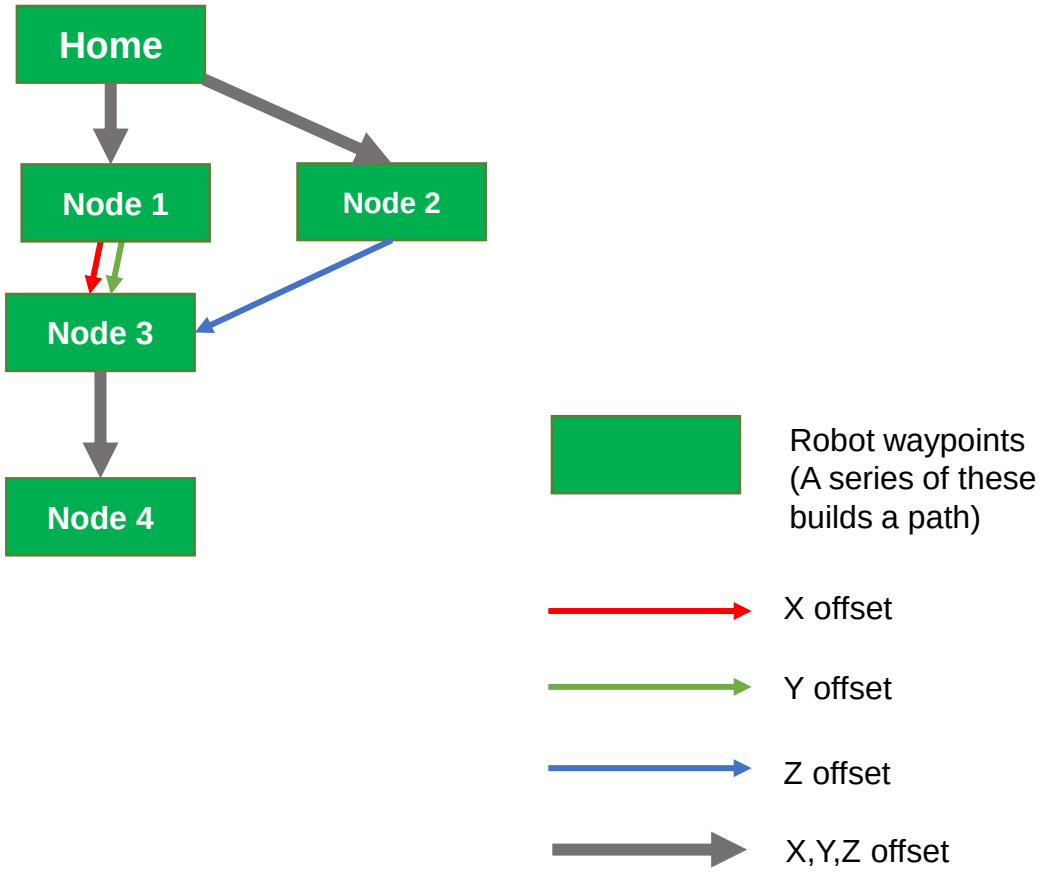
- Still reliant on operator input, relatively slow
  - Of a 2:30 min procedure, ~2 mins (80%) is spent on manually labeling tooltip positions
  - Lab colleague working on a ML based computer vision algorithm for tooltip detection

- Creates two new dependencies for **Maximum deliverables**

Robot Waypoint Calibration

- **Approach**: design and implement a custom data structure for defining robot path waypoints

- Analogous to: ROS's **tf** package
  - Except: a node can have up to three independent offset relationships
  - in 3D, no rotational component



Calibration Graph

Absolute positions (should only be 1 per graph at root node)

Abstract positions / lines / planes (Not actual robot waypoints)

Robot waypoints (A series of these builds a path)

Dynamically updated waypoints (Partially defined by default, fully defined from system runtime calculations)

API

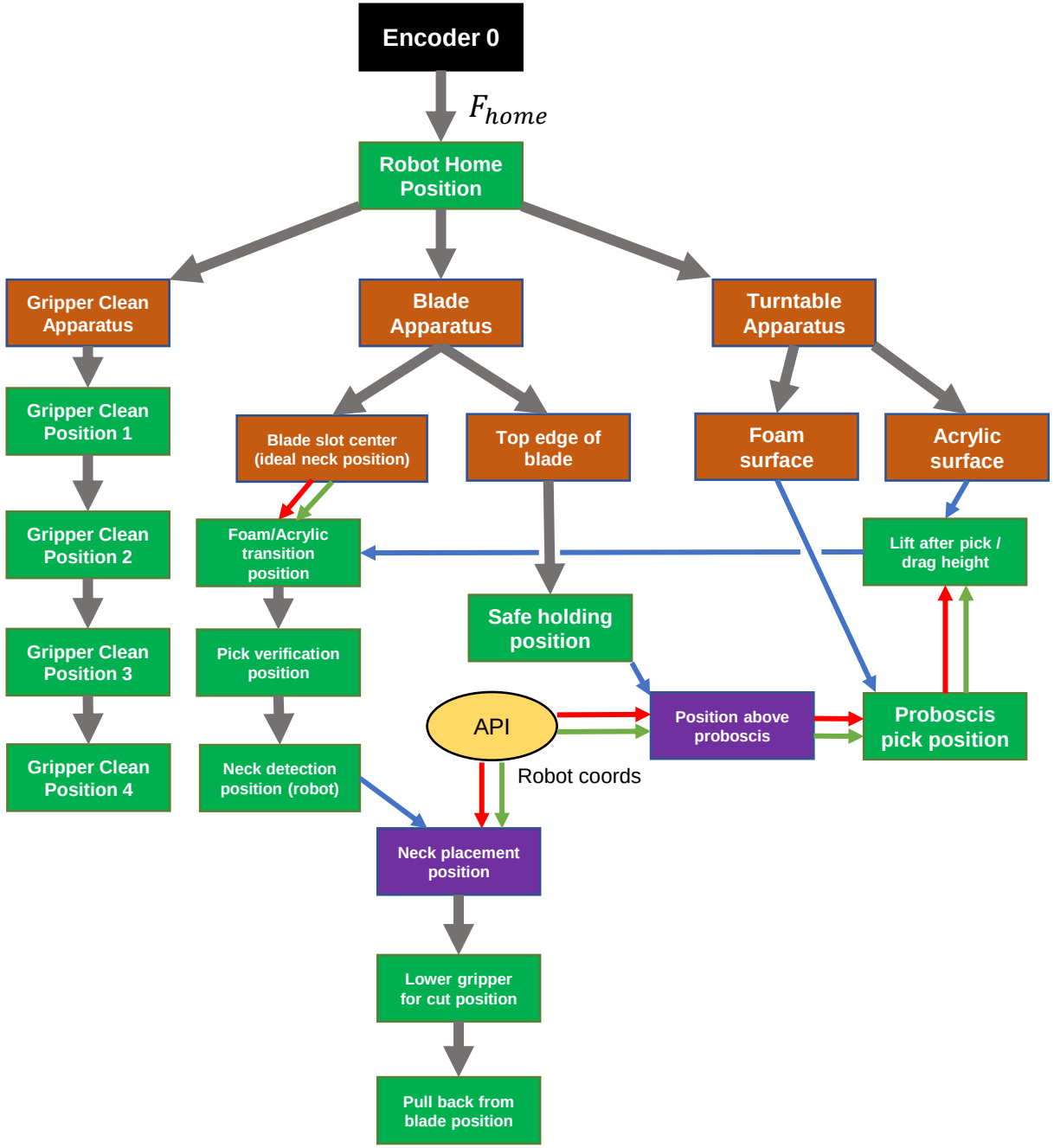
API endpoints to update dynamic waypoints

X offset

Y offset

Z offset

X,Y,Z offset



Robot Waypoint Calibration – Progress & Issues

- Data structure implemented as an independent ROS service
- Resulting graph stored as a JSON file
  - Human readable, easy to modify
- Implemented a guided calibration procedure for:
  - The entire graph (all waypoints)
  - Individual nodes
  - Nodes associated with specific hardware components

- Pending further feedback from operators on workflow for this calibration component

Handeye Calibration

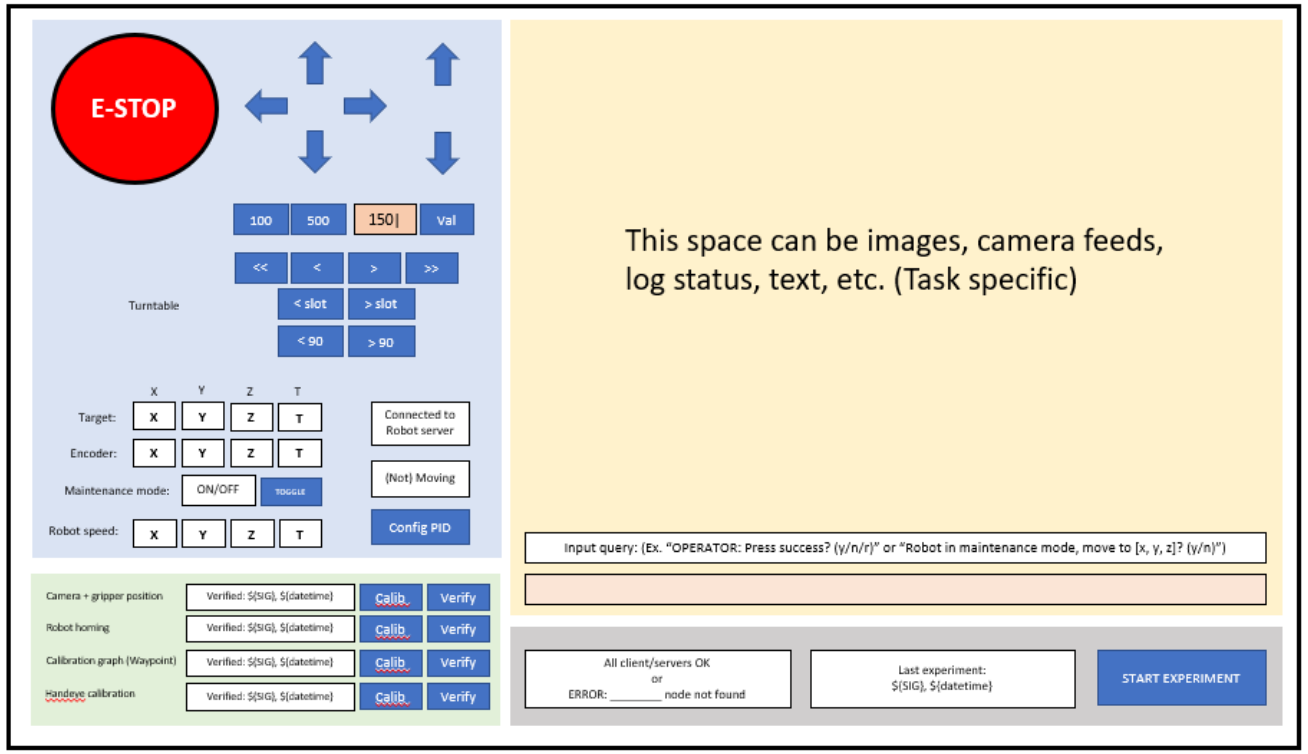
- Previous implementation functions OK, but requires a lot of operator support

- Updated old calibration procedure to new system software framework
- Previously: ~15 mins
- Currently: ~5 mins

- Could benefit greatly from the tooltip detection component being developed for homing

Consolidating into a Single Workflow/GUI

- Currently gathering operator input on GUI layout
- Can start implementation soon



User text input

Buttons (most will be disabled during operations)

Text display (not input)

Manual control of robot

Calibration & verification

Experiment panel

Main display workspace (task specific)

Project Deliverables

- **Minimum**
  - Existing calibration components integrated with ROS — **DONE**
  - Prototype implementation of new "*calibration tree*" — **DONE**
  - Significant progress with development of robot homing calibration procedures — **DONE**
  - Documentation — **Partially Done** (Subject to revisions)
    - System design documentation — **In progress**
    - Usage instructions — **DONE**
    - Commented code — **DONE**

- **Expected** (continued from minimum)
  - A single calibration workflow & GUI that covers all calibration tasks
    - Some intervention from the robot operator allowed for robot-homing.
  - Deployment version of the calibration graph
- **Maximum** (continued from expected)
  - A calibration workflow that does not require any operator input
  - A vision-based calibration validation system
  - Incorporate Sanaria feedback

Project Dependencies

	Dependency	Resolved? If yes, date resolved	Notes
1	Availability of station and robot system core components (Robot arm, tool, cameras)	**Yes,** 2/15/2022	Administrative methods to ensure no team conflicts.
2	Key hardware fixtures (Homing object/post)	**Yes,** 2/28/2022	Homing post installed and working so far. Can be further integrated into future CV processes
3	**New dependency*** Tooltip detection algorithm	**No**	Task delegated to lab member outside of CIS II In development, progress thus far seems promising, but not at deployment accuracy yet. Temporary solution: have operator manually label tooltip. Tooltip detection can be easily integrated
4	**New dependency*** Robot controller PID tuning	**No**	Task delegated to lab member outside of CIS II Not yet started

* Only affects **Maximum deliverables**.

Updated Project Milestones

	Milestone	Original Completion Estimate	New Completion Estimate	Status	Completion Percentage	Notes
1	Research and determine technical approaches	02/28/2022	No change	**Completed**	**100%**	
2	Update and cleanup existing calibration procedures	03/07/2022	No change	**Completed**	**100%**	
3	Prototype implementation of Calibration GUI	03/31/2022	**04/15/2022**	**In progress**	50%	GUI is closely related to the full calibration workflow. Expecting many incremental changes coming from operator feedback.
4	Prototype implementation of Robot homing	03/31/2022	No change	**Completed**	**100%**	
5	Prototype implementation of calibration tree	03/31/2022	No change	**Completed**	**100%**	
6	Initial verification testing on hardware	04/15/2022	No change	**In progress**	60%	All individual calibration components have been developed and tested. Waiting on GUI to test full workflow
7	Modularize components, integrate into calibration workflow	04/20/2022	No change	**In progress**	75%	Components have been modularized, but not integrated into workflow yet
8	**NEW Milestone**: Improve calibration accuracy	04/30/2022	No change	**Not started**	-	Need to be at least the accuracy of manual calibration
9	Solicit user input and implement user suggestions on workflow and GUI design	04/15/2022	No change	**In progress**	50%	Input gathered from developers and operators on the layout of GUI
10	Final poster presentation	05/04/2022	No change	**Not Started**	-	

Estimated Project Timeline

- **By End of February**
  - Finalize technical approach, deliverables, and project plan
  - Start cleanup + updating of existing calibration procedures
  - Start implementation of prototype calibration tree and calibration GUI
- **By End of March**
  - Complete update of calibration procedures, verify with in-person testing, wrap into modules
  - Complete prototype implementation of calibration graph

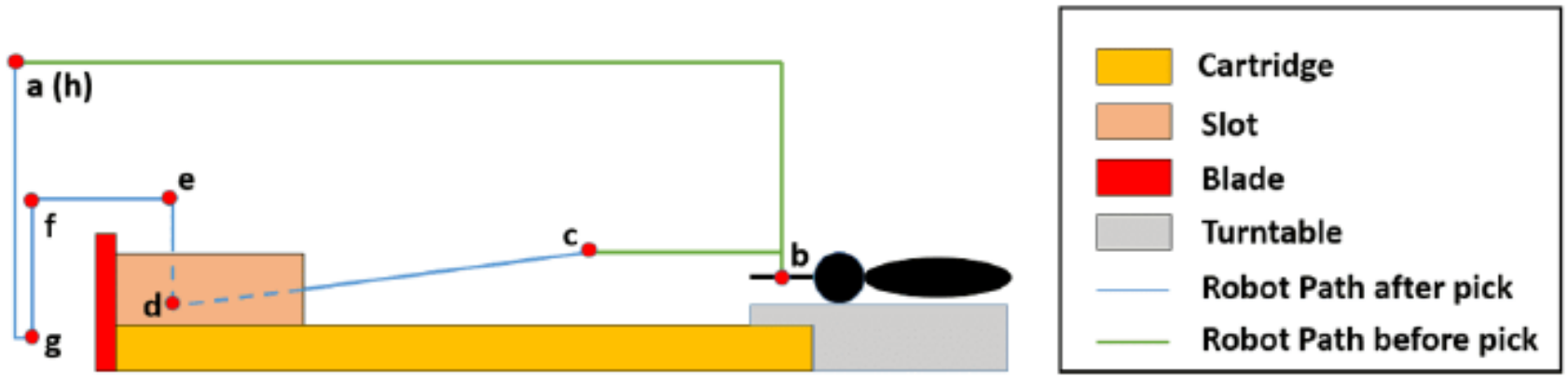
We are here

- **By Mid-April**
  - Complete prototype implementation of full calibration workflow and GUI
  - Conduct first round of testing with developed systems. Identify any system design issues
  - Debug period
- **Late April**
  - Package and finalize deliverables, develop in depth documentation
  - Prepare final poster presentation
- **May**
  - Course end evaluations and poster presentations.

Appendix

Project Goals

- Streamline and simplify calibration routines, including but not limited to:
  - Streamlined handeye calibration
  - Robot homing + robot workspace definition
  - Calibration validation
- Rethink how the robot tool paths are defined, and implement a solution that can be maintained easier by human developers

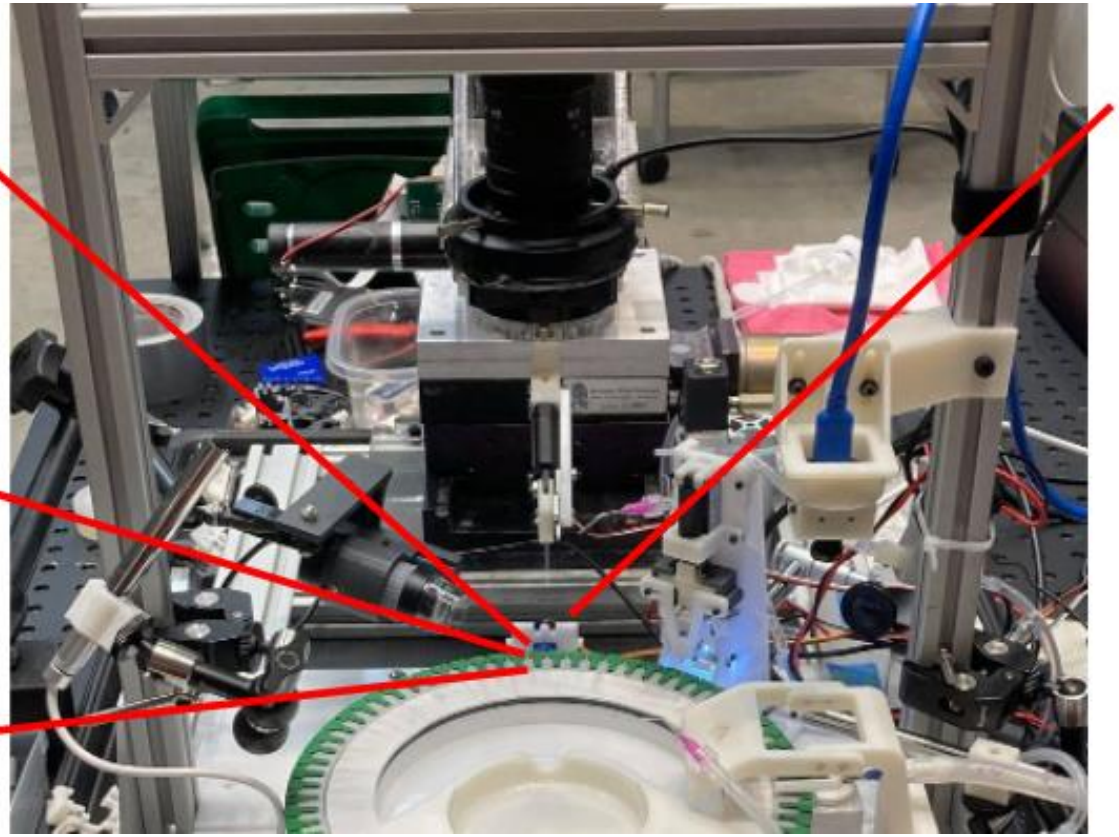


An example robot gripper path (not currently in use)

4 - CV finds mosquito neck

3 - Robot arm grips and moves mosquito into station

2 - CV finds mosquito body and proboscis



5 - Robot arm brings mosquito to blades, decapitates mosquito

Project focus area: Decapitation station

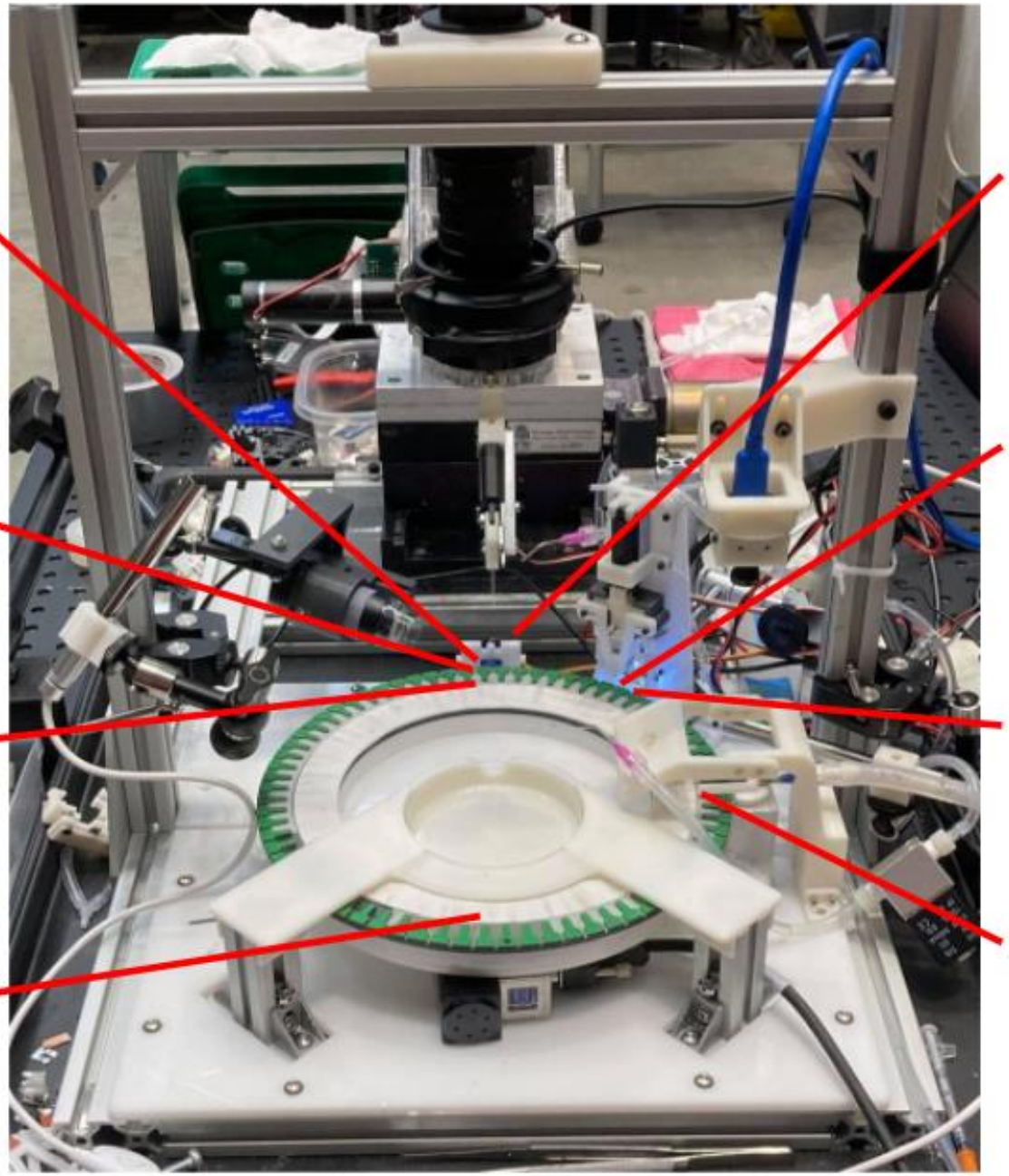
- CV used to identify mosquito anatomy
- 3 DoF prismatic robot to manipulate mosquitos

4 - CV finds mosquito neck

3 - Robot arm grips and moves mosquito into station

2 - CV finds mosquito body and proboscis

1 - Operator places mosquito here



5 - Robot arm brings mosquito to blades, decapitates mosquito

6 - Squeezer presses on torso and exposes salivary gland

7 - Pressurized tube collects exposed gland

8 - Mosquito torso disposed and robot cleaned

Reading List

- H. Wu, J. Mu, T. Da, M. Xu, R. H. Taylor, I. Iordachita, and G. S. Chirikjian, "Multi-mosquito object detection and 2D pose estimation for automation of PfSPZ malaria vaccine production", in IEEE 15th International Conference on Automation Science and Engineering (CASE), Vancouver, BC, August 22-26, 2019. pp. 411-417.
- W. Li et al., "Automated Mosquito Salivary Gland Extractor for PfSPZ-based Malaria Vaccine Production," 2021 IEEE International Conference on Robotics and Automation (ICRA), 2021, pp. 866-872, doi: 10.1109/ICRA48506.2021.9560959.