EN 601.656 Computer Integrated Surgery II

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

Background Literature Critical Review

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Project Summary

Sanaria Inc. and the team at Computer Integrated Interventional Systems Laboratory (CIIS) have been working together to develop a robot platform that can fully automate a critical step in malaria vaccine production - salivary gland extraction. Once deployed, this robot platform can significantly increase gland production rates, and thus eliminate this vaccine production bottleneck.

As the robot requires high precision mosquito manipulation movements, it will also require precise calibration for many of its components frequently during its development cycle.

This goal of this project is to streamline calibration routines and create a well-integrated single calibration package that can handle most calibration tasks automatically. This project also aims to rethink how the robot workspace and its planned paths are defined, and implement a solution that can be maintained easier by human developers.

Paper Selection

Developing a calibration procedure for a robot platform requires in depth understanding of the robot platform itself, especially the use case of each calibrated component, and what the specific requirements are of each component. The background literature that I chose for this analysis is the most recent publication on development status of the robot platform by the Sanaria and CIIS teams, "Automated Mosquito Salivary Gland Extractor for PfSPZ-based Malaria Vaccine Production" by Wanze Li, et al. This paper was published in August 2021 to the International Conference on Robotics and Automation (ICRA). [3]

Problem Summary

Aligned with the overarching objectives of this CIS II project, the robot system described in the paper aims to automate the critical step of mosquito salivary gland extraction in malaria vaccine production.

The process that the system introduces aims to minimize need for trained operators by introducing a more autonomous approach than previous systems, significantly increase production throughput, all while maintaining a high success rate of salivary gland extraction.

Key Results

Building from previous prototype approaches to this automation task, the system detailed in the publication was able to achieve the following key results:

- Reach 93% success rate for mosquito manipulation (pick-place-decapitate actions)
- Reach 87.1% success rate for salivary gland extraction (press)
- Development of a virtual simulation environment for subsystem development & visualization even during the global pandemic restrictions
- Development of robust computer vision processes to locate and identify key mosquito anatomic features

- Modularization of robot system components to a client/server architecture
- Key understanding of needed future improvements

Procedure	Step	Success	Failure	Total	Success Rate
MPPD	Pick-Place	93	7	100	93%
	Decapitate	93	0	93	100%
Gland Extract	Squeezing	81	12	93	87.1%
Overall		81	19	100	81%

Figure 1: Quantitative Evaluation Results of System Performance

Significance of Key Results

As a prototype system, the described robot platform was able to demonstrate key results as a proof of concept of critical automated steps of performing microdissection on mosquitos, especially with computer vision and mosquito manipulation techniques. This builds on the promising performance of previous system prototypes to further improve confidence in the approach.

The modularization of software architecture will be essential for future work, including increasing throughput of the system, and incorporating a robust error handling & recovery. The increased understanding of the problem at hand also highlighted necessary improvements for the next iteration of the system prototype.

Previous Work

Prior to the system prototype detailed in this paper, there was a semi-automated procedure and mechanical device (sAMMS) built to significantly streamline the manual mosquito dissection process. The sAMMS device was able to greatly improve the throughput of mosquito processing but still required operator skill and had a steep learning curve. The system described in this paper builds from the workflow of the sAMMS device and aims to make the process more autonomous. [2]

Description of System

The system described in this paper can be separated into three major components:

1. Mosquito manipulation robot hardware, including the mosquito staging system, the robot arm, decapitation station, and gland extraction station.
2. Computer vision algorithms used to identify key mosquito anatomy
3. ROS based server/client system architecture

For the physical robot platform, the system uses a stepper driven turntable as the initial staging area of pre-processed mosquitos, a 4DoF robot arm with a gripper end tool that can pick up a mosquito by the proboscis and place it into a cartridge, a pair of stainless steel blades actuated with servos to decapitate the mosquito once its placed, a linear stage to transport the decapitated mosquito to a squeezing station, and a servo-actuated squeezing pin to expose the salivary gland for extraction.

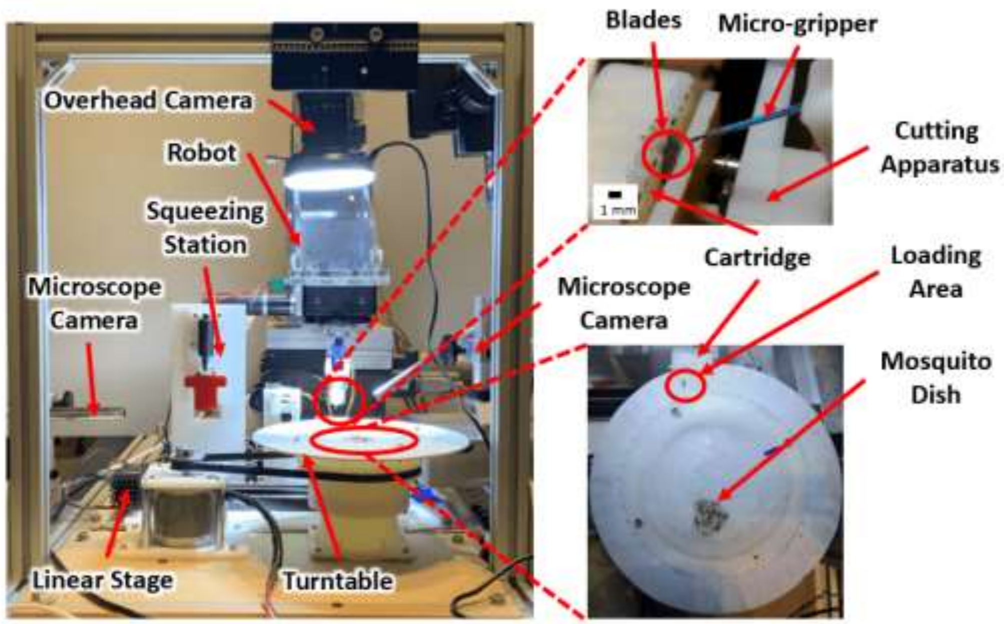

Figure 2: Main components of described system

The turntable and robot arm are controlled using a Galil robot controller through ethernet communication, while servo actuators are controlled using an Arduino Uno through serial communication.

The mosquito's process flow in this system is separated into two steps: the combined mosquito pick-place-decapitate procedure (MPPD), and the gland extraction (squeezing) step.

In the MPPD procedure, computer vision is deployed to detect and locate mosquitos on the turntable. From there, CV subroutines are called to find and locate the position of the neck, head, and proboscis of the mosquito. These vision-based detection algorithms are realized through image processing layers and feature matching on a templated hand-labeled dataset and returns image coordinates of the identified anatomic features. These image coordinates are then transformed into the robot space using a Bernstein polynomial calibration (the same calibration that my project is involved in), which is used to inform robot path planning.

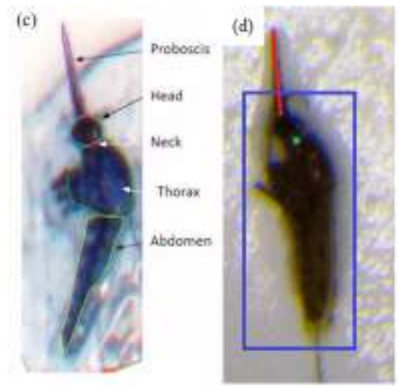

Figure 3: Example mosquito anatomy detection

Finally, the robot system's software uses ROS's server/client and service architecture. A single high level script processes the procedure's logic, while it calls upon computer vision subroutines as ROS services. This structure also allowed the team to continue development of software with ROS's RViz and rqt tools while the COVID pandemic forced limited access to robot hardware, specifically in simulating and developing system error handling and recovery.

Critical Assessment

This paper highlights critical milestones in the development of a robot platform that can automate a challenging task, and details development work that provides the necessary system performance improvements to facilitate future work on this robot platform. It is certainly exciting to see the automation of a very complex manipulation task by a highly specialized robot system.

Since my project is to develop an automated calibration procedure for this exact robot system, it is very important for me to understand how each component that I am calibrating for works in the greater system. A few major takeaways include:

- How the computer vision components are being processed, since the methods used in that task affects the camera parameters that need to be calibrated (brightness, orientation & position, etc.)
- How the calibration of the robot platform is currently being done
- What the dominant modes of failure are in the experiments being conducted, and whether their root causes are in incorrect calibration
- Actuators/encoders/robot controllers that are being used

There were still a couple of questions that still remain after analyzing the paper, as well as a few critiques:

- How will these automated procedures fit in the greater task of preparing vaccine production viable mosquito salivary glands? What other steps can be automated, and what steps must be done by human operators?

- As much as the system is a proof of concept, what is the expected throughput of this system? The paper did not explore much of the scalability and throughput potential of this automated system, despite it being one of the main objectives of developing this system.
- Many modern computer vision tasks involve deploying some machine learning algorithm to train a neural network for each vision task. Although the existing process already performs so well, can neural networks improve the performance of these components even more? Also related to this question, are there any other technical approaches for the system that have been tested, and what are their performances/limitations?

The authors of the paper highlighted the necessary improvements for the next system iteration. Some major components include: modifying the layout of the apparatus to allow for improved throughput + scalability, introducing step verification methods, improve upon computer vision performance, and a potential restructuring of system software to allow for parallel processing of mosquitos.

Conclusion

As a summary, the developments of the mosquito dissection robot platform highlighted in this paper brings the project closer to being able to realize fully autonomous, high throughput, mosquito dissection for vaccine production. This paper provides critical context for the calibration procedure that I will be developing.

Keys steps in the automated process are implemented in this version of the system, and they show very promising results. The team will continue with future work in order to being the system closer to a production viable state and introduce methods to further improve the system's throughput and success rates.

References

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3. 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.