Project 3 Paper Review

Robot System Control for Automating Mosquito Microdissection

EN 601.656 Computer Integrated Surgery II

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1 Review of CIS II Project Goals

The motivation for this project stems from a need to increase the production rate of *Plasmodium falciparum* sporozoites to meet the demands for a malaria vaccine. Our long-term goal is to automate mosquito salivary gland dissection, a bottleneck in vaccine production. Ultimately, we would like to process 600 mosquitoes per hour (mph). As a project for EN 601.656 Computer Integrated Surgery II (CIS II) at Johns Hopkins University, I want to develop a robot system controller that introduces parallel processes, error checking, and error recovery.

The automated system comprises of four components (referred to as nodes) surround a turntable node. As shown in top-view figure 1, mosquitoes are loaded one-by-one onto the mosquito loading area. Then, the turntable rotates clockwise to bring the mosquitoes in front of the robot and decapitate nodes. The robot node uses computer vision (CV) to bring the mosquito in position for decapitation. The decapitate node then actuates blades to remove the head of the mosquito. The turntable rotates further to the extraction node which collects the salivary glands and the cleaning node which removes the mosquito body. The collected glands are sent to the next step of vaccine production.

Each node in the system acts in parallel with the turntable as the unifying node. The turntable can only turn when all other nodes are done with their processes.

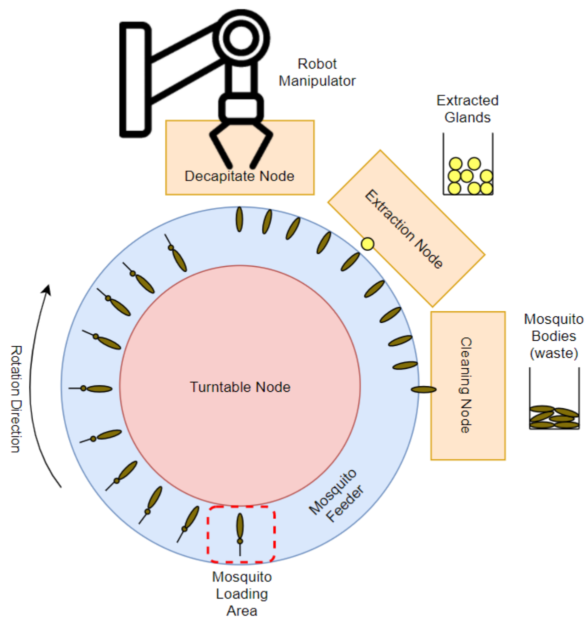

Figure 1: *Diagram showing a top-view of the current system. The turntable rotates clockwise with several nodes around the table.*

2 Paper Selection and Motivation

The selected paper for review is *Automated Mosquito Salivary Gland Extractor for PfSPZ-based Malaria Vaccine Production* authored by W. Li, Z. He, et al. [1] The paper describes a previous iteration of the mosquito dissection robot in this project. It discussed the design of a **serial robot system** for mosquito dissection which we can analyze to inform the design

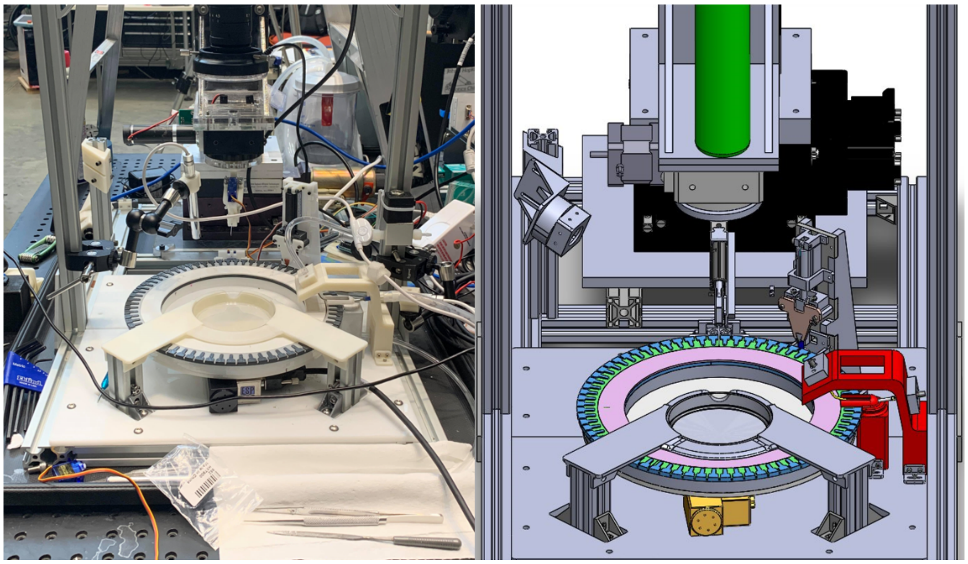

Figure 2: *The current system that this CIS II project will focus on. This is the real world model for figure 1 [1]*

of our parallel system. Furthermore, it discussed the use of a simulator that may prove to be useful to virtually test my control algorithm. Virtual testing can serve as a helpful step before testing on the physical hardware. Lastly, there are very few papers in this area of research thus papers published from our own labs are most relevant.

3 Paper Summary

3.1 Introduction & Background

Malaria is a world-wide disease infecting 228 million and causing 405,000 deaths in 2018. [4] Sanaria Inc. is working on a vaccine that provides long lasting protection against the disease. The vaccine may offer a long-term solution to combat malaria, but increasing production has its challenges. The vaccine requires large quantities of malaria sporozoite which resides in infected mosquito salivary glands as shown in figure 3. Gland extraction is very skill-intensive and acts as the rate-limiting step in production.

Our team at JHU is making significant attempts to automate and ameliorate the bottleneck. Currently, Sanaria employees must manually decapitate the mosquito using the chiseled end of a hypodermic needle, apply pressure to the upper thorax of the mosquito, and separate the extruded salivary gland. The manual process yields on average 290 mosquitoes per hour (mph). Our first attempt to improve the production speed resulted in the semi-autonomous mosquito micro-dissection system (sAMMS). Pictured in figure 4, it helped increase the rate of dissection to 450 mph by decapitating and squeezing multiple mosquitoes simultaneously. [3] The sAMMS system helped inform the design of our first fully-autonomous system by H. Phalen et al. [2] This paper builds off of Phalen's work by introducing further automations.

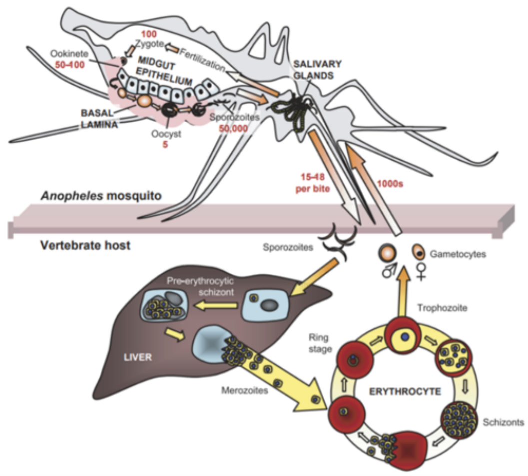

Figure 3: *Malaria life cycle. Note the position of the salivary glands within the mosquito upper abdomen and its function of storing the sporozoite immediately before infection into the vertebrate host.[3]*

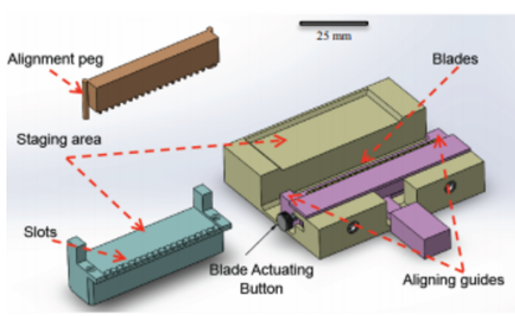

Figure 4: *The semi-autonomous mosquito micro-dissection (sAMMS) tool. The comb-like structure (blue) holds the mosquitoes while the blades decapitate them. Then the sqeezer (brown) extrudes the salivary glands from the mosquito bodies. [3]*

3.2 Hardware Overview

The robot system described in the paper is composed of sequential steps. Referencing figure **??**, a mosquito is first placed into the loading area. Then, the turntable turns until a mosquito is in front of the linear stage. The robot manipulator moves the mosquito onto the stage where the first decapitation station uses blades to remove the mosquito head. The stage then moves to the squeezing station where the salivary gland is extracted.

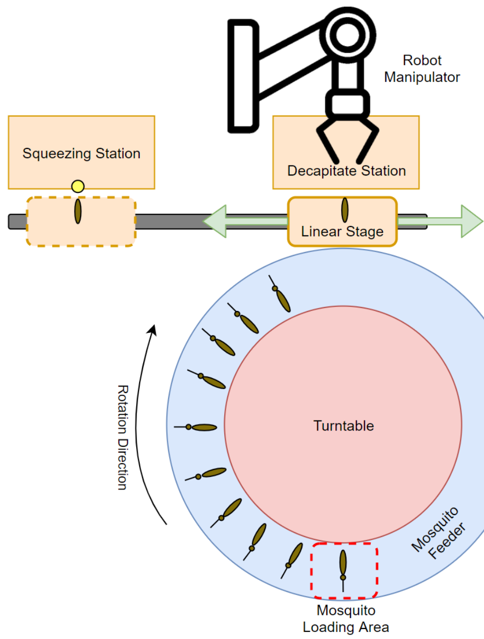

Figure 5: *A diagram of the system reported in the paper. The system steps were performed sequentially starting with placing mosquitoes on the loading area. [1]*

3.3 Software Overview

The software is designed using the Robot Operating System (ROS). ROS is commonly used in academia to control state-of-the-art robot systems. The central concept in ROS is the node. Nodes are encapsulated software used to execute a task and communicate with other nodes. Communication occurs over the command line through ROS topics. The paper used the ROS Actionlib client-service paradigm to further strengthen the communication protocols between nodes. As pictured in figure 7, the step client connects with services which execute lower-level tasks such as moving the robot arm or actuating the blades.

The high-level logic in the robot system follows figure 8. Actions occur in serial where the termination of one action prompts the next.

The paper also describes a simulation which researchers are using to debug the controller. Each hardware component is visualized using the Robot Visualization tool (RViz). Each component's back-end is a collection of ROS nodes that mimics an action-service that can be commanded by the controller. The team also developed a GUI using RQt, and built trajectory generator nodes to simulate the real robot physics.

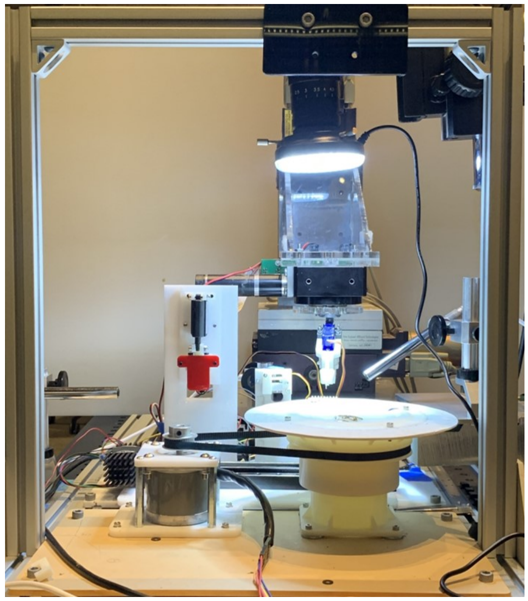

Figure 6: *A diagram of the system reported in the paper. This is the real-world system described in figure 5 [1]*

Figure 7: *An image showing the use of client-server architecture for a single node. [1]*

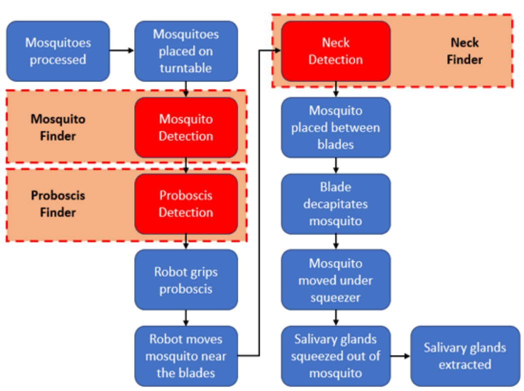

Figure 8: *A diagram showing the sequential steps from the software for the system. [1]*

3.4 Results & Discussion

The team conducted a test on 100 real mosquitoes to determine the success rate of each step in the dissection process. The quantitative results are displayed in figure 9.

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 9: *A diagram the results of the success rate of each node. The results were concluded over 100 tests on sacrificed mosquitoes. [1]*

The system produced an overall success rate of 81% which demonstrated the potential for automating mosquito dissection. The decapitation station had the strongest performance (100% success). Robot pick-and-place (93%) and gland extraction (87.1%) are the weakest, leaving room for improvement through hardware redesign, CV model restructuring, or the addition of error recovery. Gland storage and cleaning stations are still needed to fully automate the dissection process. The team also observed that the rigidity of test mosquitoes attenuated our success rate. Thus, the paper discussed methods for preserving the nimbleness of fresh mosquitoes.

4 Key Takeaways

It is evident from the paper that the stations were either effective or had the potential to be. Further improvements to the controller through error recovery could increase the lower success rates of the robot and gland extraction nodes. Although it was not included in the paper, figure 10 demonstrated that, from the mosquito output rate of 1 minute per mosquito, 47 seconds were spent on the linear stage. Thus, a system centered around the turntable could improve throughput. Additionally, parallelization of the individual stations could further improve times. The existing software structure of Actionlib clients and services appear to be effective and robust for future developments.

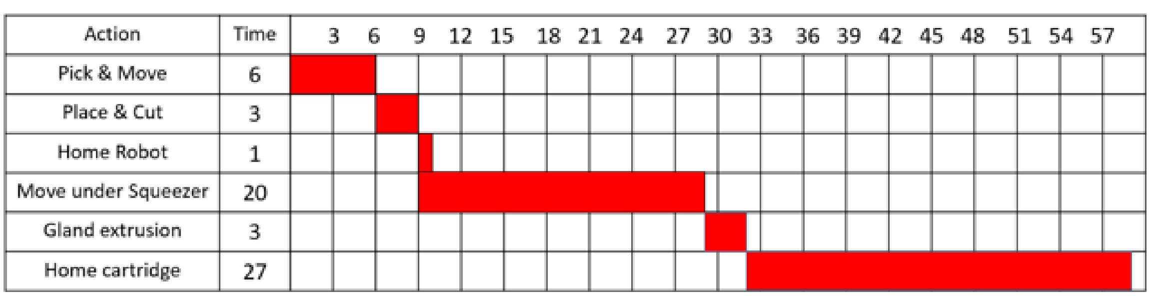

Figure 10: *A time analysis of each step reported in the paper. This diagram was not officially reported in the paper due to the page limit of the article.*

References

[1] Wanze Li, Zhuohong He, Parth Vora, Yanzhou Wang, Balazs Vagvolgyi, Simon Leonard, Anna Goodridge, Iulian Iordachita, Stephen L. Hoffman, Sumana Chakravarty, and Russel H. Taylor. Automated mosquito salivary gland extractor for pfspz-based malaria vaccine production, 2021.

[2] Henry Phalen, Prasad Vagdargi, Mariah L. Schrum, Sumana Chakravarty, Amanda Canezin, Michael Pozin, Suat Coemert, Iulian Iordachita, Stephen L. Hoffman, Gregory S. Chirikjian, and Russell H. Taylor. A mosquito pick-and-place system for pfspz-based malaria vaccine production, 2020.

[3] Mariah Schrum, Amanda Canezin, Sumana Chakravarty, Michelle Laskowski, Suat Comert, Yunuscan Sevimli, Gregory S. Chirikjian, Stephen L. Hoffman, and Russell H. Taylor. An efficient production process for extracting salivary glands from mosquitoes, 2019.

[4] World Health Organization. World malaria report 2019, Dec 2019.