Akash Chaurasia

601.496

March 10, 2020

Seminar Paper Critique

Project 5: *Mosquito Vision: Guidance for Automated Robotic Mosquito Salivary Gland Extraction*

Paper:
"Mosquito Pick-and-Place: Automating a Key Step in PfSPZ-based Malaria Vaccine Production," *2019 IEEE 15th International Conference on Automation Science and Engineering (CASE)*, Vancouver, BC, Canada, 2019, pp. 12-17.

Authors:
Henry Phalen, Prasad Vagdargi, Michael Pozin, Sumana Chakravarty, Gregory S. Chirikjian, Fellow, IEEE, Iulian Iordachita, Senior Member, IEEE and Russell H. Taylor, Life Fellow, IEEE

Project Summary:
The goal of this project is to create a ROS-integrated computer vision system for mosquito detection and keypoint identification to guide an automated mosquito dissection robotic system for live malaria vaccine production. The target keypoints on the mosquito to be identified include the proboscis, the head, and the neck. This project is in conjunction with Sanaria Inc. (Rockville, MD), who has developed a vaccine containing a live malaria parasite. The goal of the robotic system is to aid in the large-scale, efficient extraction of mosquito salivary glands to enable the mass-production of this impactful vaccine.

Paper Summary:

Introduction: The authors first introduce the public health burden of malaria, a parasitic disease which infected over 200 million individuals worldwide in 2017. To combat this, the company Sanaria, Inc. (Rockville, MD) has developed the Sanaria Plasmodium falciparum sporozoite-based vaccine. This vaccine contains a live parasite harvested from mosquitos which accounted for an estimated 95% of the deaths caused by malaria in 2017. A bottleneck in the production of this vaccine is the extraction of the mosquito salivary glands which contain the parasite to be later isolated. Previous work by the authors introduced a semi-automated mosquito micro-dissection system (sAMMS). This novel system parallelizes the process of decapitating mosquitos and extracting the exudate (matter from the mosquito body containing the desired salivary glands), ultimately resulting in a nearly twofold increase in mosquito throughput (reaching an average of 470 mosquitos per hour), as well as a reduction in training time required to reach peak performance. However, the authors seek to work towards further automation in the production process, and thus in this paper explore a system to identify mosquitos, analyze them, and best orient them for decapitation. The authors propose a vision-guided pick-and-place robotic system to load the sAMMS device, which they argue is a key step on the path to full automation.

System Design Concept: The first chronological part of the system separates mosquitos from a basin of media below the system. A rotor in the basin induces a vortex, driving mosquitos to the top of the cone. This cone contains a channel, allowing media to flow through it and into an orientable mesh cup (located on a rotating ring of mesh cups). An overhead camera captures an image of a single cup after it has passed the channel, and a vision algorithm determines if any mosquitos are present in the cup. When a cup is determined to contain a mosquito, it is rotated so the proboscis (mouth of the mosquito) faces radially outward. A linear stage dissection assembly interacts with a pick-and-place robot, with a sAMMS-like cartridge attached to the linear stage. This cartridge has a mesh cup, identical to the ones on the rotating ring with its center 23 mm away from the blades. The robot drags a mosquito into a slot on the cartridge with its neck aligned in the notches of parallel dissection blades (Figure 1), a process overseen by computer vision algorithms leveraging the overhead camera. After the blades are actuated, the head is disposed, and the rotating ring rotates to present the next cup with a mosquito while the linear stage indexes. Then, the linear stage shifts towards a squeezing apparatus where the exudate containing the salivary glands is collected.

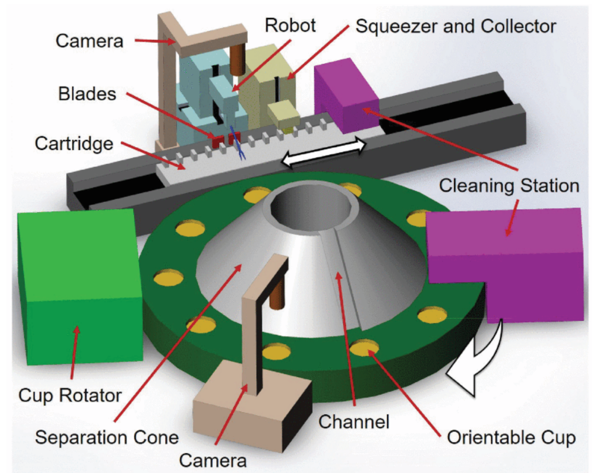

Figure 1: Concept image for automated mosquito dissection system (Phalen et. al.)

The authors identify the following system requirements:

- Dissection point must be exactly between the thorax and head to optimize PfSPZ extraction (max error: 200 μm)
- Grasping must occur only on the mosquito proboscis
- The system must be able to customize the robot's movements in each trial to account for variability in mosquito orientation, positioning, and size

A 4 degree of freedom linear stage robot was used, and each axis was measured to have a resolution of 10 µm. A custom micro-gripper mechanism is attached to this robot (Figure 2) with a cam mechanism and a servo motor to drive the rail of a linear guide, ultimately causing the tooltip to open or close. This gripping mechanism is inspired by the Alcon Grieshaber retinal surgical forceps. The staging platform is a modified sAMMS cartridge. The blades used are 0.051 mm thick with 0.5 x 1.0 mm notches cut in them to be aligned with the mosquito neck. Three cameras are placed on the system, one overhead the entire workspace and for use with the vision algorithms, one mounted on the robot to determine mosquito keypoints and one on the side for visualization and verification. The overhead camera first captures an image, which the vision algorithm uses to create a bounding box for the mosquito and locate its centroid. The tooltip is moved to this position, at which point the onboard camera locates the mosquito's proboscis. The proboscis is gripped and the mosquito is dragged to a slot in the cartridge. Then, a final onboard camera image is taken to find the offset between the mosquito head and tooltip to determine how much further the mosquito must be dragged to place the neck between the blades. A two-stage calibration procedure was followed to locate the tool tip relative to the onboard camera, and to fit to cap the camera coordinates to the robot encoder coordinates.

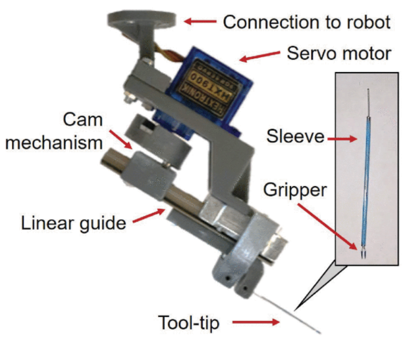

Figure 2: Implementation of micro-gripper mechanism (Phalen et. al.)

Experimental Methods: The overall investigation aims to evaluate the efficacy of the proposed system to pick a mosquito, place it between the blades, and remove its head. 50 non-infected mosquitos were stored in phosphate-buffered saline for one day after their sacrifice. All steps were performed autonomously with computer vision, with the cutting step performed manually at the end of each trial to determine success. **PICK:** Each mosquito was picked by tweezers and placed in the cup on the cartridge with its proboscis facing towards the blades or within 45 degrees of this direction. Once the centroid is identified with computer vision, the robot moves to a point 5 mm in front of this point, then lowering by 3 mm. Once the proboscis centroid is located, the gripper moves 2 mm directly above this point, drops to contact the mesh surface, and closes to grip the proboscis. The robot then lifts up 0.8 mm and drags the mosquito to a point 1.5 mm away from the blades, at which point an onboard camera image is captured. At this point, the image is used to evaluate successful grasping and determine the exact grasping position on the proboscis.

PLACE: The vision system locates the point where the proboscis attaches to the mosquito's head, which is used to calculate the head-tooltip offset. The robot then raises up 1.3 mm, moves a preprogrammed distance plus the calculated offset, and moves down 3 mm, ideally placing the mosquito neck between the blades, which are actuated manually at this point. If the head is properly remove by blade actuation, the trial is considered a success. The robot was moved at a speed of 12.5 mm/s in each axis, with a drop to 2.5 mm/s when lowering the mosquito neck into the blades. Figure 3 depicts the main steps of the pick-and-place method with the robot path and images captured at each point.

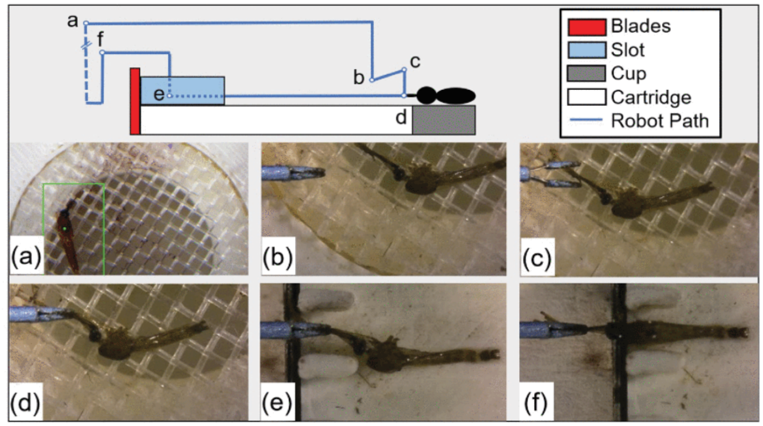

Figure 3: Side view of robot path and related representative images captured by the vision system. (a) Image captured from overhead camera showing bounding box of detected mosquito. (b) Image captured from onboard camera to determine proboscis centroid. (c) Image captured from onboard camera before grasping. (d) Image captured from onboard camera immediately after grasping. (e) Image of the mosquito taken used to calculate head-to-tooltip offset. (f) Image after aligning the mosquito neck with the blades (Phalen et. al.).

Results: 50/50 (100%) of the mosquitos were successfully grasped as evaluated by visual inspection during the second check. 45/50 (90%) of the mosquitos were placed in the cartridge so that the head could be completely removed, as was evaluated visually using video recorded during the placement and cutting steps. In the remaining 5 cases, during the final placement step, as the robot lowered the neck into the cartridge slot, the mosquito flipped over the blades or slot. This error was found to be uncorrelated to any other variables.

Discussion: The authors argue that since all gripping, moving, and localizing steps were performed free of error, the gripping mechanism and vision algorithms are robust and are able to provide adaptations to the robot's movement. They also argue that the placing step requires more accuracy, and the success rate of 90% is an encouraging result. According to them, this step requires a great deal of precision and propose improving the vision algorithm. The authors attribute the placement errors (caused by a flipping of the mosquitos about a contact point between the blades/cartridge and the head/body) to inaccurate alignment and propose both improving the calculation of head-to-tooltip offset and investigate the effect of the angle at which images are taken. Furthermore, the combined robot movements took an average of 7.7 seconds, and with an improved computer vision computation time of 0.16 seconds per image on average. The authors propose an average reduction of 2.5 seconds per trial with future work such as simply increasing the robot movement speed, resulting in a final throughput of approximately 700 mosquitos per hour.

Critique:

Overall, the authors of this paper demonstrated the efficacy of a system with a gargantuan potential impact. The design of the system makes many considerations including those that are biological (accounting for the stretching of mosquitos from grasping), electronical, mechanical, software-related, and otherwise. Most important, a clear and logical workflow for mosquito processing, from placement to decapitation has been outlined and can be adapted. However, there are several details regarding the implementation of the system that are missing. For example, it is unclear what is used to drive the system beyond interfaces such as Arduino, as well as the interactions between the various system components. Overall, reconstructing the proposed system would be quite difficult with the level of detail provided in the publication. Furthermore, the description of the vision components are quite vague. As one of the most robust parts of the system as well as one of the elements identified by the authors for improvement, it would be interesting to understand the vision system, workflow, and approaches. Finally, while the authors delineated some areas of future work, such as improving placement accuracy and execution speed, it would be interesting to know what future evaluations will specifically entail, or desirable future results, especially given that they indicated the system is prepared for future progress.

This paper is very relevant to our project, as it demonstrates the efficacy of a predecessor to the current robotic system for which we provide vision guidance. While some components of the system are different, the workflow outlined in this paper, especially the pick-and-place approach remain constant, and robust vision guidance is still a necessity.