ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

Actions to Mosquitoes

Team #4

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1 Introduction

1.1 Problem and Solution Overview

Mosquitoes are not just a source of irritation due to their itchy bites; they are also public health threats, as documented by the World Health Organization (WHO), which identifies them as vectors for diseases like malaria and dengue [1]. The challenge of controlling these agile insects is compounded by the limitations of current methods, which can be less effective and potentially harmful, as noted in studies on the environmental impact of mosquito control. To address these issues, we've developed an innovative device that actively captures mosquitoes. It operates by moving through the environment and swiftly sucking up mosquitoes upon detection, offering a more targeted and safer alternative to traditional repellents and swatters.

We intend to design our project by four subsystems: a detection subsystem, a localization subsystem, an attack subsystem, and a power and control subsystem. The detection subsystem serves as the trigger, using audio cues to activate the machine when mosquitoes are present. The localization subsystem employs a camera to locate the mosquito and provides real time location data to the attack subsystem, which then mobilizes to capture or eliminate the mosquitoes using a powerful suction device and CO2, heat, and motion-based lures. The power and control subsystem is strategically divided to supply continuous energy to the detection subsystem and activated power to the localization and attack subsystems, optimizing energy usage, and ensuring sustained operations.

Our design can be implemented equipped with some subsystem requirements. Firstly, the detection subsystem requires high sensitivity and accuracy, with a minimum detection accuracy of 85% and a false positive rate below 15%. Secondly, the localization subsystem demands a camera capable of identifying mosquitoes with at least 80% accuracy and providing real time data to the attack subsystem, which must possess precision mobility and an effective attractant mechanism for mosquito capture. What's more, the power and control subsystem is tasked with stable and efficient power delivery, featuring voltage regulation, surge protection, and a failsafe mechanism to ensure the seamless operation of the machine. Collectively, these subsystems form a comprehensive solution for mosquito detection, tracking, and elimination, emphasizing efficiency, accuracy, and safety.

1.2 Visual Aid

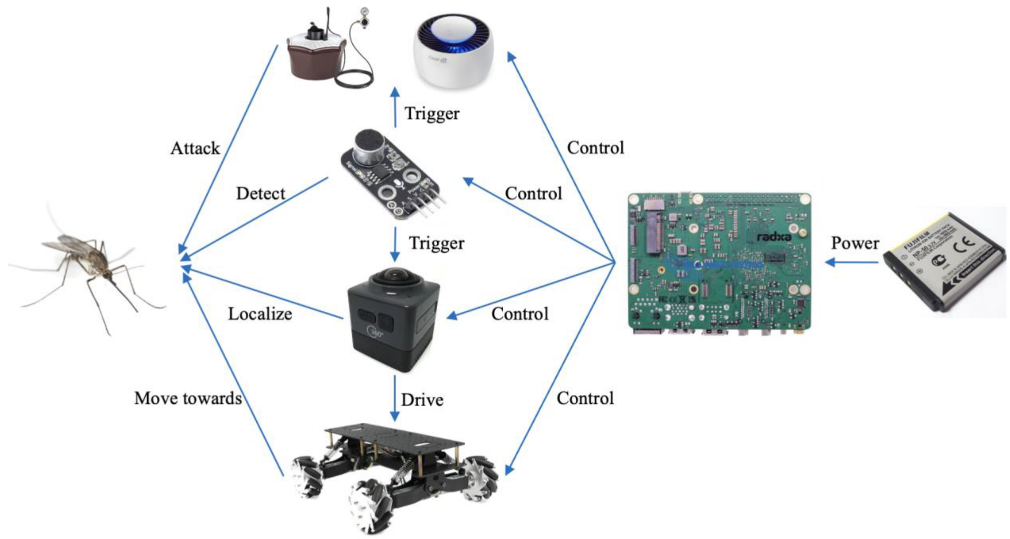

Figure 1: The overall visual graph of the design: One motor chip powers and controls all other parts, the microphone works as a trigger to enable the camera and the attacker, then the main part starts to localize and move to attack the mosquitoes.

1.3 High-Level Requirement List

1. The microphone in the detection subsystem must be directly connected to the Raspberry Pi, sensitive and efficient to mosquitoes' noise, and can also record the sound in the environment, which means it should trigger the machine only if there is noise caused by mosquitoes in its working area, and it should distinguish the noise of mosquitoes from other noises.

2. It is significant for the camera to determine direction of the mosquito once it catches mosquito in its vision, so that the machine can adjust its moving according to the action of mosquitoes.

3. We design the attack subsystem only for mosquitoes, it should contain some materials that can attract them, as well as sucking mosquitoes accurately into itself to make the work efficiently.

2 Design

2.1 Block Diagram

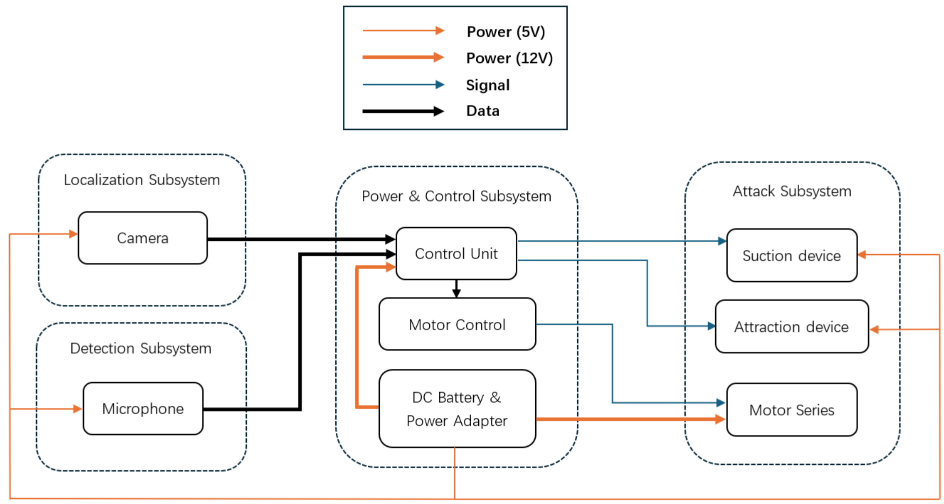

Figure 2: The block diagram of the design: The Power and Control subsystem provides 5V and 12V power for all other subsystems, the Localization subsystem determines the place of the mosquitoes and the Attack subsystem works on dealing with the mosquitoes.

2.2 Physical Design

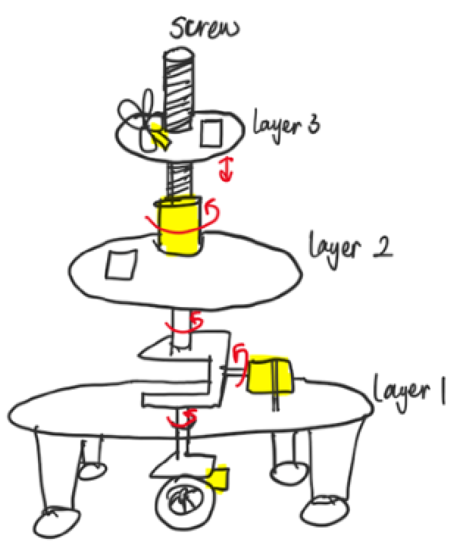

Figure 3: Recent design sketch.

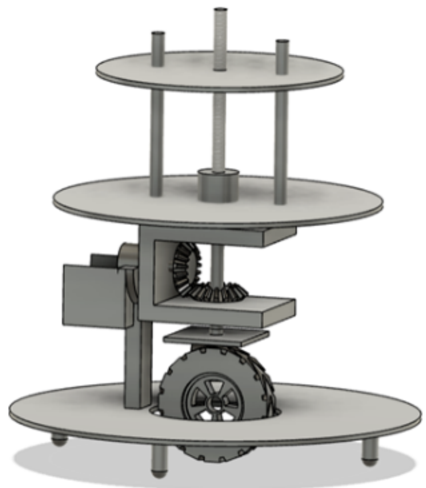

Figure 4: Current design CAD model.

There are four motors in total, arranged from top to bottom as follows: the first motor controls the rotation of the fan on the top layer, although it is not shown in the CAD model; the second motor drives the screw, enabling the conversion of rotational motion into translation. This mechanism allows the top layer to move up and down; the third motor is positioned on the bogie gearbox, ensuring synchronous rotation between the middle layer and the wheel.

The last motor provides power to the wheel. The wheel serves as a guide, and four ball bearings assist in maintaining balance while minimizing friction.

2.3 Subsystem Overview

This mosquito eradication machine is designed to detect, locate, attack, and eliminate mosquitoes autonomously. It comprises four main subsystems, each playing a crucial role in the machine's operation and interacting seamlessly with one another to achieve the goal of mosquito eradication.

2.3.1 Detection Subsystem

Description:

This subsystem, ensuring continuous surveillance, is equipped with an acoustic sensor array that captures sound waves and processes them to determine if mosquito activity is detected. The acoustic sensor is capable of distinguishing the unique wingbeat frequency of mosquitoes, which is typically between 300 to 600 Hz for most species [2]. Upon detecting a mosquito's presence, this subsystem initiate the machine's response cycle. This ensures energy efficiency by only activating the more power intensive components when necessary.

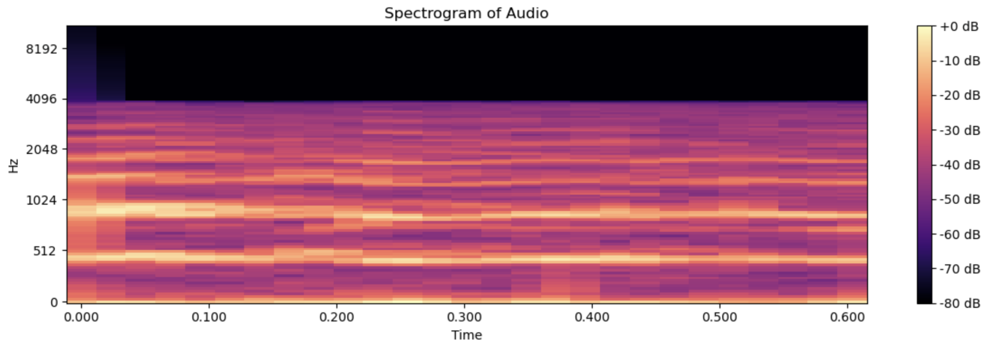

Figure 5: The frequency plot of some mosquitoes wingbeats noise.

For the microphone, we had bought a microphone for Raspberry Pi 4B, which is designed for our Raspberry Pi to use. As for the algorithm to distinguish the noise of mosquitoes, we plan to use the Mel-Frequency Cepstral Coefficient (MFCC) combined with machine learning model to train. MFCC is a feature extraction method used in audio processing to represent the short-term power spectrum of a sound, which can also be used to classify sounds according to the difference in frequency.

Requirement	**Verification**
The microphone module must be capable of capturing audio frequencies within the range of 300 to 600 Hz with a sensitivity of -47 dBV ± 4 dB.	Generate a series of audio tones covering the 300 to 600 Hz range, ensuring each frequency is tested. Connect the microphone to the audio analyzer or oscilloscope. Play each test tone and record the output signal from the microphone. Measure the output voltage for each frequency to determine the sensitivity, ensuring it is within the -47 dBV ± 4 dB range.
The machine learning model must correctly identify mosquito sounds with an accuracy of at least 85%, based on the trained dataset, and a false positive rate not exceeding 15%.	Prepare a test dataset consisting of both mosquito and non-mosquito sounds. Run the machine learning model on the test dataset and record the number of correct identifications and false positives. Calculate the accuracy and false positive rate based on the test results. Document the test dataset composition, the model's accuracy, and the false positive rate.

Table 1: Requirements & Verifications for Detection Subsystem

2.3.2 Localization Subsystem

Description:

For this subsystem, we plan to use the USB camera connected to the Raspberry Pi. This subsystem integrates advanced image processing algorithms to analyze the captured images. The camera's high resolution ensures that even small targets like mosquitoes can be clearly detected. These images are then processed to identify the mosquito's location in the space.

As for the algorithm, We will adopt the existing YOLOv8 model for real-time coordinate detection and recognition of mosquitoes [3]. The integrated dataset comes from public datasets online, and we will fine-tune it with data collected by ourselves. The subsystem also gauges the mosquito's altitude, adjusting the attack subsystem's height to align with the mosquito's vertical position. This subsystem's feedback loop with the attack subsystem allows for dynamic adjustment of the machine's position and orientation, optimizing the capture process.

Taking into account the actual environmental conditions, we will adjust the model's confidence threshold to ensure that while reducing the false positives of mosquito entities, we simultaneously increase the accuracy of mosquito detection.

Requirement	**Verification**
The camera must have the capability to identify mosquitoes in the environment in a few pixels within an appropriate distance.	Place the camera in a controlled setting with sufficient lighting and background contrast to ensure clear visibility of mosquitoes and introduce objects of known size and color in the test environment to simulate the size and shape of mosquitoes, assessing the camera's resolution and recognition accuracy and checking whether the mosquito can be recognized in a few pixels.
The YOLOv8 model should correctly identify around 90% of the mosquitoes in the validation dataset with desirable result of precision and recall.	Process the images captured by the camera using the yolov8 model to verify if the algorithm can accurately identify and locate mosquitoes and document data during the testing process, including the rate of successful identification, false positives. Based on the test results, adjust the camera settings and algorithm parameters, and perform multiple rounds of testing until satisfactory recognition performance is achieved.

Table 2: Requirements & Verifications for Localization Subsystem

2.3.3 Attack Subsystem

2.3.3.1 Overview

The control system is the central nervous system of the mosquito eradication machine, orchestrating the interplay between the power subsystem and the operational components.

It comprises a control unit integrated within the Raspberry Pi, which processes input from the microphone and camera, and a motor control system that executes the commands to maneuver the machine. It is crucial for the machine's primary function of mosquito eradication. It ensures that once a mosquito is detected, the machine can effectively capture and eliminate it, contributing directly to the reduction of mosquito-borne diseases.

2.3.3.2 Fan Capture Unit

Description: The fan subsystem is a central component of the attack system, designed to capture mosquitoes. The fan operates to create a airflow that sucks in mosquitoes, facilitating their capture by the machine.

Interfaces: The fan is connected to the servo motor and is controlled by the control unit to activate when a mosquito is detected and ready to be captured.

Contribution to Overall Design: The fan's role in capturing mosquitoes is essential for the machine's efficacy. It ensures that once a mosquito is within range, it is effectively captured, preventing escape and enabling elimination.

Verification: Testing the fan's capture efficiency with live mosquitoes in a controlled environment.

2.3.3.3 Mechanical Structure and Positioning Unit

Description: The mechanical structure subsystem includes the chassis, wheels, and lead screw that support 360-degree rotation. This subsystem, in conjunction with servo motors, allows the machine to position itself accurately for optimal mosquito capture

Interfaces: The mechanical structure interfaces with the servo motors through the motor control system, which receives commands from the control unit via GPIO.

Contribution to Overall Design: The mechanical structure provides the necessary mobility and precise positioning, ensuring that the machine can effectively capture mosquitoes from any detected location within its environment.

Verification: Confirmation of the mechanical structure's durability and ability to support the machine's components.

Requirement	Verification
Audio Detection Sensitivity	Audio detection system must reliably identify mosquito sounds within a range of 5 meters.
Camera Activation Time	The camera system must activate and begin scanning within 10 seconds of the audio detection trigger.
Servo Motor Response	Servo motors must respond to control signals within 0.5 seconds, ensuring immediate adjustment of camera positioning.
360-Degree Camera Rotating	The camera must be capable of a full 360-degree pan within 120 seconds to scan the entire environment.

Table 3: Requirements & Verifications for Attack Subsystem

2.3.3.4 Overall process

Upon startup, the machine system activates its microphone, which immediately begins to function. Once the microphone detects the sound of a mosquito, the system automatically triggers the camera and the servo motor that controls the rotation of the lead screw. The purpose of the servo motor is to rotate the lead screw, with one end connected to the camera and the other to the mobility wheels. Through the rotation of the lead screw, the camera is capable of a 360-degree panoramic scan, ensuring that the direction of the wheels aligns with the camera's field of view.

When the camera captures an image of a mosquito, the servo motor connected to the wheels lowers them to the ground. Subsequently, the motor or electric motor associated with the fan and wheels activates, propelling the wheels towards the target direction that the camera is focused on, with the fan responsible for capturing the mosquito.

To achieve precise tracking of the mosquito, the two servo motors that control the rotation of the lead screw and the lifting and lowering of the wheels will receive PWM signals from the Raspberry Pi based on the mosquito's position coordinates in the camera's view, making corresponding adjustments to ensure that the mosquito remains centered in the camera's field of view at all times.

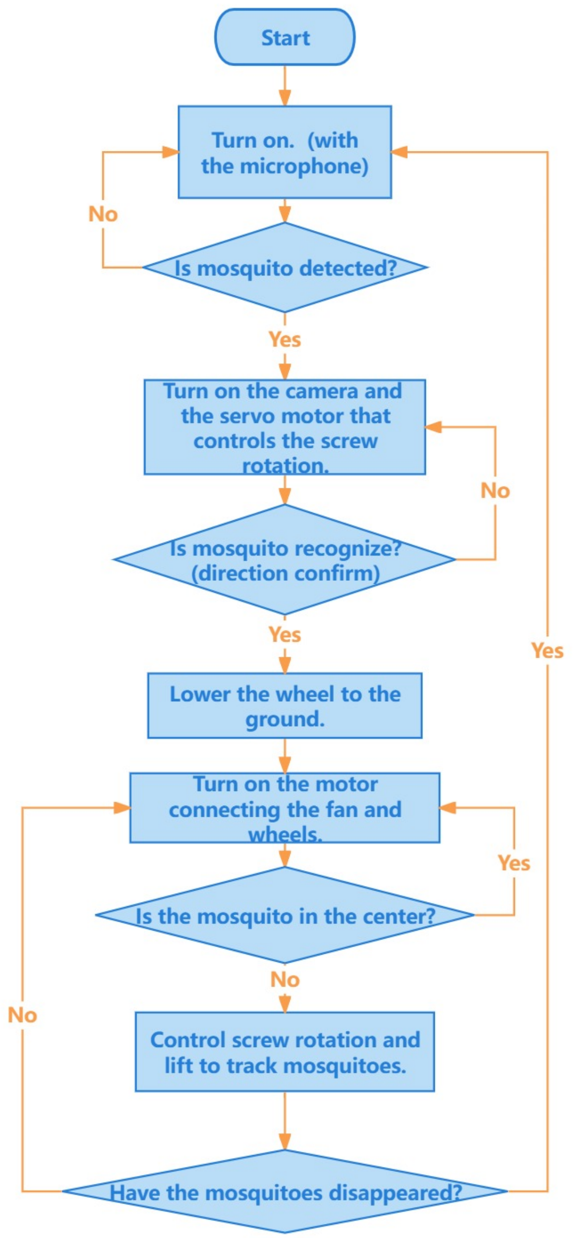

Figure 6: The flowchart of the overall process.

2.3.4 Power and Control Subsystem

2.3.4.1 Overview

The control system is the central nervous system of the mosquito eradication machine, orchestrating the interplay between the power subsystem and the operational components. It comprises a control unit integrated within the Raspberry Pi, which processes input from the microphone and camera, and a motor control system that executes the commands to maneuver the machine.

2.3.4.2 Control Unit

Description: The control unit, based on the Raspberry Pi, is responsible for real-time data processing from the microphone and camera. It runs advanced algorithms to distinguish mosquito sounds and identify mosquito positions. Based on this processed data, the control unit formulates commands for the motor control system.

Interfaces: USB interfaces for connecting the microphone and camera. Serial or I2C communication links with the motor control system for command transmission.

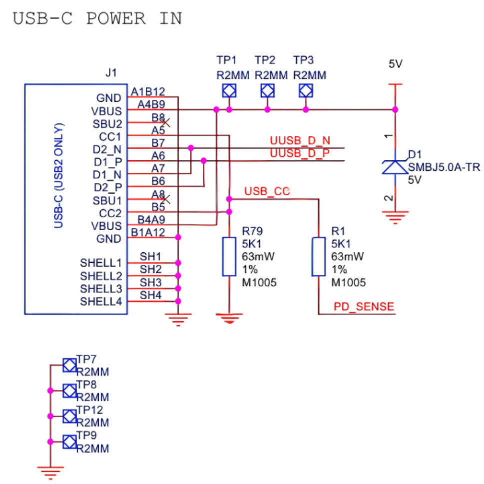

Figure 7: USB circuit of Raspberry Pi.

Contribution to Overall Design: The control system is essential for the machine's autonomous functionality. It processes sensory data, makes informed decisions, and coordinates the machine's movements and operational mechanisms, ensuring effective mosquito eradication.

Verification: Audio and visual data processing routines are tested for accuracy and response time. Command transmission protocols are verified for reliability and data integrity.

2.3.4.3 Motor Control System

Description: The motor control system interprets commands from the control unit and generates appropriate PWM signals to manage the motors. It is responsible for the precise movement and positioning of the machine, including the rotation of the camera and the movement of the capture mechanism.

Contribution to Overall Design: The motor control system interprets commands from the control unit and generates appropriate PWM signals to manage the motors. It is responsible for the precise movement and positioning of the machine, including the rotation of the camera and the movement of the capture mechanism.

Interfaces: GPIO pins on the Raspberry Pi are used to generate PWM signals for motor control.

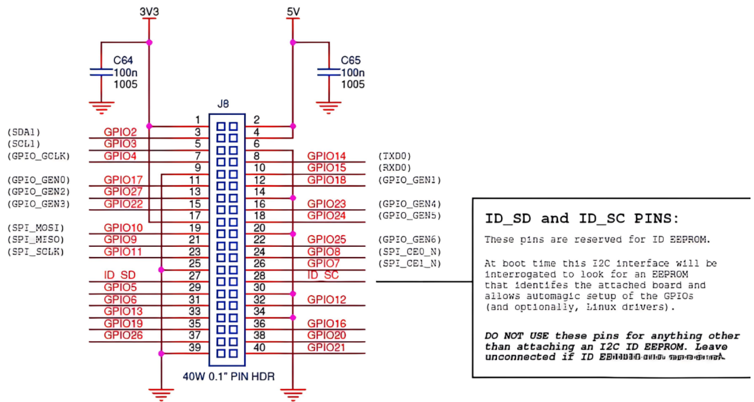

Figure 8: GPIO Pins expansion of Raspberry Pi.

PWM signals to servos and motors. Motor driver modules, L298N, interface with the Raspberry Pi and the motors.

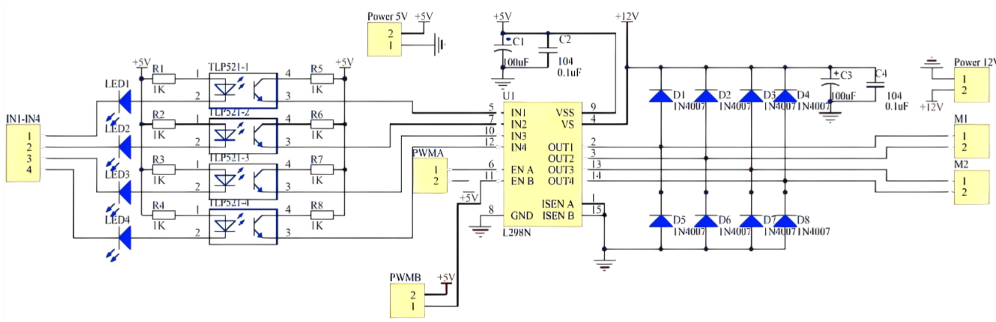

Figure 9: L298N.

Verification: Motor response to PWM signals is tested for accuracy and consistency. Motor driver modules, if used, are validated for compatibility and performance.

2.3.4.4 Power Supply Unit (PSU)

Description: The PSU is the energy source of the machine, consisting of a battery and an adapter. The battery provides a stable 12V power supply, and the adapter converts this to the appropriate voltage levels required by each component.

Contribution to Overall Design: The PSU ensures that all components receive a stable and consistent power supply, which is crucial for reliable operation and performance of the machine.

Interfaces: Direct connections to the control unit, motor control system, and other powered components.

Verification: Voltage regulation and stability are tested underload to ensure that all components receive the correct voltage levels. The battery's capacity and longevity are tested to ensure continuous operation.

Requirement	Verification
Battery for Stable Power Supply	The battery must provide a stable 12V power supply to the control unit and other components of the mosquito eradication machine.
Power Adapter for Voltage Regulation	The adapter must convert the 12V DC from the battery into appropriate voltage levels for other components, ensuring their correct functioning.
Control Unit Integration	The Raspberry Pi, serving as the control unit, must integrate audio and visual data processing, decision-making, and command execution for the motor control system.
Audio Detection and Response	The Raspberry Pi must process audio data from the USB-connected microphone to detect mosquito sounds and trigger the activation of the camera and servo motors.
Visual Detection and Servo Control	The Raspberry Pi must process video data from the USB-connected camera to identify mosquitoes and control the GPIO-connected servos for camera positioning and tracking.
Motor Control for Movement and Capture	The motor control system, managed by the Raspberry Pi, must send signals to the GPIO-connected motors to enable precise movement and positioning, including the lowering of wheels and activation of the fan for mosquito capture.
GPIO Connectivity for Motor Control	All servo motors and the fan motor must be connected via GPIO pins on the Raspberry Pi, allowing for precise control of the machine's movements and mechanisms.

Table 4: Requirements & Verifications for Power and Control Subsystem

2.4 Tolerance Analysis

2.4.1 Power Supply Analysis

There are two major parts that consume power: one is computational, including the Raspberry Pi and the L298N motor drive controller board module; the other involves mechanical movements, specifically the motors.

The working voltage for the Raspberry Pi is 5V, with a working power of 15W. The

L298N operates within a voltage range of 4.8 to 46V, with an estimated working power of 12W.

We have a total of four motors: one for the fan, which uses a 130 motor, and the others use TT motors. The 130 motor operates at a working voltage of 6V and a working current of 1A, with a working power of 0.75W. The TT motor operates at a working voltage of 4.5 to 6V, with a working current of 190mA.

Since the entire physical structure needs to move, batteries are used as the power supply. We will use No. 5 Nanfu batteries, each supplying 1.5V. Thus, for the entire system to function, we use 4 batteries for the Raspberry Pi, 4 batteries for the L298N, 4 batteries for the 130 motor, and a total of 9 batteries for the TT motors. Therefore, the total number of batteries required is 21.

2.4.2 Mechanical Structure Failure

The material for the three layers is 3mm clear acrylic, and for the shafts, it is stainless steel. In the simulation software, we consider both the bottom and the top layers, along with the representative shafts at the motors.

For the bottom layer, we approximate the load to be 5 N, pointing downward vertically due to gravity. In the simulation, the maximum stress is calculated to be 0.406 MPa, which does not exceed the yield stress.

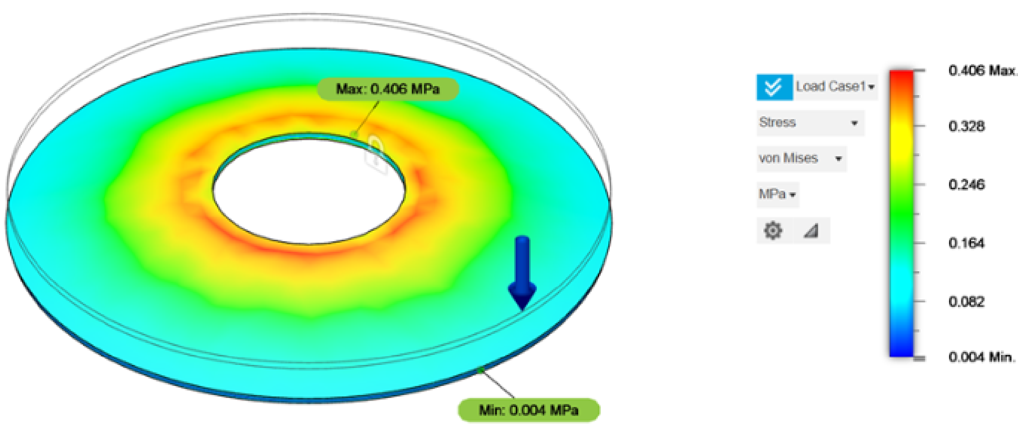

Figure 10: Simulation result for the bottom layer.

Regarding the top layer, there will be shear stress from the two guiding shafts while moving up and down, and we approximate the shear force to be 5 N. In the simulation results, the maximum stress is 0.977 MPa, which falls within the acceptable range for the material.

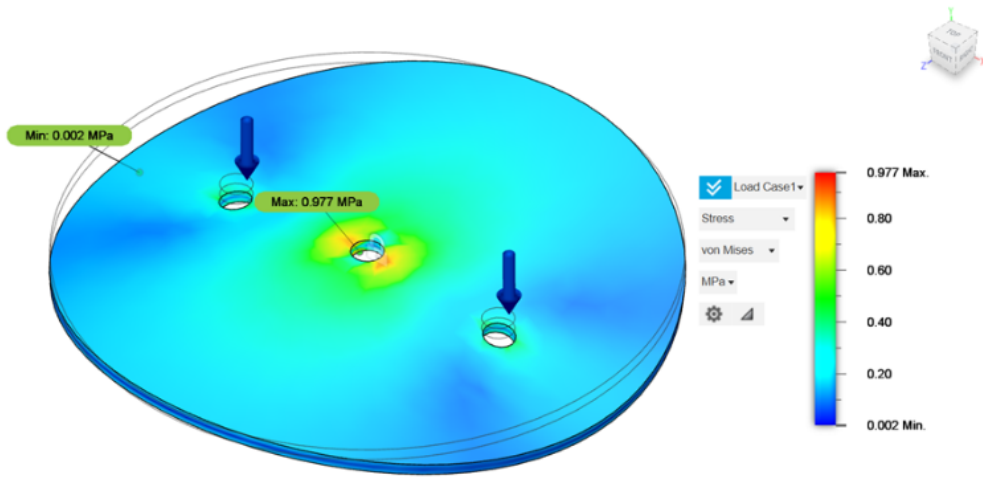

Figure 11: Simulation result for the top layer.

For the shafts, we approximate the torque to be 1000 N*mm. The maximum stress is calculated to be 7.733 MPa, which is within the safe limits.

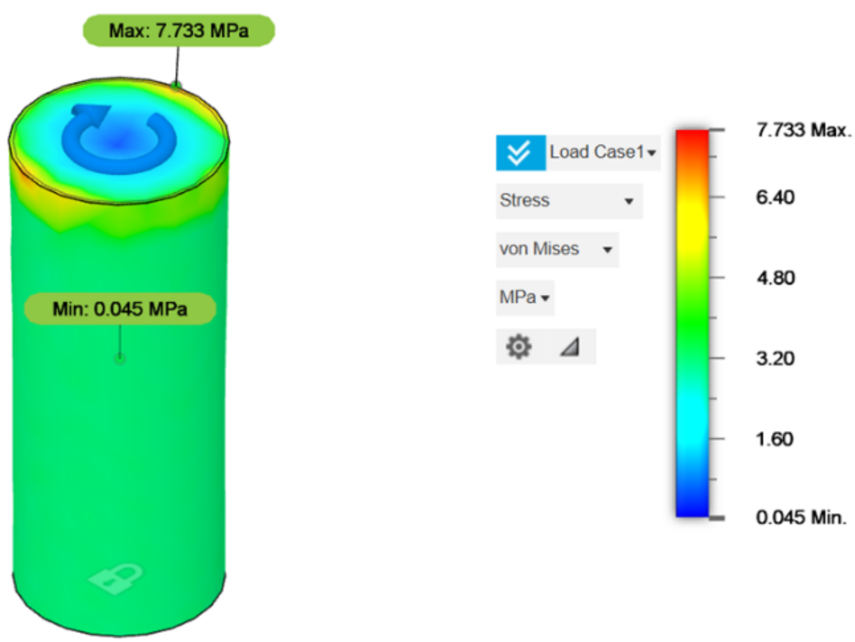

Figure 12: Simulation result for the shaft.

In general, our mechanical design appears to be theoretically safe. However, for durability assessment, further testing is required.

2.4.3 Motor Load Failure

In our design, the motor's performance is critical for the precise operation of the attack subsystem. Given the motor's specified response time of 0.12 to 0.13 seconds per 60° rotation and a working torque of 1.6 kg/cm, we must account for manufacturing tolerances to ensure the machine functions effectively. Assuming a 5% tolerance on speed and a 10% tolerance on torque, the worst-case scenario for the motor's response time can be calculated using the formula:

$$\omega_{\text{min}} = \frac{60^\circ}{\text{Response Time} \times 0.95} = \frac{60^\circ}{0.13 \text{ s} \times 0.95} \approx \frac{60}{0.1215} \approx 493.79\text{rad/s}$$

$$\omega_{\text{max}} = \frac{60^\circ}{\text{Response Time} \times 1.05} = \frac{60^\circ}{0.12 \text{ s} \times 1.05} \approx \frac{60}{0.126} \approx 476.19 \text{ rad/s},$$

which results in a range of ω_{min} and ω_{max} that must still meet the system's requirements for rapid and accurate movement. Similarly, the torque tolerance must be factored in, with the worst-case torque:

$$T_{\text{min}} = 1.6 \text{ kg/cm} \times (1 - 0.10) = 1.44 \text{ kg/cm},$$

ensuring sufficient force for the mechanical components to engage effectively. This concise analysis confirms that within the given tolerances, the motor's performance will not compromise the machine's capability to detect, track, and eliminate mosquitoes with the desired precision.

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Cost of labor

We take the average salary of UIUC graduates as our hourly wage, which is $20 per hour. Assume our team works three hours a day and five days a week, and there are 13 weeks to work. So, the total labor is $\$20 \times 3 \times 5 \times 13 \times 2.5 \times 4 = \$39000$.

3.1.2 Cost of parts

Part #	Description	Manufacturer	Quantity	Cost
1	Raspberry Pi 4B plus camera	Chuanglebo Flagship Store	1	589 RMB
2	Arduino Development Board ATMEGA16U2	Raspberry PI Retailer	1	80 RMB
3	Microphone for Raspberry Pi 4B	Raspberry PI Retailer	1	9 RMB
4	Small fan	Telesky Flagship Store	1	7 RMB
5	Single chip small car	Beikemu Flagship Store	1	30 RMB
6	Bogie	Boxi Mechanical Parts	1	90 RMB
7	L298N	Youxin Electronics	1	6 RMB
8	No.5 Nanfu Battery	Nanfu Flagship Store	24	50 RMB
Total				861 RMB

Table 5: Cost Table.

3.1.3 Sum of Costs

The grand total costs is approximately $\$40000$.

3.2 Schedule

Week	Xiangmei Chen	Peiqi Cai	Yang Dai	Lumeng Xu
3/25	Finish CAD model version 1. Finish purchases. Laser cut major parts.	Set up the running environment of Yolov8 on raspberry pi, and deploy the Yolov8 model.	Improve the YOLOv8 algorithm and start work on PCB design.	Research and identify a suitable dataset for mosquito wingbeat sounds, download and organize the dataset for further processing.
4/1	Assemble things together and test stability.	Ensure that the microphone is properly connected to the Raspberry Pi and set up the audio processing software to capture sound data.	Research on the codes and algorithms to perform data augmentation on the visual and audio datasets.	Begin coding the neural network architecture for sound classification and implement preliminary training using a portion of the dataset.
4/8	Test motor to see if the cart can move, revolute, and move up and down. Refine CAD if needed. Add features by 3D printing. Work on individual progress report.	Develop or adapt existing software to process the audio input from the microphone and detect mosquito sounds.	Collect and organize actual image and audio datasets and perform data augmentation on them.	Continue training the neural network with the full dataset. Validate the neural network's performance using a separate validation dataset.
4/15	Cooperate with detection subsystem and localization subsystem.	Create a program that can generate PWM signals to control the speed and direction of the motors connected to the servos.	Label the new datasets with a more complex background and train the model on them.	Connect the microphone to the Raspberry Pi. Set up the audio processing software to capture sound data accurately and test microphone functionality and ensure high-quality audio input.
4/22	Test the entire system. Add features by 3D printing or laser cutting if needed.	Build a PWM generation program on Raspberry Pi, responsible for sending PWM signals to the servos based on the mosquito's position in the camera's field of view.	Research on the codes and algorithms to locate the target based on the images feedback from Raspberry Pi.	Conduct tests with new, unseen sounds to verify the neural network's accuracy and begin integrating the neural network into the real-world environment for initial testing.
4/29	Make sure that the entire system is robust.	Calibrate the system for mosquito tracking, ensure that the camera and motors work in harmony.	Build the interfaces for the Yolov8 to control the rotation information contained in PWM, based on the target position.	Collaborate with the team on the design of the attacking subsystem and begin manufacturing or prototyping components for the subsystem.
5/6	Work on final report draft.	Develop or implement an algorithm that uses the mosquito's position data to control the motors, keeping the mosquito centered in the camera's view.	Test the performance of the localization subsystem in normal cases.	Finalize the design of the attacking subsystem, integrate the neural network into the system for real-time mosquito detection and response.
5/13	Work on demo and revision of individual report.	Test the system components individually.	Collaborate with other teammates with the testing on the components.	Test each component of the system individually to ensure proper functionality and identify and address any issues that arise during testing.
5/20	Prepare presentation and final report.	Ensure that the Raspberry Pi and all connected components are properly powered, and optimize power usage for efficient operation, especially if the system is battery-operated.	Ensure the performance of the device and make refinement on logic bugs.	Ensure the code can be run correctly and the connection of all parts are correct, check for overall integration.

Table 6: Schedule of the project.

4 Ethics and Safety

4.1 Ethics

A qualified project must adhere to the ethics codes outlined in IEEE Policies and ACM [4], [5]. As stipulated in the team contract, the four of us will collaborate, ensuring mutual respect and fairness. We commit to upholding these codes collectively.

Our project aims to effectively manage mosquitoes, contributing to the creation of a healthier public environment. The presence of mosquitoes has been associated with the spread of diseases and unfortunate fatalities worldwide. Our goal is to mitigate these challenges for the well being of communities globally.

Our project can be divided into three main components: mosquito detection, using a camera for mosquito localization, and mosquito elimination. Regarding the detection phase, we believe there are no ethical concerns. How ever, the use of a camera for positioning raises privacy issues, as it may inadvertently capture irrelevant people and items. To address this, we propose providing advance notifications in the experimental area to inform individuals about the monitoring process.

When it comes to mosquito elimination, we acknowledge the ethical consideration of taking a life. We respect all forms of life, and our approach ensures mosquitoes are eliminated in a humane and conventional manner. It is important to note that none of our team members endorse or derive pleasure from any cruelty towards mosquitoes.

4.2 Safety

We must prioritize the safety of both electrical and mechanical components in our project. To acquire fundamental safety knowledge, all team members will complete the UIUC online safety training. During experiments, it is mandatory for at least two teammates to be present in the lab at all times.

For electrical safety, we will use batteries as the power supply. Our group fully understands and adheres to the guide lines for safe battery usage [6]. We will routinely check the device to ensure it operates in a proper environment.

Concerning mechanical safety, potential hazards include the high-speed fan designed for mosquito elimination, which can pose a risk if fingers are inserted. The moving cart also has the potential to impact individuals, and during assembly, the gear system may pose a piercing risk. To address these issues, precautions such as keeping people at a safe distance during operations and having at least two teammates present in the lab will be implemented.

There are inherent risks associated with raising mosquitoes; if they escape, there is a risk of people getting bitten and falling ill. To mitigate this, mosquitoes will be strictly controlled within the working area, and advance notifications will be provided to individuals in the vicinity.

References

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