ECE 445

SENIOR DESIGN PROJECT

PROJECT PROPOSAL

Laser System to Shoot Down Mosquitos

Team #12
Fan Yang(fy10@illinois.edu)
Ruochen Wu(rw12@illinois.edu)
Yuxin Qu(yuxinqu2@illinois.edu)
Zhongqi Wu(zhongqi5@illinois.edu)

TA: Xinyi Xu

Sponsor: Timothy Lee

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Content

1 Introduction

1.1 Problem and Solution Overview

Mosquito bites and blood feeding can cause itchy bumps and possibly an undesirable infection. Mosquitoes cause at least 2.7 million deaths every year and about 500 million cases of mosquito-borne diseases occur annually [1]. Mosquito-borne diseases and illnesses are caused by bacteria, viruses, or parasites transmitted by mosquitoes. The most prominent mosquito-borne diseases include malaria, West Nile virus, yellow fever, dengue, chikungunya, and Zika virus. Therefore, an effective method of protection against mosquitoes is necessary. Since traditional methods like nets, incense, traps, and lotions are not autonomous, we hope to design an autonomous device to detect mosquitoes based on vision and attack them using a laser.

The design can be divided into a positioning system, an attacking system, and a power system. The main task of the positioning system is to detect a mosquito in the environment from a camera and locate its position. The attacking system moves the laser and switches the laser to kill the mosquito by emitting a high-power laser. The power subsystem supplies voltage to enable the components in the positioning system and attacking system.

For the operation procedure, firstly, the laser gun attached to the camera will emit a low-power laser to indicate the drop point, which is the position that can be attacked. We employ the yolov5s on our computation platform to do real-time detection with the input from the camera. Then, we move the camera to diminish the distance between the drop point and the mosquito until they are at the same place. This triggers the laser to emit a high-power laser to destroy the mosquito.

1.2 Visual Aid

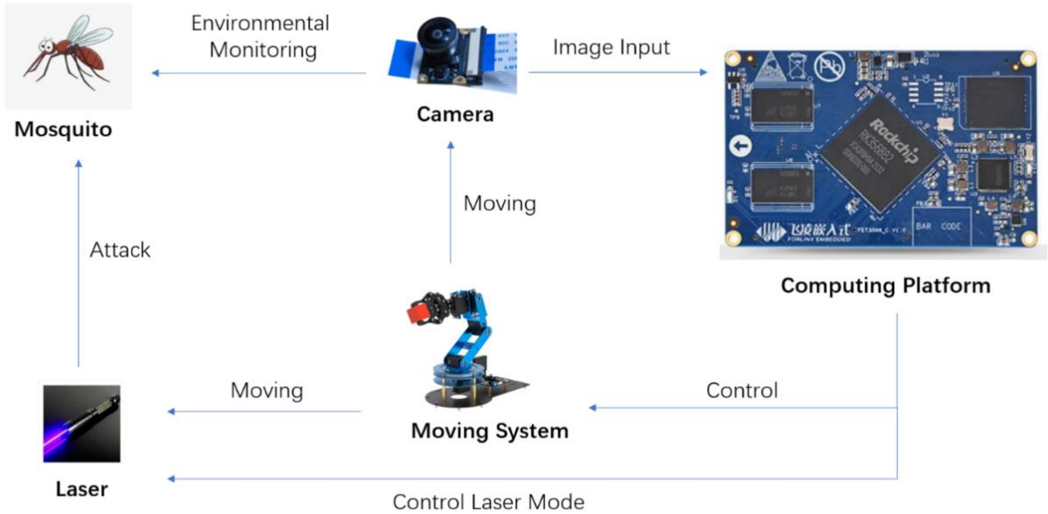

Figure 1. Visual Aid

1.3 High-level Requirements List

1. Our software was able to identify mosquitoes that occupy at least 1/20 the size of the total pixels in the image.
2. The location of the attacking point should not be more than 3 millimeters away from the mosquito to ensure that it will hit the mosquito.
3. The power of the laser should be larger enough to kill mosquitoes, so a 1 W power laser is considered.

2 Design

2.1 Block Diagram

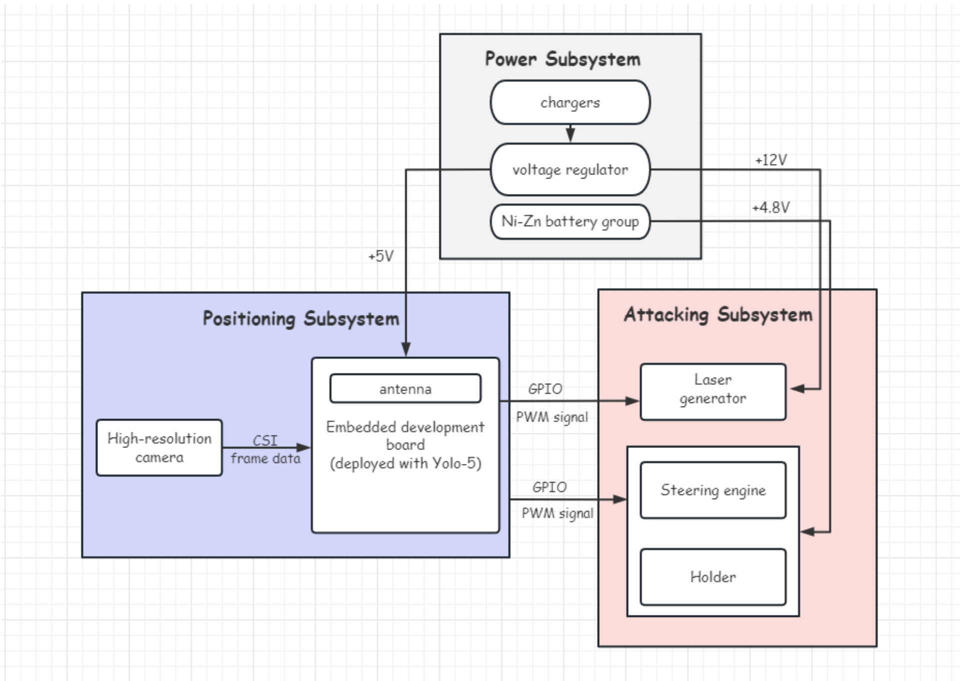

Figure 2. Block Diagram

The embedded development board deployed with Yolo-5 analyzes the images from the high-resolution camera in real-time, and detects the position of the mosquito. We will train Yolo-5 with lots of photos of mosquitoes of different sizes to make sure that our model can identify mosquitoes that occupy at least 1/20 the size of the total pixels in the image. Yolo-5 also detects and figures out the position of the drop point of the laser in the images, and compares this position with the mosquito position. We will build a program that outputs a suitable PWM signal through the GPIO interface to control steering gear movement, making the laser drop point and mosquito at the same position in the image We try to restrain the distance error within 3mm after ca hanging to a high-power laser when attacking. The laser used for attacking is larger enough to kill mosquitoes. All processes are powered by the power system with suitable voltages.

2.2 Subsystem Overview

2.2.1 Positioning Subsystem

The purpose of this subsystem is to capture the mosquito, analyze the coordinates of the mosquito and the laser, and command the attacking system. The positioning subsystem is composed of a high-resolution camera and an embedded development board. The high-resolution camera captures the surroundings which may include mosquitos and sends frames to the embedded development board.

Yolo5 is deployed on the embedded development board to detect the positions of mosquitos and the laser drop point in each frame. Then it will send the corresponding pulse signal to the attacking subsystem to control the rotation speed and direction. Also, if the laser and the mosquito overlap each other, it will send an attack-mode signal to the attacking subsystem to emit the high-power laser.

2.2.2 Attacking Subsystem

The purpose of this subsystem is to let the laser aim at the mosquito and fire a high-intensity laser to kill mosquitoes. The attacking subsystem includes the rotation module and the laser generator. The rotation module contains two steering engines to rotate horizontally and vertically respectively and a holder to hold the camera and the laser generator. according to the pulse signal from RK3399PRO, the embedded development board, the rotation module will rotate so that the drop point of the laser can overlap with the target. The laser generator chooses different power according to the mode signal from the positioning subsystem. In the positioning mode, it emits a lower-power laser to illustrate the drop point for the positioning system. In the attacking mode, the laser generator will release a killing laser to attack the target.

2.2.3 Power Subsystem

The power subsystem supplies stable voltage to the components in the positioning subsystem and attacking subsystem according to their nominal voltages. The power source is the 220v AC. There are official adapters and chargers for the embedded development board and the laser generator, which can transform 220v AC to 5v DC and 12v DC accordingly to use. Also, there are 4 Ni-Zn batteries supplying 4.8v voltage for each servo in the rotation module in the attacking subsystem.

2.3 Flow Chart

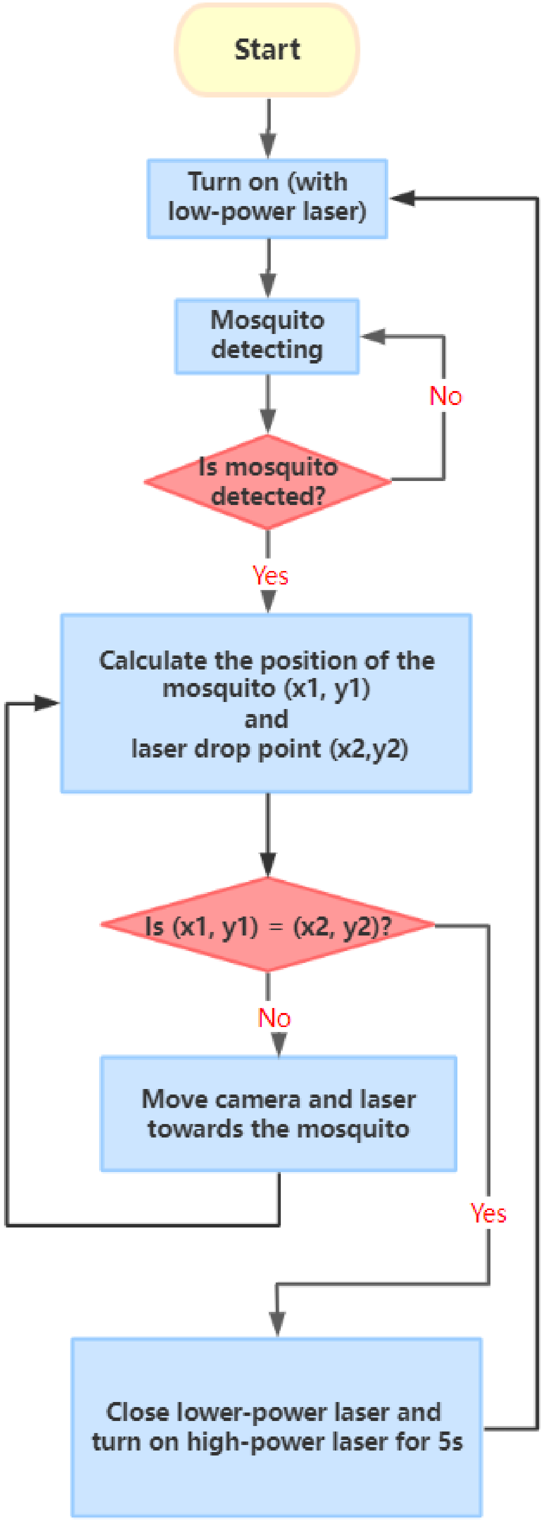

Figure 3. Overall Flow Chart

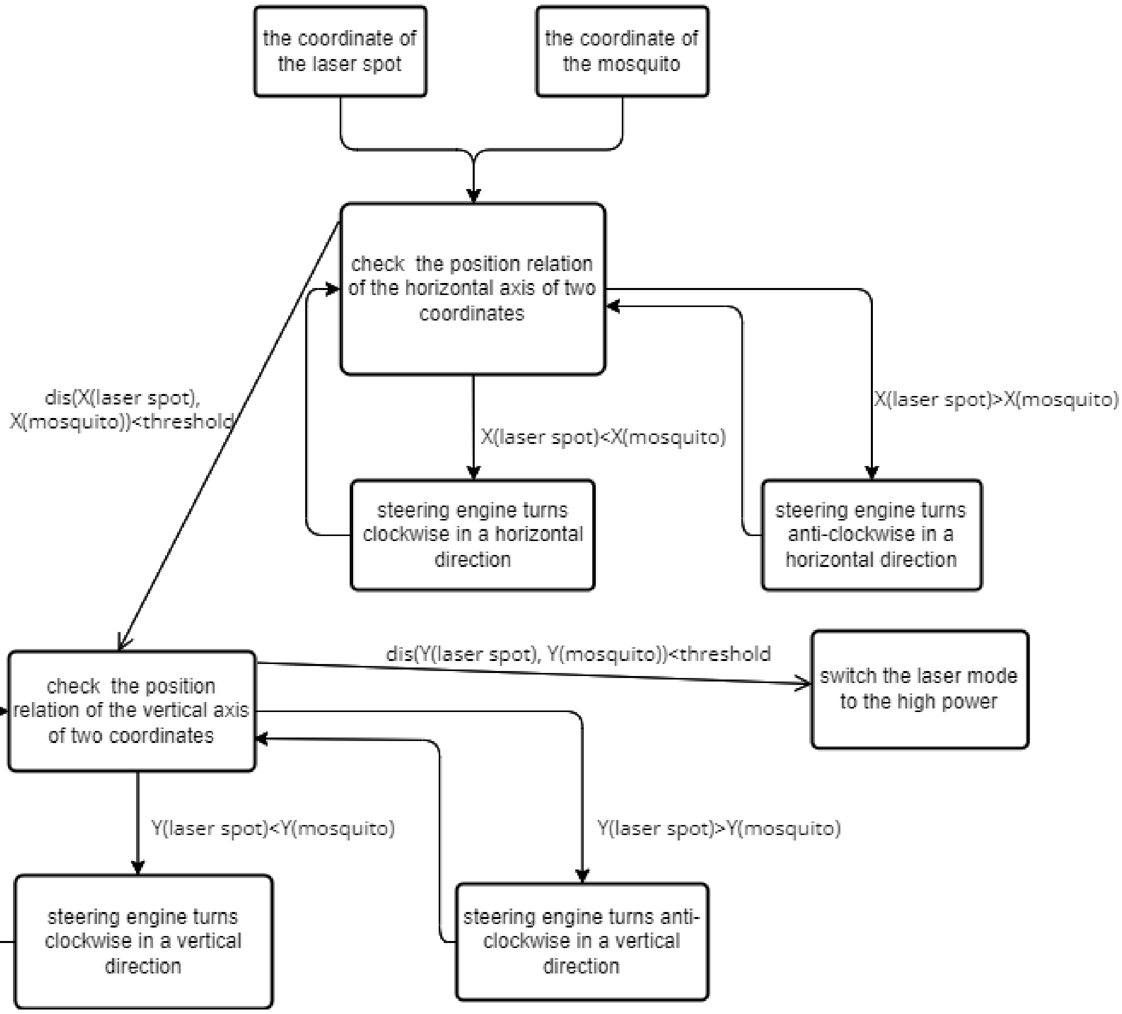

Figure 4. Attacking Subsystem Flow Chart

2.4 Software Algorithm

Our device should recognize and position the mosquito once it appears in the image. Therefore, we will use yolov5 to process the image derived from the camera. Yolov5-s is a suitable pretrained model for us to fine-tune because its demand of computing capability is not beyond our embedded board RK3588 and its pretrained weight can help us to train a mosquito recognition model more efficiently.

The input of yolov5-s is an image and the output of the yolov5-s involves multiple information of the recognized items in the image. It will return the class of the item, the probability of the classification, the x, y coordinates of the item, and the height and width of the item (it always uses a rectangle to mark the item). In our model, there will only be three classes, mosquito, laser drop point, and human.

To fine-tune our model, we collect 4000 mosquito images with different appearances in different backgrounds and manually label all the images. We also augment our dataset by resizing the mosquito size. Only in this way, can our model recognize the mosquito from different distances.

2.5 Schematics

The following are the schematics of the MIPI interface from RK3588. It can connect to our camera.

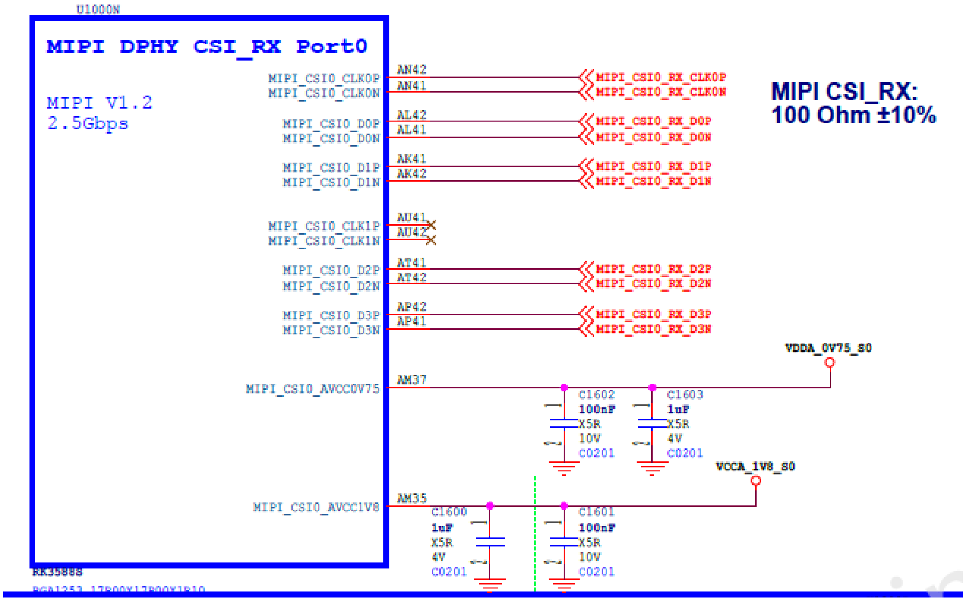

Figure 5. MIPI CSI Schematics

2.6 Physical Design Sketch

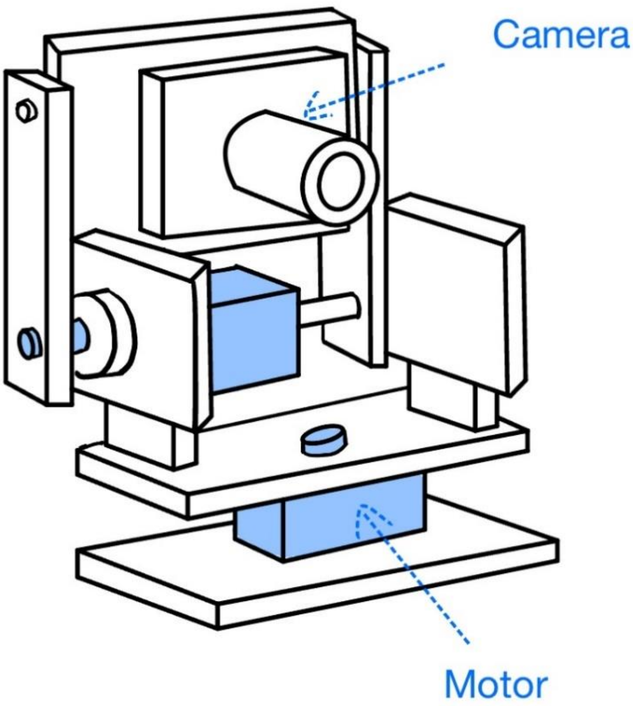

Figure 6. Camera Holder

The above diagram is a mechanical diagram of the device that controls the motion of the camera. This device has two degrees of freedom. The steering gear which is fixed to the base enables the part on top of it to rotate 360 degrees in a plane. The upper steering gear rotates the camera 360 degrees about an axis parallel to the bottom. A combination of two steering gears enables the camera to acquire the whole space images.

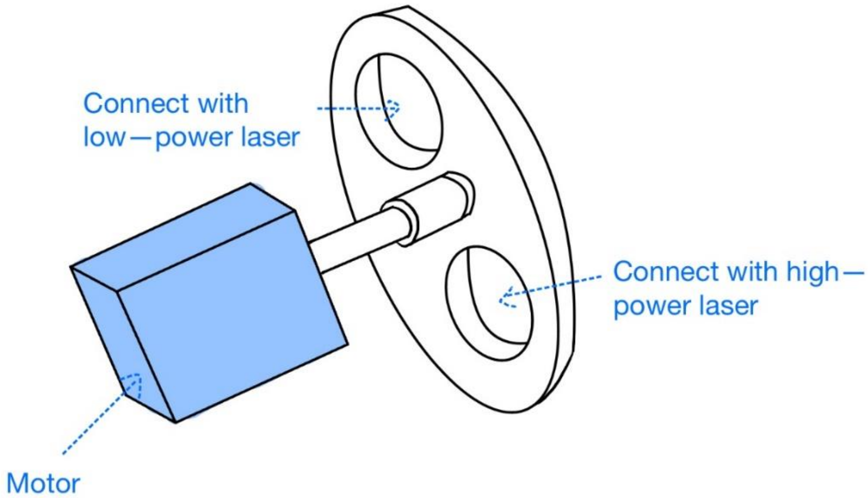

Figure 7. Laser Switch

The above diagram is a mechanical diagram of a device that can switch between the low-power laser and the high-power laser. Assume that the upper hole is used to target and attack mosquitoes, and that the hole below is in an inactivity state. Therefore, when it needs to switch laser types, rotate 180 degrees clockwise or 180 degrees counterclockwise.

2.7 Requirements and Verifications

2.7.1 Camera

Camera input data to the processor through one MIPI-CSI input interface.

Requirements	Verification
1. The camera should have resolution higher than 3200(H) x 2100(V). 2. The focal length is larger or equal to 11.54mm.	1. Connect the camera to the processor, and input one image. Check whether the resolution of the image is higher than 3200(H) x 2100(V). 2. Use a paperboard with 1cm height and 1cm width as the target object. Take the picture of this paperboard at the best working distance (300mm). Calculate the focal length of the camera.

2.7.2 Processor

The embedded development board is a processor for computing.

Requirements	Verification
1. The board needs to have the MIPI CSI interface to receive the data from the camera and image preprocessor.	1. Connect the processor with the MIPI camera. 2. Input a video with a resolution of 3200(H) x 2100(V) and 6 FPS and operate a known program

2. The board should have the ability to receive and process images with a resolution higher than 3200(H) x 2100(V) and a frame rate higher than 6 frames per second (FPS). 3. The board should support to process yolov5 model. 4. Output PWM through the GPIO interface.	on this video. Check whether the program works as expected. 3. Operate a known program based on yolov5. Confirm that the program works as expected. 4. Write a program to control PWM and test the output waveform by an oscilloscope.

2.7.3 Power Supply Unit

The power source is a 220V alternating current. It will feed the laser generator with a 12V AC and feed the embedded development board with a 5V AC through a voltage regulator. Therefore, we need to stable 220V AC to satisfy our power needs.

Requirement	Verification
1. Output 220V AC (actual voltage will be between 215V and 235V)	A. Use the uniform voltage port of 220V B. Measure the voltage with a voltmeter to make sure the voltage is between 215V to 235V

2.7.4 Adapter

This regulator will transform the 215V-225V voltage to 5V and 12V.

Requirement	Verification
1. Output 12V +/-5% voltage and 5A +/- 5% current from a 215V - 235V source.	A. Measure the output current with an oscilloscope to make sure the output current is within 5% of 5A B. Measure the output voltage with an oscilloscope to make sure the output voltage is within 5% of 12V

2.7.5 Laser

the laser generator connects with RK3399PRO, which sends a mode signal to control its power. In the general case, the generator emits a low-power laser. Once the mode signal is received, it will switch to high-power mode to kill the mosquito. The low power should be in the range of 1mW-5mW, which is the safe range for humans. The high power should be carefully selected so that it can kill mosquitos while generally not harming humans (excluding sensitive parts like eyes). The preliminary set value is 1 W.

Requirement	Verification
The laser can kill the mosquito The laser generator can be put on the holder The generator can switch power immediately once the mode signal received	Buy the laser generator with high power at least 1w. Buy the generator at proper size, or use the optical to let the laser move freely Test it with RK3399PRO and make sure it can work immediately.

2.7.6 Steering engine

Two steering engines connect with RK3399PRO, and receives an analog signal containing the message of the coordinates of the laser and the mosquito. They enable the attacking system to have two degrees of freedom, horizontally and vertically, allowing the laser to reach any direction in space. The max rotation angle of the horizontal servo should be 360 degrees. And the vertical one should be able to rotate at least 180 degrees. The rotation module should be able to run slower than 0.032 rad/s. The proof of the speed is in the tolerance analysis part.

Requirement	Verification
1. It can't shake violently while rotating 2. The speed must be slower than 0.032 rad/s 3. It satisfies the above max rotation angle	1. Test it by sending signals to it and make sure it will not shake violently especially when the laser spot is close to the mosquito 2. Fix a mosquito on the wall and make sure it can be reached by the laser spot 3. Make sure steering engines can reach any direction in space

2.7.7 Holder

The holder is placed on steering engines to hold the camera and the laser.

Requirement	Verification
It has enough strength to hold the camera and the laser	Make the holder of a load-bearing material.

2.8 Tolerance Analysis

One critical tolerance analysis is about energy loss when the laser is shooting in the air. To ensure it will have at least 1 w power when it hit the mosquito after spreading in the air, we have to recalculate the origin power when the laser is attacking. According to the energy loss in the air formula, where R is the distance(km) and α is the laser coefficient. In our case, R is at most 50 cm and α is 3.9/V for visible light. Therefore, ΔE is between 0.116% and 0.194%. Therefore, the original power $E' \quad of\ laser$ should be at least 1.002w.

$$\Delta E = E(1 - exp(-\alpha R))$$
$$E' = \frac{1w}{(1 - \Delta E)}$$

Given that the mosquito is tiny, the camera should have high resolution (choose 4096×2160 pixels) and low distortion (less than 1%). To ensure that yolov5 can recognize the mosquito with better accuracy at a distance of 30cm-50cm (ideal work environment), the software should be able to recognize the mosquito drawn by at least 2 x108 pixels (about 1/40 field of view). Then, D_{best} /v is at least 1/40.

Since w_{target} has a minimum value of 3mm, w_{CDD} should be larger than 3/25".

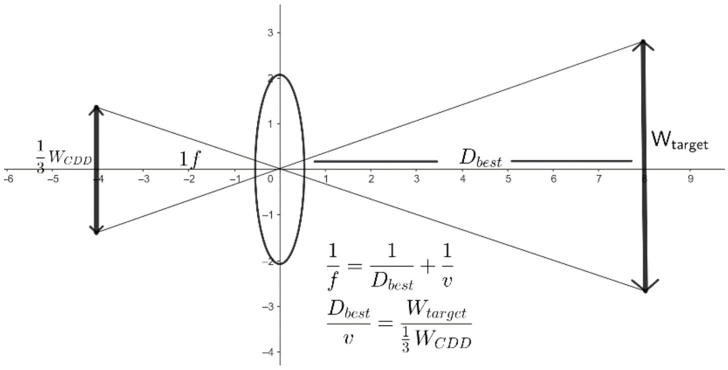

Figure 8. Derivation of proper focal length

w_{CDD} means the size of CMOS in the camera, which is 1/4" and larger than 3/25" w_{target} is the size of the mosquito, which is around 3mm~6mm.And the best work distance D_{best} is set to 30cm. According to focal length formula,

$$f = \frac{w_{CDD}\ D_{best}}{w_{CDD} + 20\ w_{target}}$$

The focal length should be around 12mm.

The rotation module must have at least two degrees of freedom, allowing the laser to reach any direction in space, which is implemented by connecting two servos with rotation axes perpendicular to each other (see Fig. 6) [5]. The max rotation angle of the horizontal servo should be 360 degrees. And the vertical one should be able to rotate at least 90 degrees. To make the laser fall precisely on the target, the minimum reachable speed of the rotation module should be (see Fig. 5 for details)

$$\omega_{min} \leq \frac{FPS\ \cdot\ W_{target}}{D_{best}}$$

where FPS represents the number of frames processed by the positioning subsystem per second (about 6 s^{-1}).

The rotation module that can run slower than 0.032 rad/s should be used.

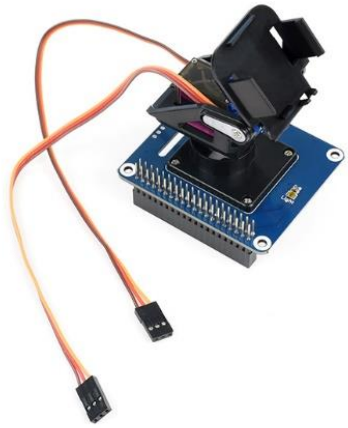

Figure 9. Two-DOF rotation module

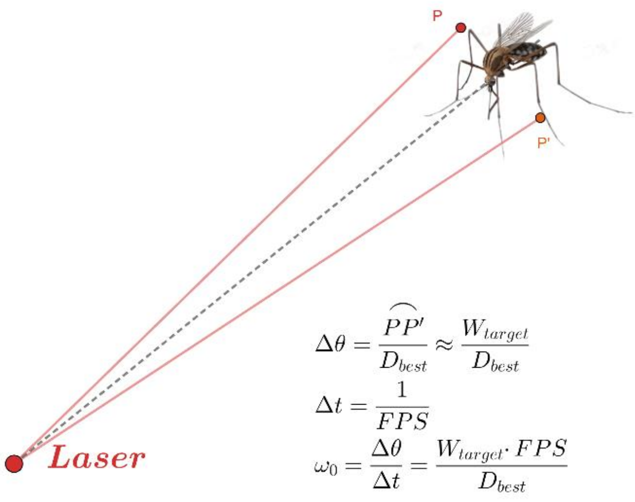

Figure 10. Derivation of ω_{min} requirement

The laser generator should be able to switch between high power and low power. The low power should be in the range of 1mW-5mW, which is the safe range for humans. The high power should be carefully selected so that it can kill mosquitos while generally not harming humans (excluding sensitive parts like eyes). The preliminary set value is 1 W.

3. Cost and Schedule

3.1 Cost Analysis

Labor:

The team members are expected to work 2 hours per day and 5 days per week, starting from Mar.20th to May.22nd. Totally there will be 45days x 2h/day = 90 h. The salary is 20 RMB/hour.

Therefore, the money spent for the total labor is 20RMB/h x 2.5 x 90h = 4500RMB

Parts:

Part #	Description	Manufacturer	Quantity	Cost
1	Camera (IMX219-77)	Sony	1	78RMB
2	Embedded Development Board (RK3399pro)	Rockchip	1	825RMB
3	Servos and pan-tilt	Yahboom	1	100RMB
4	High-Power Laser	Xinrui Tech	1	180RMB
5	Acrylic Plate	Knighthut	4	16RMB

The sum of costs in a total:
Grand Total=4500+1199=5699 RMB

3.2 Schedule

The timeline is shown in the table below. Week 1 refers to the week starting from Mar.20th to Mar.26th.

	Overall Goal	
Week1	Prepare the necessary parts and environment.	● Zhongqi Wu: Train the Yolov5 model on the basic mosquito dataset ● Ruochen Wu: Buy all the needed parts listed above. Build a PWM generation program on RK3399pro ● Yuxin Qu: Drive the camera with RK3399pro, add a mini telescope if needed ● Fan Yang: Set up the running environment of Yolov5 on RK3399pro.
Week2	Setup the subsystems	● Zhongqi Wu: Create a dataset for figures of laser drop points and train the model on it ● Ruochen Wu: Create the above dataset. Use the PWM generation program to drive the servos ● Yuxin Qu: Build the rotation module (a 2-DOF pan-tile) and test it ● Fan Yang: Deploy the Yolov5 model on RK3399pro

Week3	Optimize the subsystems	• Zhongqi Wu and Ruochen Wu: Train the model on an augmented dataset to simulate the observation from a far distance. • Yuxin Qu: Decide what kind of high-power laser should be used. Buy it and test if it can kill mosquitos. • Fan Yang: Use PWM to drive the high-power laser, use NPU (neural network process unit) to accelerate the inference of the model
Week4	Integrate the subsystems	• Zhongqi Wu and Ruochen Wu: Build the interfaces for the Yolov5 to control the rotation information contained in PWM, based on the target position • Yuxin Qu and Fan Yang: Build the circuit connecting all the hardware. Build the mechanical structure and mount all the subsystems on it (only add low-power laser)
Week5	System evaluation and refinement	• Zhongqi Wu, Ruochen Wu, Fan Yang: Test the performance of the positioning subsystem in normal cases and edge cases, make refinement on logic bugs • Yuxin Qu: Test the robustness of the circuit. Evaluate the precision of the rotation module. Evaluate the stability of the mechanical structure.
Week6	Launch high-power laser	• Zhongqi Wu, Ruochen Wu, Fan Yang Design a mechanism to avoid shooting when there is potential harm to humans • Yuxin Qu: Add a high-power laser to the laser module
Week7	Optimization	• Zhongqi Wu and Ruochen Wu: Label a new dataset with a more complex background. Train model on it. • Yuxin Qu: Label the new dataset, prepare for the mock demo • Fan Yang: Label the new dataset, optimize the detection algorithm

Week8	Test and refinement	• Zhongqi Wu and Ruochen Wu: Test the positioning subsystem and make refinement • Yuxin Qu: Test the attacking subsystem and make refinement
Week9	Application scenario extension	• All members: Discuss how we can extend the application scenario of our system. For example, enable the system to work at a farther distance. Enable the system to work at night. And implement it.

4. Discussion of Ethics and Safety

4.1 Ethics

Our project aims to kill the mosquito with a powerful laser. It will impose a great positive influence on killing mosquitoes efficiently and widely in some areas that suffer from the disease and death brought by mosquitoes. However, lasers not only brought efficiency and a wide range of attacks, but they also brought some potential safety problems. For example, a laser with high power that can kill mosquitoes can also hurt people in some way.

According to IEEE Ethics term 1 [7] and ACM Ethics term 1.2 [8], protecting the health of people is our first principle. Therefore, in our project, we should use a model with high accuracy and double check to avoid the laser going out of control to hurt non-mosquito objects. In other words, we have to improve our accuracy in recognizing a mosquito and shoot it after we make sure it is indeed a mosquito.

Another ethical issue is about privacy. Because we have to use a camera to monitor the surrounding environment to identify whether an item is a mosquito a not, it is unavoidable to identify some private items or people. IEEE Ethics [7] and ACM Ethics [8] both focus on the importance of privacy. To avoid private data leakage, we would delete it after finishing the identification.

4.2 Safety

4.2.1 Electrical safety

Since our device will rely on electricity, electrical safety should be considered in our project. According to basic electrical safety at the University of Washington [9], we should prevent electrical shock, and electrical explosions during our device work. Therefore, checking the device to ensure each component is connected properly and not placed in a wet environment is the premise.

4.2.2 Environment safety

Also, during detection, the laser with low power will move freely in the room, it may hurt people's eyes if there are people in the work area. Therefore, we want to keep people away from the work area after the device starts. It means we would use a manipulator to start and end it remotely. Just in case, we will also set up a mechanism that limits the moving trail of the laser to avoid people when detecting the mosquito.

4.2.3 Work mechanism safety

When the device detects the mosquito, it will shoot it with a laser of high power until it finds the mosquito dead. It raises a concern that if the laser shoots one spot for a long time, it may cause danger. To address this problem, we will improve the accuracy of identifying the vital signs of mosquitoes by using multiple methods to check. We will also limit the time of the continuous shooting. For example, the device can only emit a laser for 5 seconds at most. After that, it will automatically stop for 15 seconds and then restart.

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