24-671 Special Topics: Electromechanical Systems Design

Safeguard Against Pests

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Team 4

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1. Executive Summary

The SAP project has been created to tackle the crucial issue of pest infestations, with a particular emphasis on lantern flies. These pests not only annoy but also pose a significant threat to agriculture and home gardening. Traditional pest control methods typically involve the use of chemicals, which carry environmental and health risks. In this context, there is an evident need for an efficient, sustainable, and self-sufficient solution.

Key Customer Needs and Design Description

Customers, mainly homeowners and farmers, need a pest control solution that is effective, easy to use, and environmentally friendly. The Solution for Automated Pest Control (SAP) is designed to meet these requirements by incorporating the following features:

- Autonomous Operation: The SAP is equipped with motorized movement, which allows it to navigate through various terrains, providing hands-free operation.
- Precision in Pest Control: The SAP uses a sophisticated computer vision system based on YOLO models to accurately identify pests, ensuring targeted treatment.
- Environmentally Friendly Approach: The SAP's design minimizes chemical usage, aligning with the rising demand for sustainable pest control methods.
- User-Friendly Interface: The system is designed to be easily operable by non-experts, making it accessible to a broad range of customers.

Final Prototype Functionality and Evaluation

The latest version of the SAP project showcases an exceptional amalgamation of technological advancement and practical application. The key features of the prototype are:

- Efficient Pest Identification and Elimination: The turret mechanism, coupled with the computer vision system, guarantees accurate targeting and elimination of pests.
- Sustainability and Safety: The prototype reduces the dependence on chemicals, promoting a safer and more sustainable approach to pest control.
- Market Feasibility: The preliminary tests indicate that the prototype has a high potential for market adoption, considering its effectiveness and user-friendly design.

To conclude, the SAP (Safeguard Against Pests) project aims to tackle the issue of pest infestations, particularly lantern flies, which can cause significant harm to agriculture and home gardens. The project focuses on meeting the needs of customers who require effective, autonomous pest control that minimizes environmental impact and reduces chemical usage. The SAP system features a computer vision system that uses YOLO models to identify pests accurately. It also includes a turret that allows for targeted pesticide application, motorized movement for autonomous operation, and an environmentally friendly approach. The final prototype has been evaluated for functionality and effectiveness and has a balance of simplicity and technological sophistication, making it a promising solution for homeowners and farmers seeking sustainable pest control methods. This user-friendly and innovative system represents a significant advancement in pest management technology.

2. Problem Definition

Problem description

Markets addressed and primary competitors

There are some developing prototypes for different pest control options, but most are currently unavailable for the market.

The mosquito control robot by SMP robotics is one of the few options available for purchase. The mosquito control robot is able to lure in mosquitoes with CO_2 emissions and then use air suction to capture them. This method is effective but requires constant emissions. Our robot will stick to pesticide that can be used in concentrations, making it more environmentally friendly.

Figure 1: Mosquito Control Robot

An agricultural pest control robot is being developed by Kansas State Researchers. The robot is designed to use AI to track pest infestations to apply pesticide in concentrated areas. Because it is designed for agricultural use, multiple robots must be used and communicate with each other throughout a huge area. Our prototype will also apply AI to track and apply concentrated bursts of pesticide, but will require less computation since it will be suited for home garden use.

Figure 2: Agricultural Pest Control Robot

Another prototype being developed is the cockroach laser deterrent, which uses stereo vision to detect and calculate distance of a cockroach. Once calculations are made a laser is pointed to deter the cockroach away. Due to the small hardware, the computation is slow and limited. Our prototype aims to use faster computation to identify and track targets.

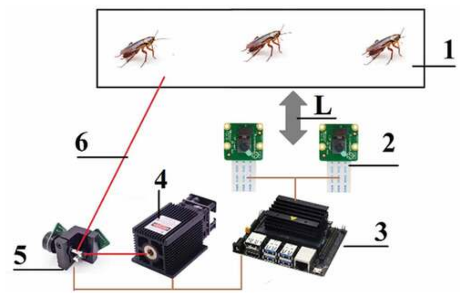


Figure 3: Cockroach Laser Deterrent

Assumptions and constraints (2 pages)

3. Stakeholders and Customer Needs

Stakeholder identification plays a crucial role in pest control robot projects. It ensures that the robot's design and functionality meet the needs and expectations of all direct or indirect participants. The main stakeholders of this project are homeowners and gardeners who face pest infestations, local communities that prioritize environmental sustainability, and potential investors who are interested in innovative pest control solutions. Additionally, environmental agencies, health organizations, and regulatory agencies are also key stakeholders since they are concerned about the impact of traditional pest control methods on the environment and health. Academic institutions and researchers are also important stakeholders as they can benefit from the technological advancements and insights into autonomous pest control systems that the project offers. Identifying and engaging with these stakeholders is crucial for shaping a robot that not only meets end users' needs but also adheres to ethical, environmental, and legal considerations.

To determine the objectives of our final prototype, we conducted a google form survey to CMU students, friends, and family members. Our survey focused mostly on receiving responses from people on CMU campus that had experienced the recent lantern fly infestation. WIth a total of 27 responses, the following results were obtained:

- Problem Environment
  - The most prevalent pests are insects, which are almost 5 times as prevalent as the second highest option. Lantern flies also fit into this category but the issue could extend to other

common bugs

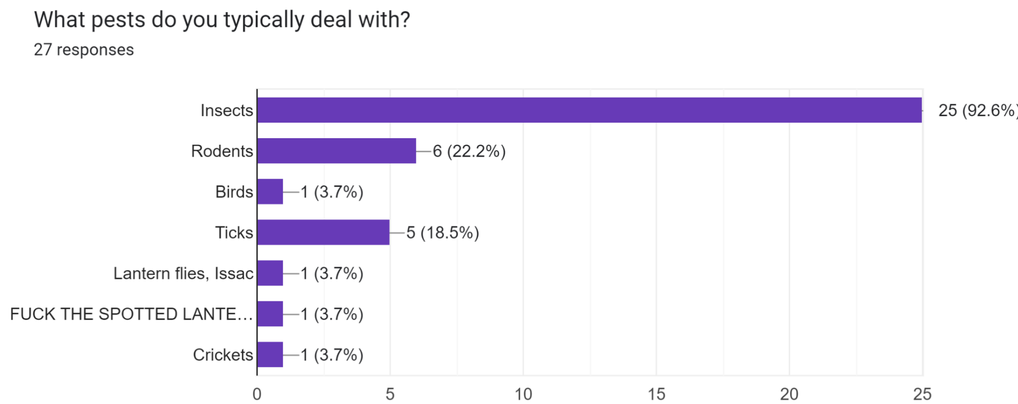


Figure 4: Common Pest Survey Question

- Most pest issues occur in outdoor environments, reaffirming our decision to design our robot for a home garden environment.

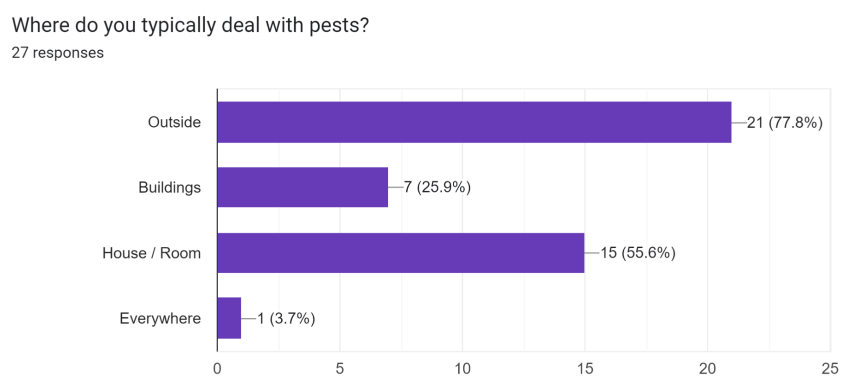


Figure 5: Environment Question

- Conventional Methods
  - Most respondents use a blunt object, traps, and pesticide spray. These methods are common due to their availability through many different retailers and affordability.

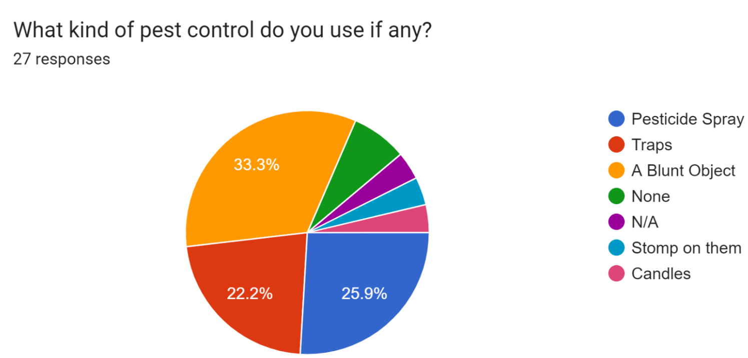


Figure 6: Common Methods Question

- Limitation 1: less than 75% accuracy for 65% of respondents. Having a prototype with high accuracy would differentiate our product.

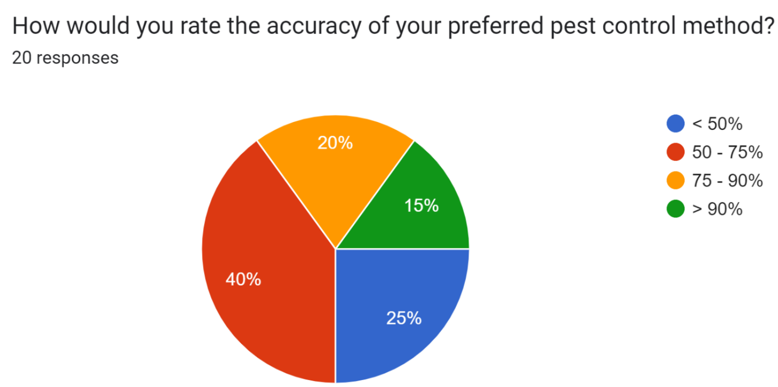


Figure 7: Accuracy of Common Methods Question

- Limitation 2: Most conventional methods have a short range of less than 5 feet. Having a prototype with a large range would differentiate our product.

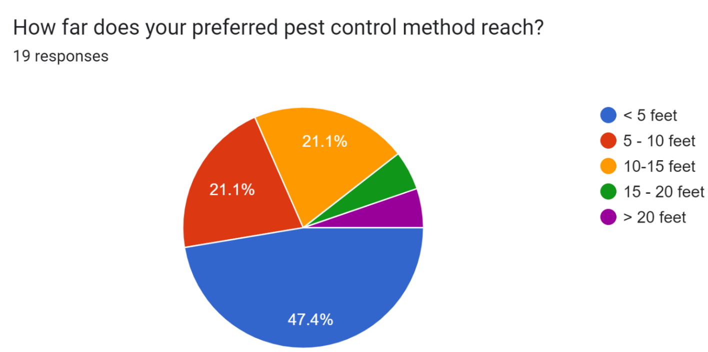


Figure 8: Preferred Method Range Question

- Limitation 3: Requires repeated manual work/setup, most used pest control methods once a month or greater. If setup can be limited to once a month, our product would have a competitive advantage over conventional methods that may be more affordable.

What are the disadvantages to your current pest control option ?

They keep on coming

Needs effort to keep going.

Requires active use.

Requires manual spraying

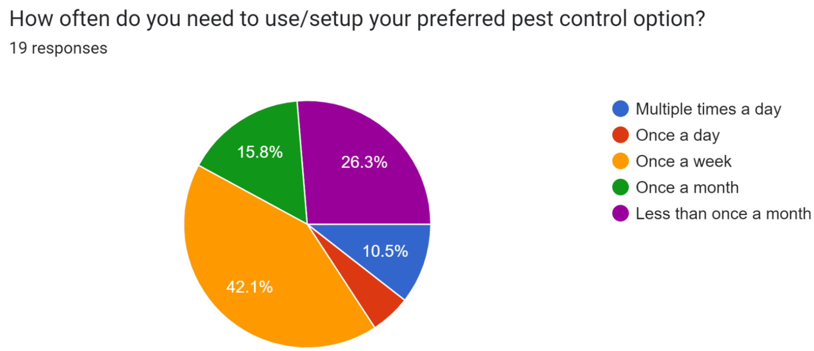


Figure 9: Input for Common Methods Question

- Public Attitude to Pest Control
    - Environmental concern is the largest priority, followed by health concerns and effectiveness. Most users will be concerned about the amount of pesticide used based on this response.

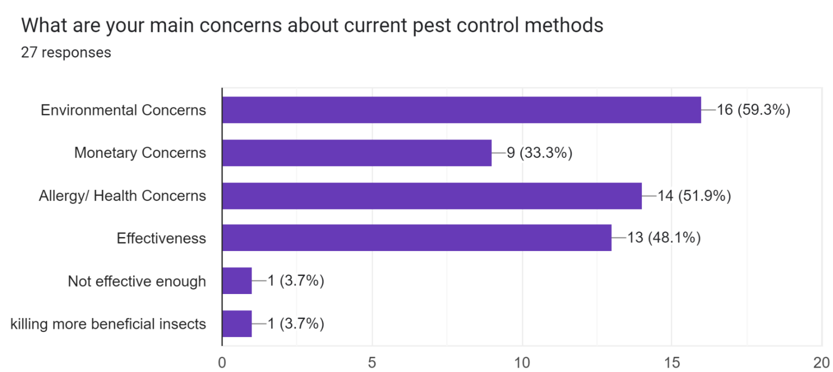


Figure 10: Main Concerns Question

Based on the results, the following needs were determined. The first two needs are categorized as basic needs since they differentiate our product from retail options and are the most popular concerns. The performance needs are still crucial to make our product more satisfactory to customers, but would not solely justify the increased price of our prototype unless basic needs were met.

Number	Need	Priority
1	The robot operates for long periods autonomously	B
2	The robot is environmentally friendly	B
3	The robot has high accuracy	P

4	Has large effective range	P

Table 1: Customer Needs Table

4. Target Specifications

Based on the needs list and survey results, the following metrics were established:

1. Minimum Liquid Storage
2. Maximum Liquid used per Insect
3. Minimum Battery Life
4. Minimum Accuracy Rate
5. Minimum Shooting Range

Metrics 1-3 all determine how long the robot can operate autonomously. Even if our robot is able to detect and shoot without any human input, replenishing liquid or battery often would remove the autonomous aspect of our project. We aim to set the replenishment rate for the liquid and battery to be equal, but we believe it is easier to replenish liquid and can afford for that rate to be higher. Metrics 2 and 3 determine environmental friendliness and how often resources are used. Insuring that these metrics are minimized ensures that our product is desirable for customers that are conscious about the harmful effects of pesticide and energy consumption. Metric 4 and Metric 5 directly measure the 3rd and 4th need into a comparable value. Finding a cutoff value that is not only high, but also marketable will differentiate our product.

When looking for comparable products to do a competitive analysis, there were issues finding products that had all metrics that we would measure. Only the agricultural pest robot had all features that our robot contained, but information was limited due to the prototype still being in development. It was decided to complete the competitive analysis with blunt objects and pesticide spray since they are common retail options. To obtain competitive metrics, specifically metric 4 and 5, we referred to the survey answers we obtained and filtered for each method. Because of how differently our competitive products behave to our prototype, the competitive analysis had constraints for the first three metrics. For battery life, it was determined that it would be the minimum amount of times a user had to provide manual input. These values were also obtained through the survey. Unfortunately, there was no simple solution to obtain the first two metrics in the competitive analysis. To overcome this issue, we obtained marginal and ideal values for metrics 1 and 2 by pairing comparisons with metric 3. For example, since battery life has a marginal value of .5 to reduce manual setup, values for storage and per insect volume are chosen so that no replenishment is needed until half a month.

Ideal values for metrics 3, 4, and 5 were chosen not only by the main two comparisons but also by the comparison of other products and the survey. The ideal range was chosen by comparing the range of water guns. The ideal battery life and accuracy took into account all survey responses. Liquid storage, liquid per insect, and battery life are our most important metrics since they relate to our basic needs. Accuracy and range are still important for performance needs, but marginal values are more lenient.

Metric #	Need #	Metric	Unit	Importance (1-5)	Comp A	Comp B	Marginal	Ideal
1 (Min)	1	Liquid Storage	L	4	0	0	1	2
2 (Max)	1, 2	Liquid per Insect	mL	4	0	0	35	25
3 (Min)	1, 2	Battery Life	month	5	.25	.25	.5	1
4 (Min)	3	Accuracy Rate	%	3	90	75	75	90
5 (Min)	4	Shooting Range	ft	3	2	3	5	10

Table 2: Target Specifications

5. Concept Generation

Functional Decomposition:

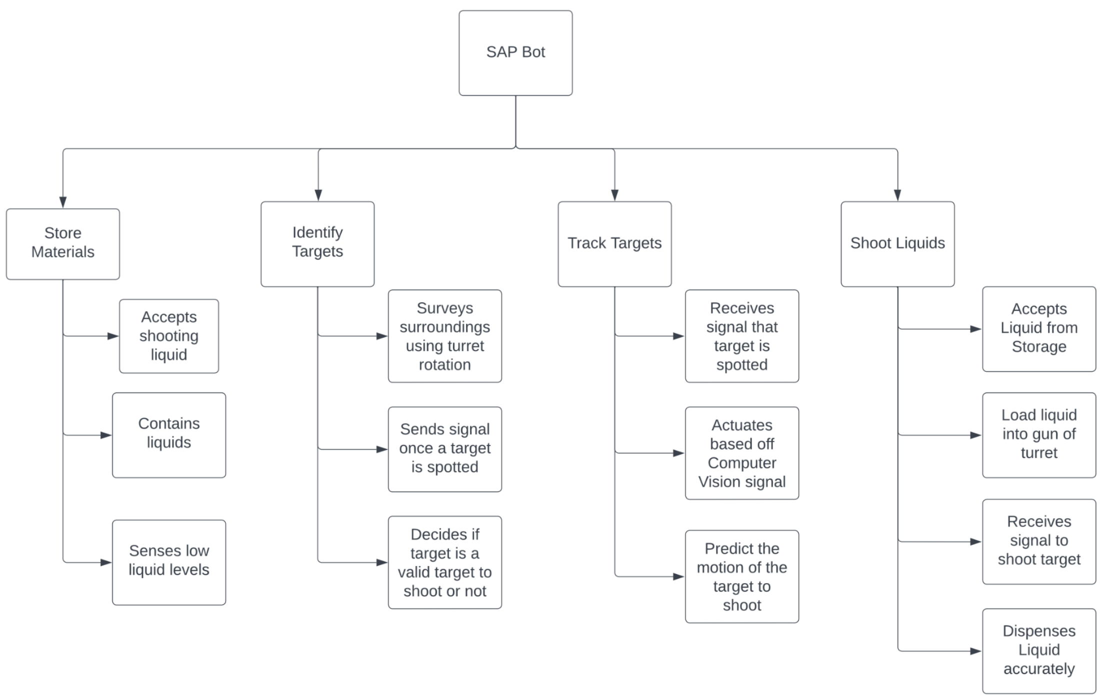


Figure 4:

Functional Decomposition tree showing four of the main subsystems of our design. Below each of the subsystems, we can see some of the main functions for each of them.

Store Materials:

This subsystem is responsible for storing the materials we need for the operation of the design. The main material we are concerned about is the shooting liquid. This subsystem should allow the user to fill a container with the shooting liquid of their choice, and this container should store it until it needs to be dispensed. Another main function of this subsystem is sensing the liquid level. The subsystem should be able to sense when the liquid level is low in the container and should notify the user through a visual signal.

Identify Targets:

This subsystem is responsible for identifying possible targets to shoot at in the near surroundings and confirming that it is a target we need to shoot at. This will take care of constant 360-degree surveillance of the surroundings by rotating the camera around until a potential lantern fly is spotted in the frame. When a target is seen, the subsystem should decide whether or not this object is actually a target we need to shoot at, as it is possible that other pests or animals can be in the frame. Once it is confirmed that the target is valid to shoot at, a signal of its current location should be sent to the Track Targets subsystem to aim at the target correctly.

Track Targets:

This subsystem is responsible for tracking the valid target's location and aiming the shooting mechanism directly at the target. This subsystem will receive the location of a seen valid target, and this subsystem will start rotation of the shooting mechanism to aim it in line with the target. The subsystem should detect if this target has moved by the time the mechanism is in line with the signaled location, if it has, the subsystem will send signals of its real-time location to follow the target's new location. This subsystem will also send a signal to the shooting liquid subsystem once the target is not moving and the mechanism is aiming at the target to shoot liquid at it.

Shooting Liquids:

This subsystem is responsible for actually shooting the liquid at the target. Once the signal has been received that the shooting mechanism is currently aiming at a valid target, this subsystem should dispense some amount of shooting liquid at a high enough flow rate to kill the target. This subsystem should only use liquid that is stored in the liquid container from the Store Materials subsystem. Ideally, this subsystem should determine if we have killed the target or not, by detecting any movement by the target once it is shot. If it can be confirmed that the target is not moving, we can ignore this particular target when surveying the surroundings for more potential targets.

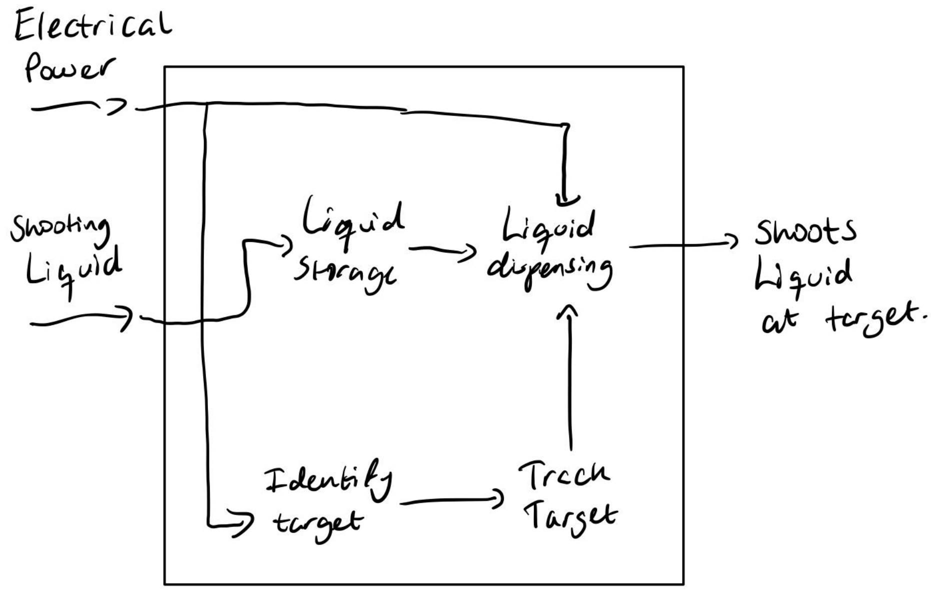


Figure 11:
The black box diagram of our design shows how each subsystem will interact with each other to produce successful outputs and results. Inputs would be electrical power supplied to the system and the actual shooting liquid to be dispensed. A successful output would be dispensing liquid at a valid target in the surroundings.

<u>Sub-System Concepts:</u>

Identify Targets (Object Classification):

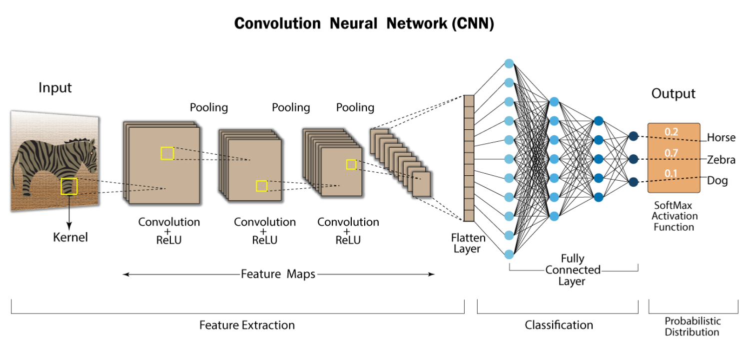


Figure 12:
Convolutional Neural Network Concept

In terms of identifying the lantern flies, we came up with four concepts to complete this task. The first one was using a convolutional neural network to act as a classifier for the objects found within the camera scene, where the objects would be found via an object recognition algorithm. In terms of the object recognition algorithm, we will most likely be using openCV for the recognition and segmentation.

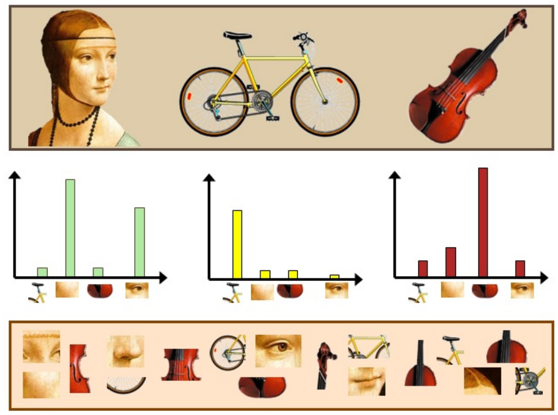


Figure 13:
Bag of Words Approach

We also thought about using a Bag of Words Approach with K-Nearest-Neighbours classification. This would require us to identify relevant features within the camera scene and then create a histogram of these features, thus creating the bag of words. Once these features are extracted we can use K-Nearest Neighbours to classify whether the features within an image correspond to the object we are trying to classify. Overall, this approach is comparable to the convolutional neural network in terms of classification ability, however since we are only worried about identifying lantern flies this approach would be unnecessary since it's used to identify multiple objects. We also identified simple template matching and color matching as potential concepts. These concepts are further explained in the appendix.
Track Targets:

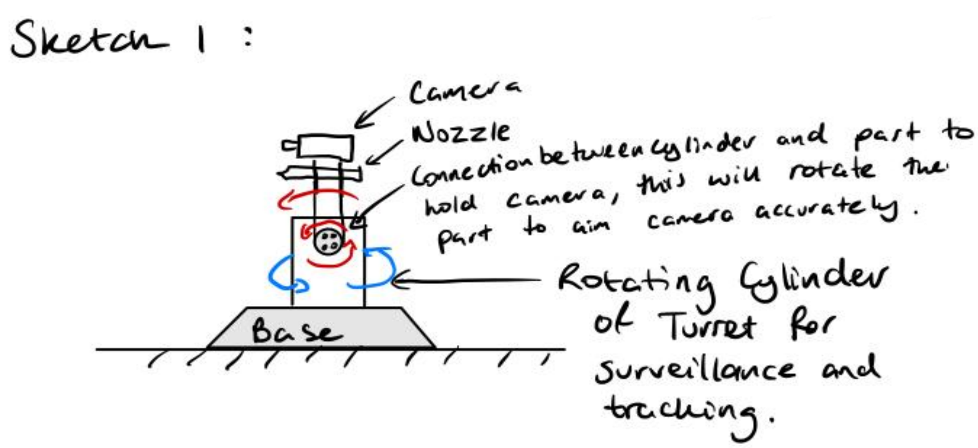


Figure 14:
First sketch of a concept for the Track Targets subsystem.

This sketch shows an initial concept for achieving all the main functions of the track targets subsystem. The rotating cylinder in the sketch allows us to have 360-degree surveillance of the surroundings, and this cylinder is what would contain the liquid as well. Connected to this same cylinder would be an attachment that controls the pitch of the camera and nozzle (shooting mechanism). This attachment allows the subsystem to accurately aim at the target when a location is given as a signal. Once the nozzle is aimed at the target, a signal is sent to dispense liquid at the target.

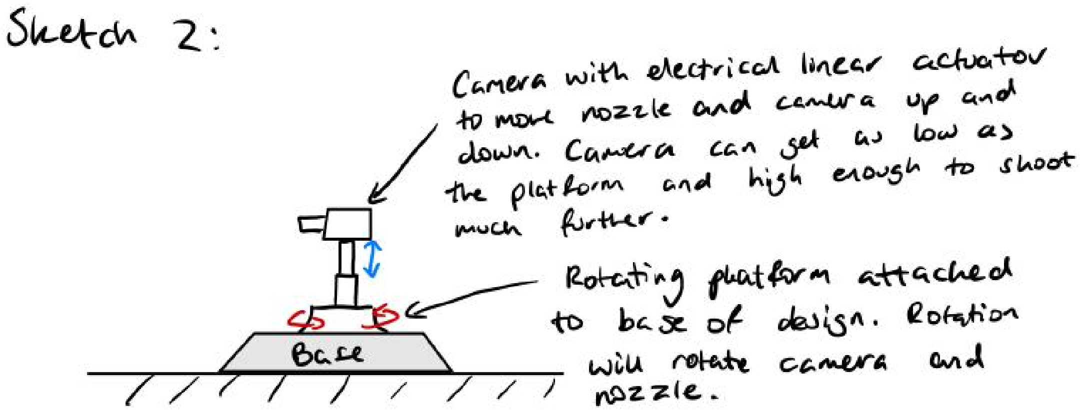


Figure 15:
Second sketch of a concept for the Track Targets subsystem

This sketch shows another concept that we generated for this subsystem. This concept consists of a different rotating mechanism, as there is just a rotating base that holds onto the camera and nozzle, rather than having the whole cylinder rotate. This rotating base will allow for the 360 degree surveillance as we want for this subsystem. For this concept however, there is no pitch, rather we have a linear actuator that moves the camera and nozzle vertically to aim and shoot at the target. This mechanism for aiming should achieve similar results for aiming and accuracy. This is because we can vary the horizontal distance the liquid goes by varying the vertical height of the nozzle.

Shooting at Targets:

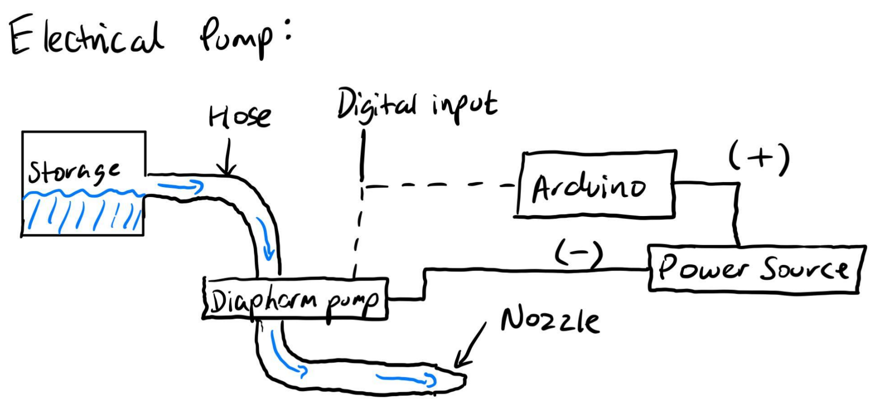


Figure 16: Electrical Pump Sketch Configuration

This sketch shows the electric pump configuration. For this concept, an electric diaphragm pump would displace the water in the storage container straight to the nozzle. The pump would have electrical connections attached to the power source and the arduino, with the arduino digital input completing the circuit when instructed. Hose connections would need to be provided to connect the storage to the pump and the pump to the nozzle. Because of hose connection flexibility in path and length, the placement of the physical components can vary based on other needs.

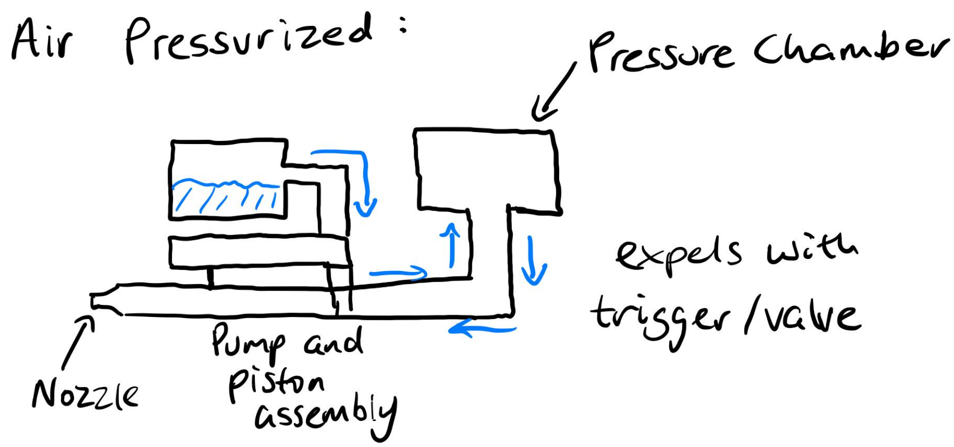


Figure 17: Pressurized Air System

This sketch shows the air pressurized concept, which is heavily inspired by traditional super soakers. Through linear actuation of a pump and piston assembly, the water in the storage is moved to the pressure chamber that already has air. As pumping continues, the chamber's pressure increases. When the valve is opened, all the water in the chamber is expelled at a high speed based on the pressure. The location of the chamber and storage does have some flexibility with the use of one way valves. The ability for the chamber to hold high pressures is a determining factor for how fast the water can be expelled. Arduino digital inputs can be used to move the pump.

Storage of Materials:

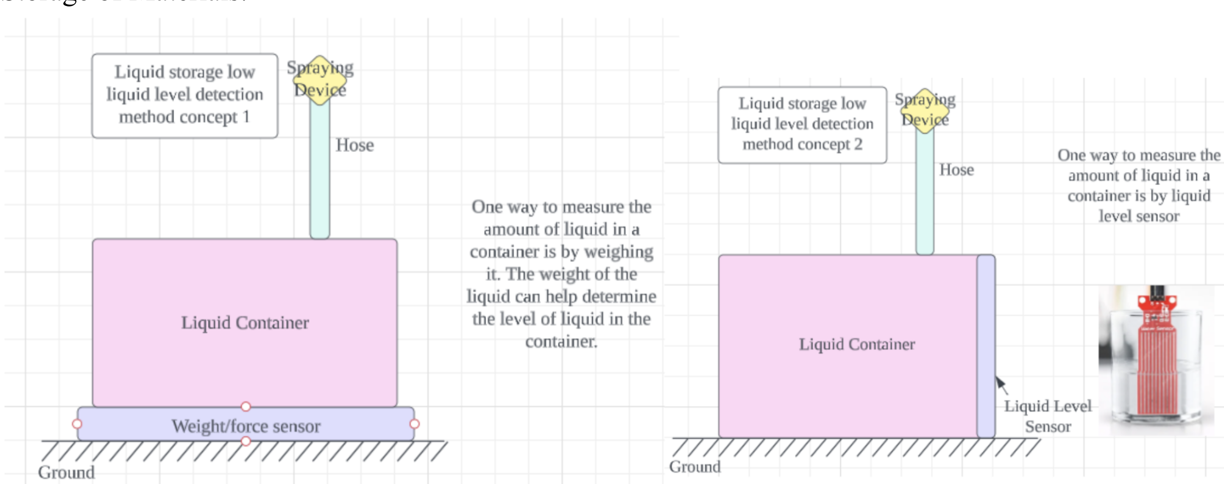


Figure 18:

Liquid Level Detection Method Concept (Concept 1 uses a force sensor on the left, while Concept 2 on the right uses a liquid-level sensor.)

The Figure above illustrates two different methods for measuring liquid levels in a container. Concept 1 involves using a force sensor to measure the relationship between changes in gravity force and changes in liquid level caused by the container during use. This allows us to infer the liquid level in the container by measuring the gravity force of the container itself.

Concept 2, on the other hand, is more straightforward. By installing a liquid level sensor in the container, we can directly measure the level of liquid inside the container.

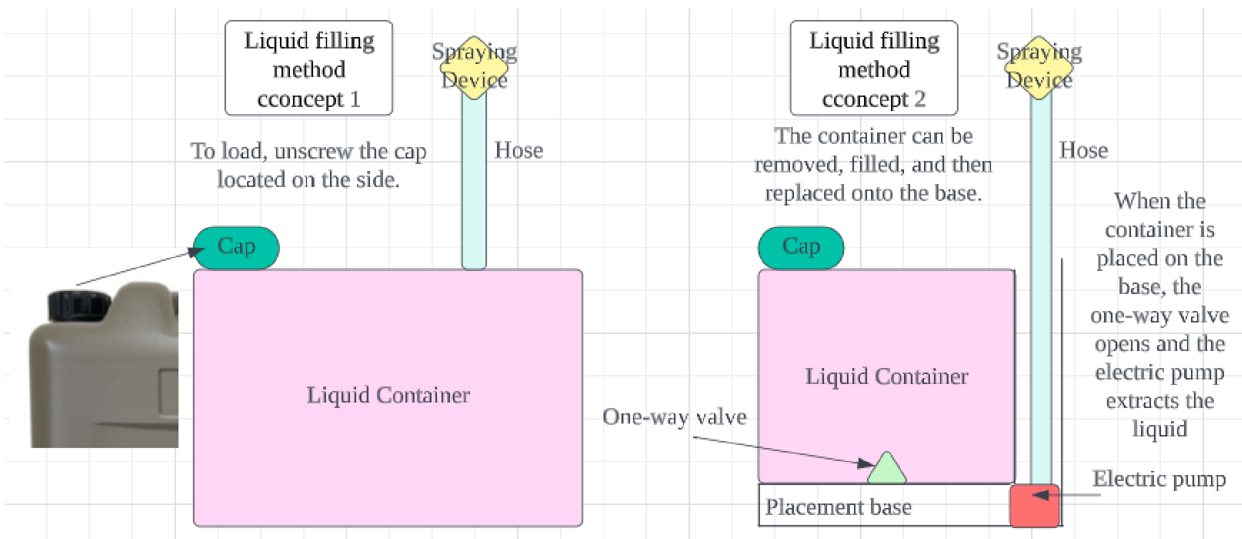


Figure 19:
Liquid Filling Method Concept (Concept 1 uses a simple on the left, while Concept 2 on the right uses a one way valve.)

The figure above demonstrates two distinct methods of filling containers. In concept 1, the liquid container is fixed to the ground, and a simple screw cap is located above the container. Refilling the container is as easy as unscrewing the cap and pouring the liquid directly into the container.

Concept 2 is slightly more complex than concept 1. In this case, the liquid container can be removed individually, and just like in concept 1, there is a simple screw cap at the top of the container to open and fill. Once the filling process is complete, the container should be placed back on its base. The protrusion on the base will open the one-way valve at the bottom of the container, and the liquid will flow to the electric pump through gravity, completing the entire filling process.

6. Concept Selection

After deciding on our top concepts for each subsystem, we created whole system concepts. The following table below shows the different whole system concepts we created and the individual sub-system concepts that compose them.

Table 3: Concept Grouping

System Concept #	Liquid Level Detection	Liquid Filling and Pressurization	Identify Targets	Track Targets	Shoot Liquids
1	Weight/Force Sensor	Simple Cap	Neural Network	Rotating Cylinder and Tilt	Electric Pump
2	Liquid Level Sensor	One Way Valve	Neural Network	Rotating Cylinder and Linear Actuation	Air Pressurized
3	Weight/Force Sensor	Simple Cap	Neural Network	Height Controlled Linear Actuation and Rotating Platform	Piston Pump
4	Weight/Force Sensor	Simple Cap	Bag of Words	Rotating Cylinder and Tilt	Electric Pump
5	Liquid Level Sensor	One Way Valve	Bag of Words	Rotating Cylinder and Linear Actuation	Air Pressurized
6	Weight/Force Sensor	Simple Cap	Bag of Words	Height Controlled Linear Actuation and Rotating Platform	Piston Pump
7	Weight/Force Sensor	Simple Cap	Color Matching	Rotating Cylinder and Tilt	Electric Pump
8	Liquid Level Sensor	One Way Valve	Color Matching	Rotating Cylinder and Linear Actuation	Air Pressurized

From these system concepts, we used a screening matrix to find our top five system concepts based on our identified selection criteria. The following matrix below shows our concept selection screening matrix, with the highlighted concepts being our chosen concepts. We used the Autonomous Pest Control Robot as our reference for the concept selection screening.

Table 4: Concept Selection Screening

Selection Criteria	Autonomous Pest Control Robot	1	2	3	4	5	6	7	8
Feasibility	0	1	1	0	1	-1	0	1	0
Precision	0	1	0	-1	1	1	-1	-1	-1
Minimal Complexity	0	0	0	0	-1	-1	0	1	0

Large Workspace	0	1	1	-1	1	1	-1	1	-1
Less Parts	0	0	-1	1	0	0	1	0	1
Totals	0	**3**	**1**	**-1**	**2**	**0**	**-1**	**2**	**-1**

As shown in the table, our selection criteria focused on ensuring that the robot would be within scope while also prioritizing the performance of the robot. For instance, to ensure that our robot would be within scope, we used minimal complexity, fewer parts, and feasibility as our selection criteria. Then, we included precision and a large workspace to ensure that our requirements, in terms of customer needs, would be met. This led us to select system concepts number 1,4,5 and 7.

We then took these concepts and used a scoring matrix to further help select our final system concept. The matrix below shows our selection matrix including the main scoring criteria we considered. We highlighted our final system concept in green and our secondary concept in yellow.

Table 5: Concept Selection Scoring

		System Number				
Scoring Criteria	**Weight**	1	2	4	5	7
Pest Identification	0.7	4	4	4	4	1
Easy to Refill	0.4	5	3	5	3	5
Can Be Used In the Dark	0.4	4	3	2	2	1
Precise and Accurate Shooting	0.7	5	4	5	4	5
Pest Detection Range	0.5	4	5	4	5	4
Pest Shooting Range	0.6	5	3	5	1	3
Total		**14.9**	**12.3**	**14.1**	**10.7**	**10.4**

For our final concept selection, we selected criteria that were directly related to our requirements and customer needs. For example, we included a pest shooting range and pest detection range criteria to ensure that our robot's workspace satisfied our requirement of being about 10 feet. The weights for the matrix were chosen based on the overall importance of the criteria to our project. We found that pest identification and precise and accurate shooting to be the most important criteria for our robot. Overall, after scoring each of the system design concepts we found that system number 1 to score the highest.

Storage material subsystem:

For our storage material subsystem, we decided to use concept 1 for both the liquid level detection method and the liquid filling method. We considered using concept 2 for the liquid level detection method, which is more direct and easier to implement, but it requires placing the sensor inside the container. This is challenging due to the container being relatively closed, making it difficult to position the sensor correctly within the container. Additionally, we must consider the wiring, routing, and waterproofing of the wiring in the container. Thus, the use of concept 1 for the liquid level monitoring method is more suitable.

Regarding the liquid filling method, we chose concept 1 because it is easier to implement than concept 2. While concept 2 is more convenient for users to fill, it has a relatively complex structure that requires us to consider the airtightness of the chassis. Completing concept 2 within the given time limit of the course may not be feasible, so we opted for concept 1.

Track target subsystem:

For our final choice of the track target subsystem, we decided to combine features from both sketches 1 and 2, however, the main ideas are from the first sketch. The combination of these sketches comes from using the rotating platform rather than the rotating cylinder, as it would be easier to have a rotation of the camera and this makes the design much less complex when achieving the same results. But for controlling the camera and nozzle directly, we moved forward with the concept from the first sketch, where we controlled the pitch, rather than moving vertically with a linear actuator. This is because we are given more freedom for the camera and nozzle when we can control the pitch, and accuracy and precision would be significantly better for the nozzle if we can change the pitch rather than the height. If we are varying the height, we would be using equations of projectile motion to hit a target, but this would need to be calculated in real time and then the nozzle must be configured to this certain height, just for it to not be very accurate. Instead, actually aiming directly at the target would be much more effective for our main functions. When looking at the selection matrix criteria, the combination of these concepts produces the greatest pest detection range and shooting range, which are very highly weighted criteria points for our prototype. This gave us plenty of evidence to conclude that we will be using this final concept for the subsystem.

Shooting subsystem:

For the shooting subsystem, we looked into scoring for accuracy/precision as well as feasibility and complexity . The electric pump configuration provides the most consistent shooting power, increasing accuracy and precision. Feasibility is also easier because the assembly is very simple and component locations are flexible. When looking at other concepts, the arduino requires linear actuation and it becomes an extra factor taken into account when testing if the proper power is being applied. Furthermore, large amounts of concentrated space is needed for the other concepts. While the total assembly for the electric pump concept is not small, the space taken is spread out into different components across the entire robot. These advantages were considered during scoring and we concluded that the electric pump configuration is the best concept for the subsystem.

Identify targets subsystem:

Considering that the robot will be used outside and in variable environments, we must ensure that our identification process can handle any vision challenge we encounter. For example, we must consider variable viewpoints when looking at the lantern fly, variable illumination due to the sun since the turret will be outside, and even any occlusion that may occur with other objects within our scene. These challenges would make it hard to identify lantern flies with simple algorithms such as template matching. Therefore, we would need to use a data-driven approach, such as some sort of machine learning / deep learning approach, in order to compensate for these potential challenges. Thus, this leaves us with the bag of words approach and convolutional neural network as our main concepts for the identification of lantern flies. Furthermore, if we consider the fact that our robot should be able to function at night, with possibly some illumination provided by a stationary light source, a convolutional neural network would be more effective than a bag of words approach. Feature extraction and clustering would be hard to do with footage taken at night since some features would be hidden thus increasing potential noise due to lack of illumination. This would render this approach unusable by our standards which is why system one, which uses a neural network, has a higher score than system four.

With our final system design chosen based on the matrix, we created our CAD model to reflect our chosen sub-system concepts and requirements. The following figure depicts our CAD model with each subsystem highlighted.

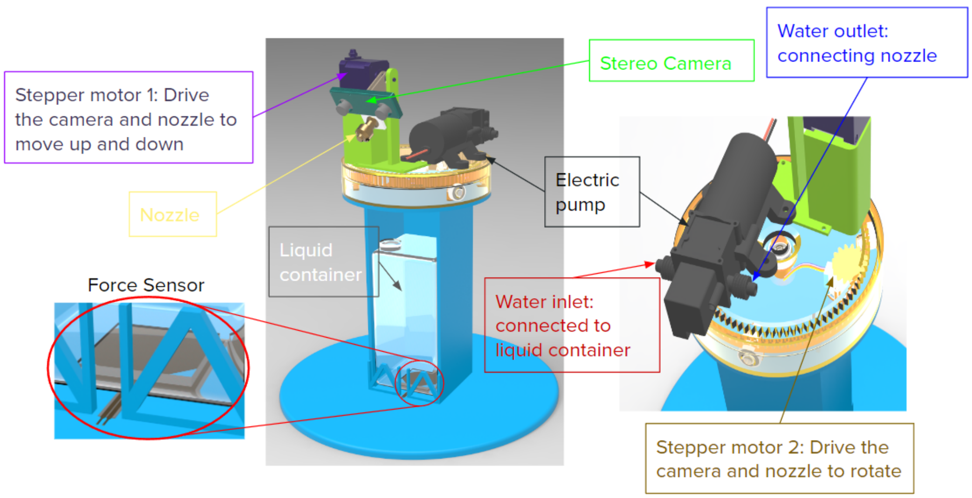


Figure 20: Initial Prototype CAD Model

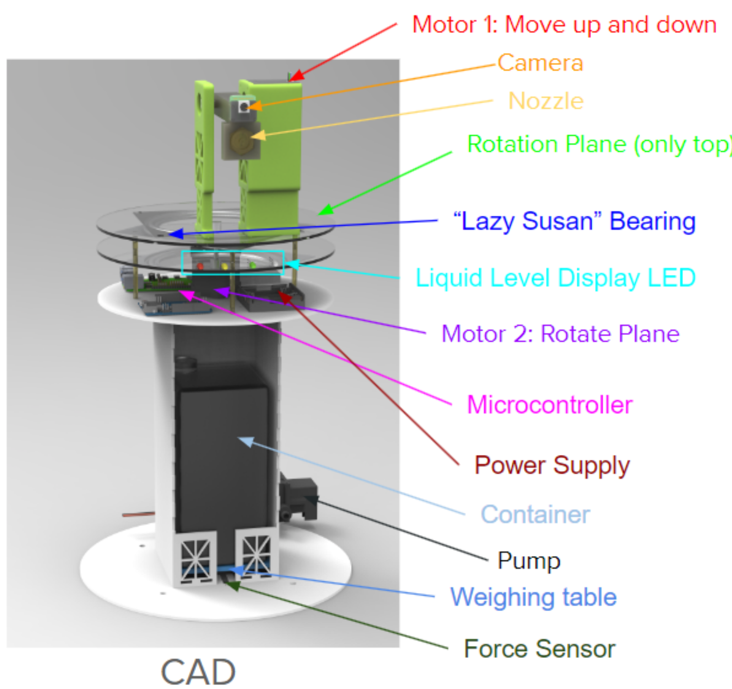


Figure 21: Final Prototype CAD Model

7. Detailed Design and Engineering Analysis

Storage Subsystem:

The storage subsystem only includes a force sensor pad. This sensor is essential for determining the liquid level in the container and reminding users when it's time to refill. Therefore, it's crucial to analyze the detection effect of the liquid level. Its working principle is based on detecting the gravity (voltage reading) of the container placed above the weighing platform (as shown in Figure 000). This data is combined with actual observed data to derive a fitting equation between the two sets of data (as shown in Figure 111). Once the fitting equation is obtained, the robot only needs readings from the force sensor to estimate the liquid level in the container.

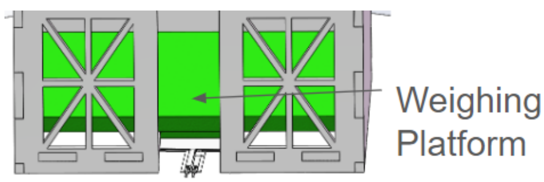


Figure 22: weighing platform above force sensor

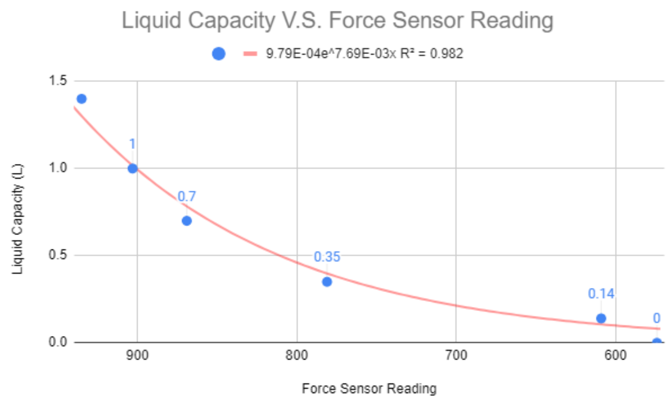


Figure 23: Fitting equations based on force sensor readings and observed quantity

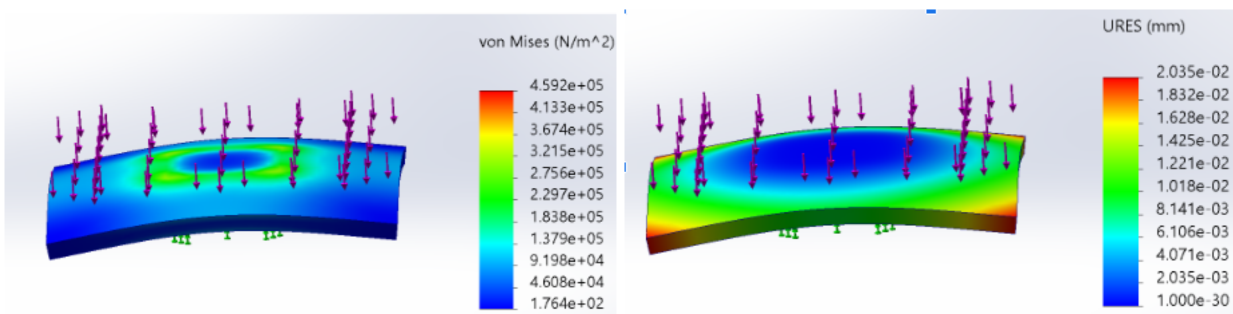
The following analysis involved measuring and recording the actual capacity of the force sensor readings and observations. The recorded data is presented in Table 00. From the data, we can observe that the percentage error generally increases as the liquid level in the container decreases. Although the overall percentage error is not perfect (% error>5%), this is due to the characteristics of the force sensor itself. However, the data is still within an acceptable range because the project is mainly concerned about liquid levels less than 25%. When the liquid level is less than 25%, it indicates that users need to refill the container. The percentage error for this level is 13.05%. The theoretical residual liquid in the container is 400ml, while the actual observed residual liquid is about 350ml. The difference of 50ml between them is only the amount of additional one shot by the robot (approximately 48ml), so such errors have little impact on customer usage and experience.

Theoretical quantity (L)	Observed quantity (L)	% of Error
1.30	1.4 (100%)	7.63
1.01	1 (75%)	1.10
0.78	0.7 (50%)	11.20
0.40	0.35 (25%)	13.05
0.11	0.14 (10%)	24.70

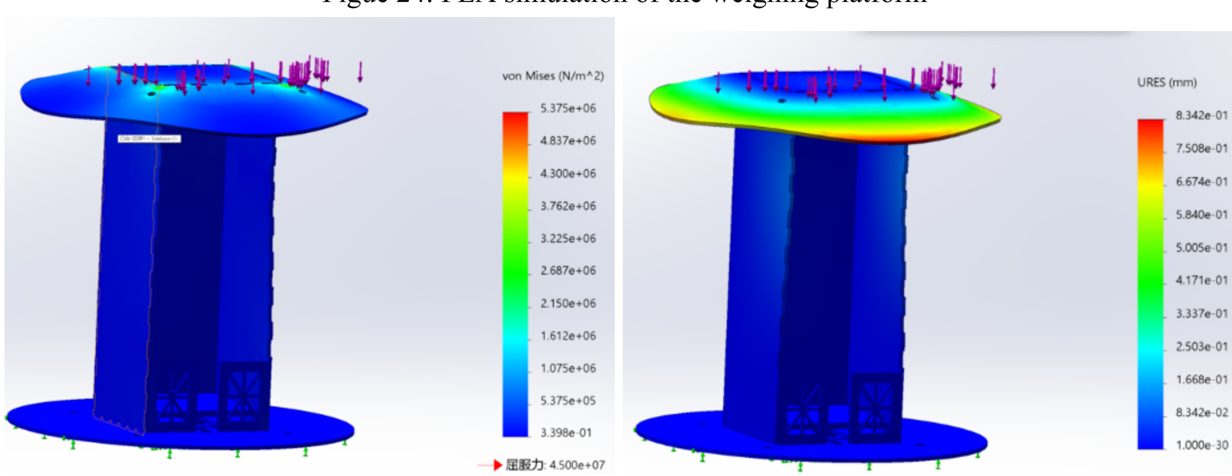
0.08	0.01(Assuming residual)	705.39

Table: Recorded the actual capacity and theoretical quantity

It is important to conduct a finite element analysis (FEA) on the weighing platform and the main weighing plate of the robot. These two components carry most of the weight of the robot. The analysis assumes that the force is evenly distributed on the force surface and ignores the impact of the hose mass on the robot. The aim of this analysis is to ensure that the stressed components can withstand the expected load without excessive deformation or failure. The FEA simulation of the weighing platform and weighing plate is displayed in Figure 24 and 25.



Figue 24: FEA simulation of the weighing platform



Figue 25: FEA simulation of the weighing plate

Based on the FEA simulation results, the weighing platform can withstand a uniform force of 1.4kg (13.72N) with a maximum deformation of less than 0.021mm. The von Mises stress distribution shows that stress levels are lower than the yield strength of the PLA material, indicating that the weighing platform meets the project's requirements. Additionally, the weighing plate can bear a force of 3kg (29.4N, 30% chance) with a maximum deformation of less than 0.84mm. The von Mises stress distribution results show that stress levels are also lower than the yield strength of acrylic materials, indicating that the weighing plate meets the requirements for project use.

Shooting Subsystem:

When analyzing the shooting subsystem, it was crucial to see how concentrated our nozzle was and measure overall precision/repeatability. Our nozzle and pump assembly was taped to a vertical support and shot from our ideal distance. A target was constructed with the bullseye representing the dimensions of a typical lantern fly. Marks were made for each half inch offset from the target for simple calculations. 8 trials marking the concentration of the burst and the contact location were added.

Trial	Hit Target (T/F)	Spread (in)	Offset y (in)	Offset x (in)
1	F	1.5	1.25	0
2	F	1.5	1.25	0
3	F	1.5	1.25	0
4	F	1.5	< -2.5	0

Trial	Hit Target (T/F)	Spread (in)	Offset y (in)	Offset x (in)
5	F	1.5	1	-1.25
6	F	1.5	1	-1.75
7	F	1.5	-1.75	0
8	T	1.5	0	0

Figure 26: Shooting Analysis Results

When taking these trials and placing them in a heat map, the following results are shown:

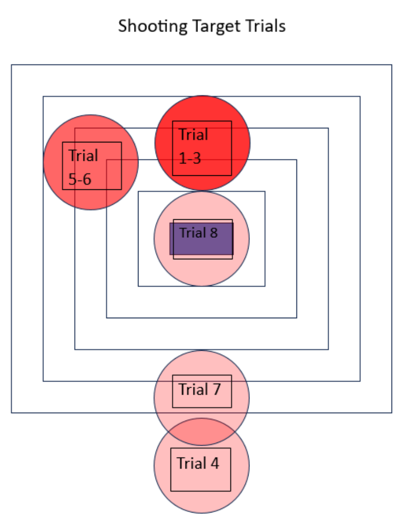


Figure 27: Shooting Analysis Heat Map

The biggest takeaway was the switch from a standard hose nozzle to a sprayer tip nozzle. The concentration was much higher than the target size at 1.5 in radius. Furthermore, the standard hose nozzle concentration is not standardized because the outlet diameter can be changed. Our analysis had issues maintaining a consistent contetration without slight manual input. The nozzle switch ensures that the outlet diameter is still small but is more concentrated at the center from farther distances.

Although the tape initially held firm, seen by the consistent precision in the first few trials, it slowly began to loosen and vary contact location. Despite issues, this observation gave our team the confidence that our precision would be strong as long as the motor could firmly hold the nozzle still. To ensure stability, motor torque analysis was done for the track target subsystem (shown below)

Once the nozzle was changed and we had confidence in our motor hardware, integrated analysis with the storage subsystem helped determine the flow rate and helped reduce the amount of pesticide being shot. We first calculated the average rate for 10 seconds, which gave us a flow rate of 40mL per second. Trying to only shoot an ideal burst amount, we turned the pump on for .75 sec which led to an undeveloped shot that slopped out of the nozzle without strength. With trial and error, the nozzle developed to full strength at 1.2 seconds which leads to an estimate of 48 mL per burst.

When looking at standards to follow, ISO 9906 is a standard for rotodynamic pumps and provides performance measures to ensure the pump is performing to an appropriate standard. Although it is intended for rotodynamic pumps and not positive displacement pumps, some tests can still be applied to test general quality. Aspects such as power efficiency, volume rate of flow, head loss, and pipe friction loss can be observed and tested.

Identification Subsystem:

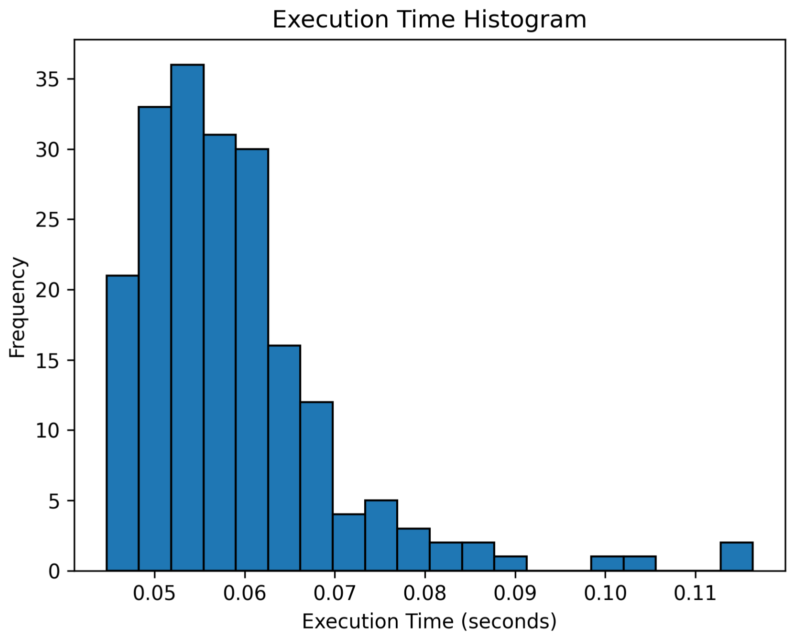


Figure 28: The execution times for 16 sample images being analyzed by the CNN. The times were gathered on a Ryzen 4500.

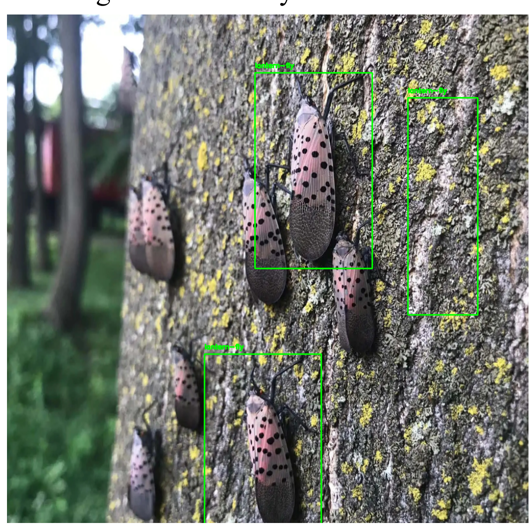


Figure 29: CNN and Selective Search Output

Initially, most of the analysis for the identification subsystem revolved around optimizing the accuracy of the Convolutional Neural Network that we were utilizing. This meticulous analysis involved extensive training, fine-tuning, and validation procedures using relevant datasets to enhance the network's ability to accurately identify objects within images. We would essentially create a model, train the model, evaluate the model, and then tune one of the numerous hyperparameters and restart the process to see whether there was improvement in the model. Techniques such as data augmentation, transfer learning, and adjusting network architecture were explored to the fullest in order to enhance the CNN's performance in accurately detecting and classifying objects. Although we were able to refine our execution time to sub 90 milliseconds (see the figure 15 above) for object detection, using the selective search algorithm was simply too expensive. The algorithm took about 15 seconds to run resulting in this approach simply being inadequate. Furthermore, we found that the Neural Network was simply inaccurate in categorizing images spacially, resulting in it missing subjects as demonstrated in Figure 16 above.

Figure 30 : Output from YOLO Model

As a result of these findings, the focus shifted towards not just accuracy but also the efficiency of execution, leading to the realization that although the CNN produced accurate identifications, its speed was insufficient for real-time processing, hence necessitating the transition to the YOLO model. This transition was crucial to ensure a balance between accuracy and real-time performance, addressing the limitations encountered with the initial CNN-based approach for object identification within the computer vision system.

The adoption of the YOLO (You Only Look Once) model transformed the identification subsystem by capitalizing on a unique single-pass and grid-based approach, which notably enhanced the system's speed and operational efficiency. Unlike conventional methods that relied on multi-stage algorithms for object detection, YOLO's single-pass architecture streamlined the process by predicting bounding boxes and class probabilities directly from the entire image in a single evaluation. This streamlined approach significantly reduced redundancy and computational overhead, enabling rapid and accurate object detection without the need for multiple passes or complex region proposal networks.

Further optimizing its speed, YOLO's grid-based methodology divided the input image into a grid, allowing simultaneous predictions within each grid cell. As a result of transitioning to YOLO, the total execution time for object detection within the computer vision system witnessed a remarkable decrease, achieving an impressive 500 milliseconds. The model was also more spatially aware, resulting in even more accurate detections as shown in Figure 17. This substantial improvement in both speed and accuracy was pivotal in enabling real-time capabilities for object identification, meeting the performance requirements across various applications and scenarios.

<u>Tracking Targets Subsystem:</u>

For this subsystem, we analyzed two major problems we encountered when prototyping. The first problem was ensuring that the stepper motors we were using were powerful enough to move the weights of all the parts that needed to be moved. We initially used a more inexpensive stepper motor with a very lower torque rating, so we needed to analyze our subsystem to determine the minimum torque rating needed for the pitch and yaw of the surveillance. The other problem we encountered with this subsystem was actually powering the stepper motors and their drivers. We would often run into issues related to powering the motors and seeing a decrease in torque and performance due to this issue. The goal of this analysis was to find a suitable and realistic power source that was reliable for when we needed to demo the prototype and for when this product would go to market.

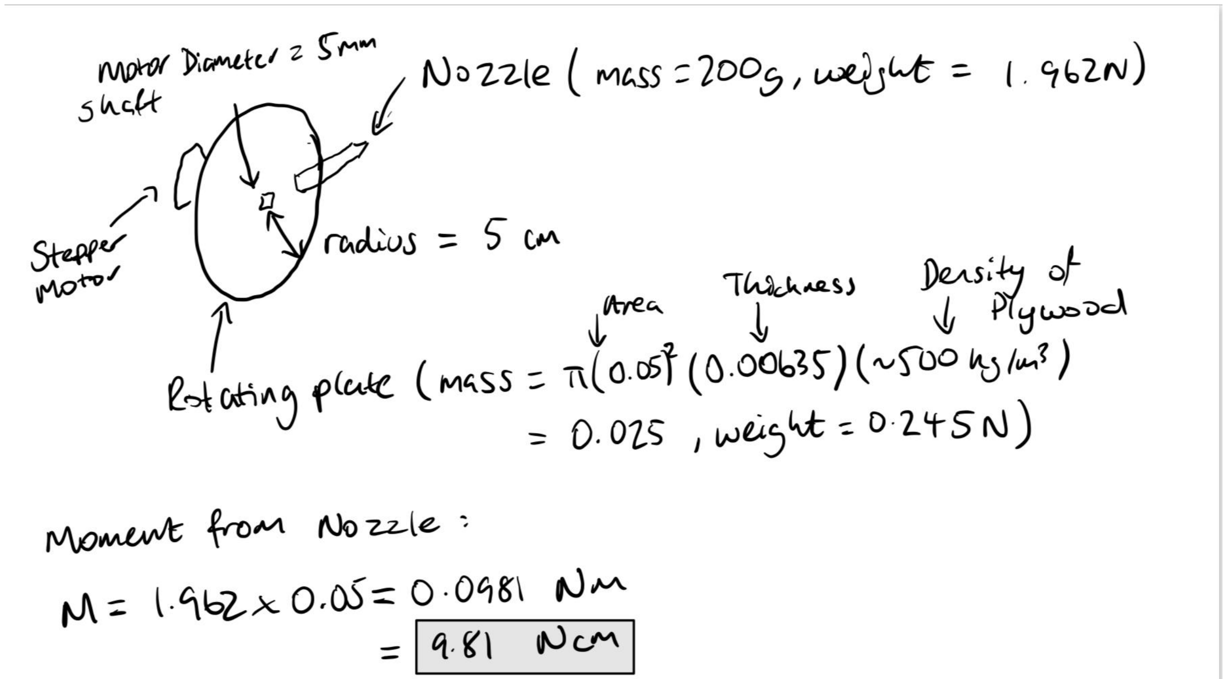


Figure 31: Free-body diagram of pitch stepper motor, and moment calculations to find the minimum torque needed to make the subsystem work effectively.

Based on the above calculations of moments on the pitch stepper motor from the weights of the nozzle, camera and structure holding the two, we found that the minimum torque required for the stepper motor was 9.81 Ncm for a Factor of Safety of 1. We ideally wanted to have a higher Factor of Safeties in our project to avoid complications in the future with prototyping and other design aspects. After finding the minimum torque rating needed, we went online shopping for new stepper motors, and found some that can provide a torque rating of around 60 Ncm. We decided that these motors would suffice for our project because, even though they were bigger in mass and size, we found that they would still be viable to use for our final prototype. The old stepper motors we were using only had a torque rating of around 2 Ncm, so we have seen a performance improvement of 2000% in the new stepper motors. We experimentally tested these motors for the pitch and yaw and found that they were very strong and fast for the project, which was exactly what we wanted. The issue with these new motors was actually powering them and their new drivers we needed. We wanted to have one power source for both motors and drivers for simplicity of the electronics. To conduct this analysis on the electrical power needed for these motors and drivers, we set up a variable DC power supply with these motors and changed the readings of the voltage to find at what points the motors would rotate smoothly rather than statically. If we found the motor was rotating statically, then we are just not providing enough power to the motors and drivers. What we were able to conclude from these experiments was that we needed 12 volts and approximately 1.5 amps for these motors and drivers. For the final prototype, we found that using a portable DC power supply to power these motors would be very viable as this would yield the best result when showcasing our product to an audience. We would also not need to worry about the battery life of the power supply, something that was quite ambiguous to us with our previous battery packs that we used for powering these subsystems.

A standard which we followed for this subsystem was IEEE 1100-2005 - IEEE Recommended Practice for Powering and Grounding Electronic Equipment. This standard helped us understand the necessary requirements when coming to supplying enough electrical power to different components of a project, stepper motors and drivers specifically for us. This standard directed us in how to maintain enough power and safely grounding the wiring for the subsystem. The standard also offers recommendations for maintaining stable and reliable power sources for electronic equipment. It addresses issues such as voltage variations, transients, and harmonics that can affect the performance of sensitive electronic devices. This was very helpful to us when finding future sources of power for our project.

We can conclude that the new stepper motors are more than effective enough to do the job we need them to do. The torque rating was more than 6x the rating we needed, providing us a Factor of Safety of 6 for this part of the subsystem. Whereas, with the power supply, we found that the most reliable and stable power source would be one from a DC power supply. We concluded this after our experiment and reading the standards we referenced previously. These two analyses we conducted on this subsystem helped us design and our subsystem to make it as effective as possible for the final prototype.

8. FMEA

The previous section involved utilizing design and engineering analysis to enhance the overall design. However, even with the best possible design, the final product may still encounter failures. In order to identify any potential fault areas and determine how they might impact the entire system, a failure mode and impact analysis was conducted on the final design. The analysis table can be found in Table 6.

Function	Failure Modes	Effects	S	Cause	O	Controls	D	RPN
Tracking	Detects dead bug	Repeatedly shoots same target	6	Keep checking the same target	9	Stop tracking same target after shooting it	2	108
Classification	Misidentification	Shoots invalid target	7	Poor Vision Environment	5	Detect Multiple times	2	70
Liquid-Level Detecting	Pump vibration	Affect Force sensor reading	4	Force sensor feedback is inaccurate	8	Fix the pump to the bottom of the robot to transmit	1	32

						vibration to the ground		
Liquid-Level Detecting	Rotational inertia	Affect Force sensor reading	6	Force sensor feedback is inaccurate	8	Reduce rotational speed to reduce inertial impact	1	48
Rotation	Overactuates and misses the bug	Bug goes out of frame and is missed	3	Motor torque not calibrated	4	Adjust motor driver current settings and code speed	2	24
Rotation	Water damages motors	Rust accumulation; motor not working correctly	5	There is leakage from the nozzle	4	Add waterproof casing to electronic component storage area	5	100
Shooting	Too much dirt in Pump and hose	Damages Pump	4	Pump extraction of foreign objects	2	The pump inlet is only stored in a container and add filtration in the hose	9	72
Shooting	Pump running continuously with no material	Loss of pressure/ damages to pump	7	Lack of communication between shooting and storage values	5	Add code to halt shooting until over lower boundary	2	70
Storage Materials	Wrong shooting Liquid was given	Doesn't kill bug, could clog pump	7	Poor liquid quality check	1	Filter for unwanted contaminants	8	56

Table 6: FMEA Analysis

The design of the SAP robots has identified three main failure modes which are tracking fault, rotating fault(Water damages motors), and shooting failure(Too much dirt in Pump and hose). During tracking faults, the system may continue to aim and shoot at insects that have already been eliminated, which is inefficient and counterproductive. To solve this issue, a control mechanism has been implemented through code to identify the movement stop or shape change of the target pest, indicating the success of the attack. This feedback loop is integrated into the tracking system, which allows the robot to quickly move to the next target, saving resources and reducing unnecessary exposure to control substances.

Water damage is a common problem during the rotating failure of the robot. Water intrusion can cause short circuits, corrosion, or mechanical failures, making the robot unable to function. To address this issue, a waterproof shell has been added around the electronic component storage area. This protective measure can safeguard the sensitive electrical components from the influence of moisture, ensuring that the robot can maintain its work and operational integrity even under normal spray leakage or liquid splashing.

During shooting failure, dirt can enter the pump and hoses, leading to blockage, reduced pest control effectiveness, and potential damage to the pump mechanism. To prevent these issues, the system ensures that the pump inlet is only exposed when necessary, otherwise stored in a clean container, and a filter is added to the inlet hose to filter out larger foreign objects and prevent pump blockage.

9. Manufacturing and Assembly Techniques

The team has created the final prototype of their robot by using both ready-made components purchased online and customized components that were manufactured at the Carnegie Mellon University Innovation Studio and TechSpark. The total cost for the robot was approximately ($420 + $3D printed) which is lower than the budget allocated for $750 at the beginning of the project. It's worth noting that some team members had certain components such as Arduino Mega, or certain fasteners from TechSpark's free inventory, which were not recorded in the budget. However, they will be included in the BOM (Bill of Materials) for completeness. A complete material list (Table.??) is provided below along with all the costs associated with purchasing parts and manufacturing customized parts.

Bill of Materials (BOM)

Name	Quantity	Price ($)	Website
Force sensor	1	14.99	Amazon
Water Pump	1	20.99	Amazon
608-2RS Ball Bearing	1	9.99	Amazon
Hose	10ft*1	16.7	Mcmaster
Raspberry Pi	1	55	Sparkfun
Arduino	1	Owned	Owned
Arduino Accessories	-	Owned	Owned
3D PLA	-	150	Techspark
28BYJ-48 Stepper Motor	1	14.99	Amazon
1.5 m USB Arduino Cable	1	7.99	Amazon
1 m USB Arduino Cable	1	9.99	Amazon
Cable Twist Ties 4-inch	1	11.97	Amazon
PiCam Cable	1	9.99	Amazon
Nema 17 Stepper Motors	2	13.99	Amazon
Stepper Motor Driver Board	1	9.99	Amazon
SD Card	1	22.99	Amazon
Raspberry Pi Camera	1	25	Amazon
Camera Cable	1	5.38	Amazon
Raspberry Pi Battery Pack	1	25.95	Amazon
Raspberry Pi	1	61.77	Amazon

Nozzle	1	12.5	Amazon
Lazy Susan package	1	29.33	Amazon
M3 Brass Hex Spacer	1	10.99	Amazon
Total		540.49	

Design for Manufacturability (DFM)

The final prototype of the robot was mainly constructed using laser-cut 3mm acrylic plates. However, for more complex parts such as fixtures, supports, and microcontroller casings, 3D printing was used. This decision was made considering the cost and material strength. Initially, the project had planned to use numerous 3D printed parts to create the robot's main body. Although the strength of the 3D printed parts met the project's requirements, the cost was too high. Therefore, the project ultimately decided to use acrylic panels as the main structural material. The plates were joined together using a "dovetail joint" method, eliminating the need for nails or screws. This joint method creates a strong bond and is commonly used in woodworking for furniture and cabinets. A demonstration of the installation can be seen in Figure 32.

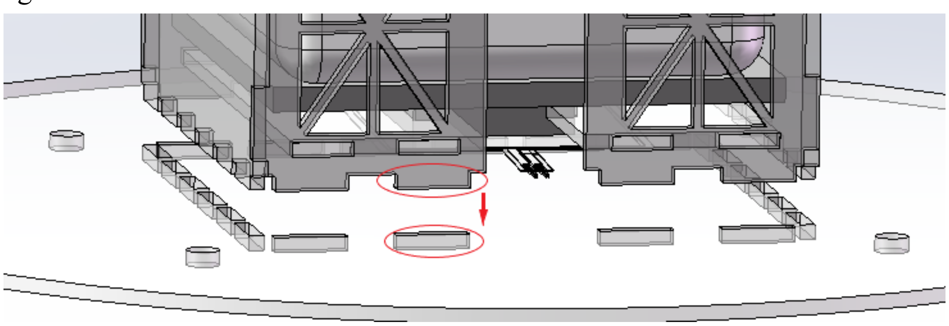


Figure 32 : A demonstration of the installation of "dovetail joint"

In addition, the acrylic board has undergone finite element analysis (FEA) simulation and it has been found that it meets all the strength requirements of the robot. Furthermore, acrylic material is stronger than wood, which makes it possible for the robot to hold up the weight of all its components. Additionally, as it is harder than wood, the material can absorb the vibration of the motor and thus improve the robot's reliability. The 3D printed parts are created with a layer height of 0.2% and a filling of 20%, which is sufficient to meet the requirements of the parts.

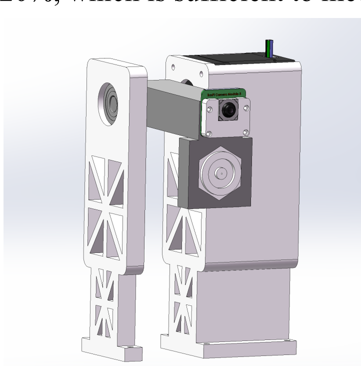


Figure 33: Camera and nozzle motion fixture

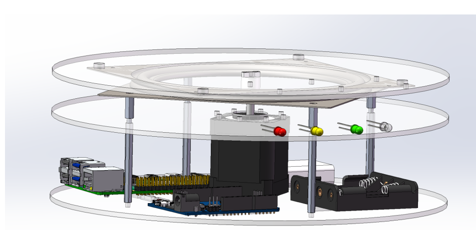


Figure 34: Rotating platform

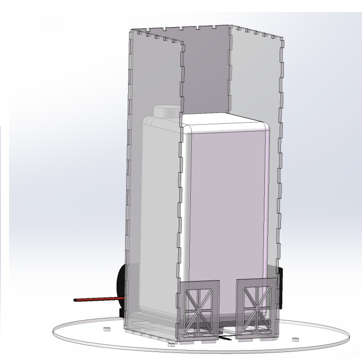


Figure 35: Bottom base

The robot consists of three main structures: the camera and nozzle motion fixture, the rotating platform, and the bottom base. These structures are shown in Figure 33-35. The camera and nozzle motion fixture are made using 3D printing and are used to position the camera, nozzle, and motor that move them up and down. They are connected directly using the method illustrated in Figure 33. The rotating platform is designed using the "Automated Turntable" [000] and supports the acrylic platform using a standoff spacer. The motor drives the lazy Susan bearing to rotate the platform that holds the camera and nozzle motion fixture at the top. The detailed installation process is shown in Figure 0.0. Finally, the bottom base is installed using acrylic plates and a "dovetail joint" method, as demonstrated in Figure 36.

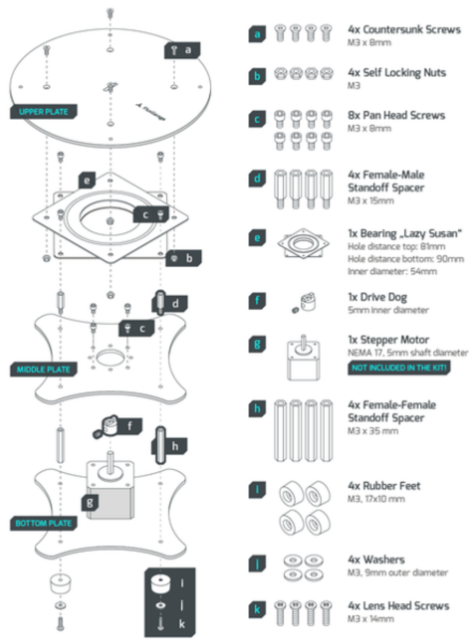


Figure 36: "Automated Turntable" detailed installation process [000]

If the team decides to mass-produce this type of robot, there will be significant changes in the manufacturing methods used. The team will create a metal mold with a shape similar to the main structure and part design of the prototype. They will use injection molding to create a plastic overall framework and some complex parts for the robot. This will replace the current process of laser cutting acrylic and 3D printing to install the parts together. The injection molding process will use ABS plastic, which includes four main steps: melting the plastic, injecting the melted plastic into the mold, allowing the plastic to cool, and removing the parts from the mold.

Compared to the prototype, this method will greatly save long-term material and manual installation costs as it is more time-saving compared to laser cutting and 3D printing. ABS plastic also has a more advantageous raw material price. In addition, it does not require a large amount of manual installation, which also saves labor costs.

In addition to making these changes to the overall structure of the robot, electrical integration will also be modified to improve mass production. On the prototype, wiring is completed through a series of power supplies, motor drivers, and microcontrollers all of which are connected using loose wiring and breadboards. Although this is hidden in the prototype and will be hidden in the final manufactured version, retaining the wiring in this way can easily lead to problems such as corrosion or vibration damage. Any attempt to repair it will be unnecessarily complex due to the number of wires involved.

Therefore, the manufacturing version of the robot will include printed circuit boards (PCBs). These boards combine many of these features to form a board that will handle all electronic communication between microcontrollers and individual components. This will further reduce the manufacturing cost of individual robots.

Key Challenges

Producing robots on a large scale can be challenging due to various factors such as facility requirements, material procurement, cost management, and ensuring consistent quality in mass production. While injection molding can offer significant advantages, there is a high upfront cost involved in making the molds for the parts and buying the machinery needed to melt and inject ABS plastic. This investment will eventually pay off, but it will take time. Furthermore, the mold design needs to be perfect from the start because modifying it is often difficult and costly, and creating a new mold is also expensive. Therefore, producing the product before making a profit could lead to initial revenue loss. Additionally, since the product contains many non-self-produced components, if the supply price of these products cannot be resolved or self-produced, the final market price of the product will be high, resulting in a lack of competitive advantage in the market.

10. Final Prototype

Design problem context:

For our design of this project, we considered several different factors when making certain decisions in our design process and choices. Especially with a product like ours, where it is intended to eliminate pests within a vicinity with pesticides, we thoroughly weighed external factors, such as environmental impacts and public safety, very heavily. We believe that the first steps in making a successful design were to address these sorts of issues, otherwise our product could cause more harm than good.

For public health and safety, we always knew that a major concern for customers would be whether the product would accidently disperse pesticide at a person, electronics, or other forms of wildlife. Since we are intending for users of the product to use pesticides with it, we must ensure that the product would never shoot at other targets than pests. In order to account for this issue, we decided that the solution would be found in the identifying targets subsystem and decomposed how our current approach would identify these pests as targets. Our current approach would give different identified targets in the frame different scores, which were derived from many factors such as size, distance from center etc. We realized that we could use our classifier that was able to recognize many several items in the frame, to find other items that could be nearby these targets. We decided to apply penalties to each target's original score if the target was near an object that we don't want to be shooting near at. To derive these penalties, we used an inverse square relationship with the distance between the target and other objects in the frame, giving certain objects more weight (people, electronics etc.). Using a method like this to solve this issue seemed very viable to us, as the implementation was fairly straight-forward and the computational cost was not affected too much. After the implementation of this technique, the robot would not target any lantern-fly that had a negative score after the penalties to each target were applied. This would eliminate any concerns to the users of shooting other objects and even shooting targets that were in close proximity of the targets.

When considering the environmental impacts of this design, we thought of our shooting material, pesticide, and how we were going to power the prototype to be in use. Pesticides can contaminate its surroundings consisting of water, soil and other vegetation and it can also harm other forms of wildlife such as birds, fish and other beneficial insects. In order to account for the fact that we are dispersing an environmentally harmful substance, we decided to test and measure the minimum amount to disperse for a target. We needed to measure the time taken for our pump to run until the stream coming from the nozzle was reaching its greatest distance. We found that we needed to run the pump for about 1.2 seconds for this to happen. We then measured the difference in the liquid level in our container to see how much pesticide we would be dispersing when running the pump for 1.2 seconds. We found that we were only dispersing around 40 ml, therefore we were able to conclude that this level of pesticide being dispersed in the surroundings for each found target was very minimal and so the harm would not be much of a concern to the soil/water. Our design also will not shoot at the target if there are other forms of wildlife close to the target, thanks to the penalty application algorithm we used for the identifying targets subsystem.

In terms of the societal and economic impacts of this design, we need to consider the sudden outburst in the lantern-fly population in areas like Carnegie Mellon's campus in Pittsburgh. At the start of the academic year, there was an incredible amount of these pests that would infestate and crowd certain areas of the campus. From the findings of our surveys, which were sent to several members of CMU's community, we found that people don't appreciate the sudden presence of lantern-flies in their campus. We then wanted to accommodate these parties by making our product work in other places rather than just a crop-field. We realized that we could place our product in these over-populated areas and let the product do its work, essentially scaring these lantern-flies off the campus and other areas in Pittsburgh. For the economic impact from our design, we must look at the different stakeholders in our product. In the short run, pesticide suppliers and manufacturers may see an increase in demand for their goods, as pesticide goes hand and hand with our design. Essentially, for farmers to use our product, they would need to buy more pesticide to store it in the containers of each device. In the long run, agricultural suppliers would see an increase in productivity as this product would be assisting in getting rid of pests and harm to their crops. In general, when the agricultural industry is doing well, we will see major economic benefits as crops become cheaper and, potentially, of better quality. Keeping in mind, this would be a very long time until we saw economic impacts like this, however, we can expect a boost in pesticides' demands once our product is in the market.

An ethical implication of our design would be the job displacement for firms in the sector of pest control. A fully autonomous pest control option like our design would essentially threaten job security and company success for workers and entrepreneurs in the pest control industry. Our design would do the same job that these companies and workers do, so they become less attractive for agricultural companies to hire them to set up their pest control. If our technology becomes more widespread, we would see this problem becoming much more of a bigger deal. However, for now, we don't need to worry about this impact just yet as the growth of this product would not be extremely fast, due to the fact that this would be new technology to the users.

Demonstration of the design:

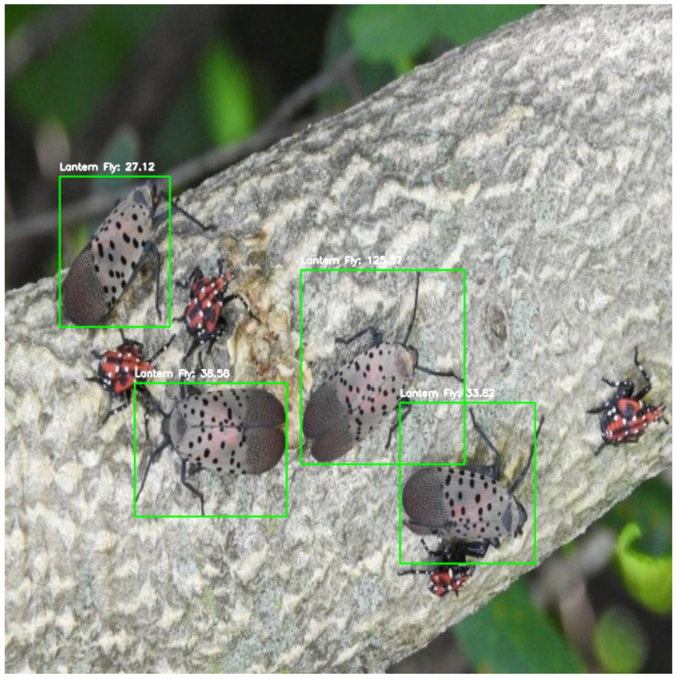


Figure 37: Demonstration of the identifying targets subsystem, this image shows how our detection algorithm finds and scores different targets, and how they can differentiate from other types of insects.

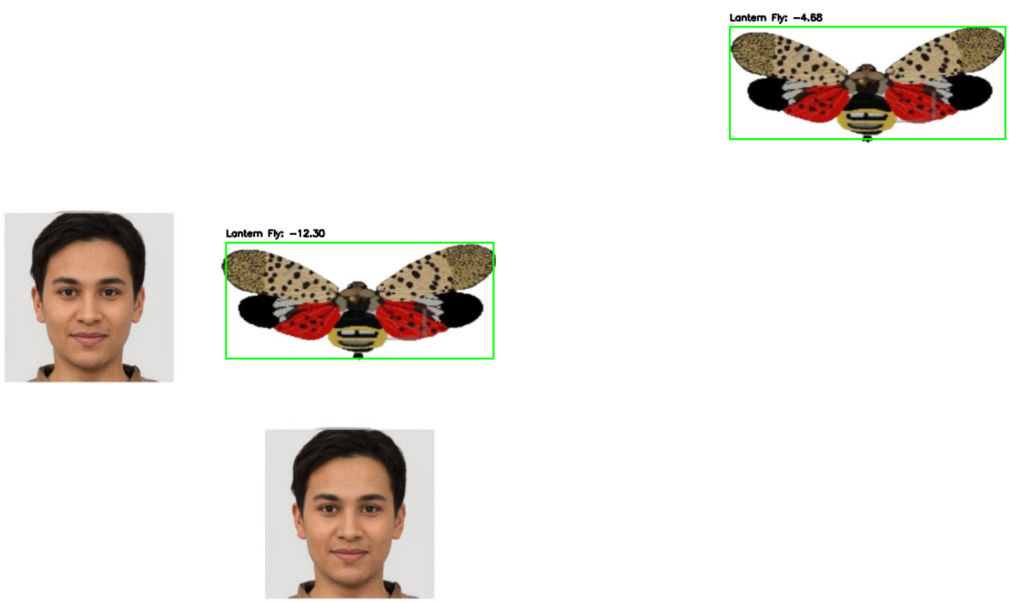


Figure 38: Demonstration of the penalty application algorithm to the target lantern-flies, we can see the negative scores on the bounding boxes, suggesting it is not a target anymore, due to the proximity to a person’s face.

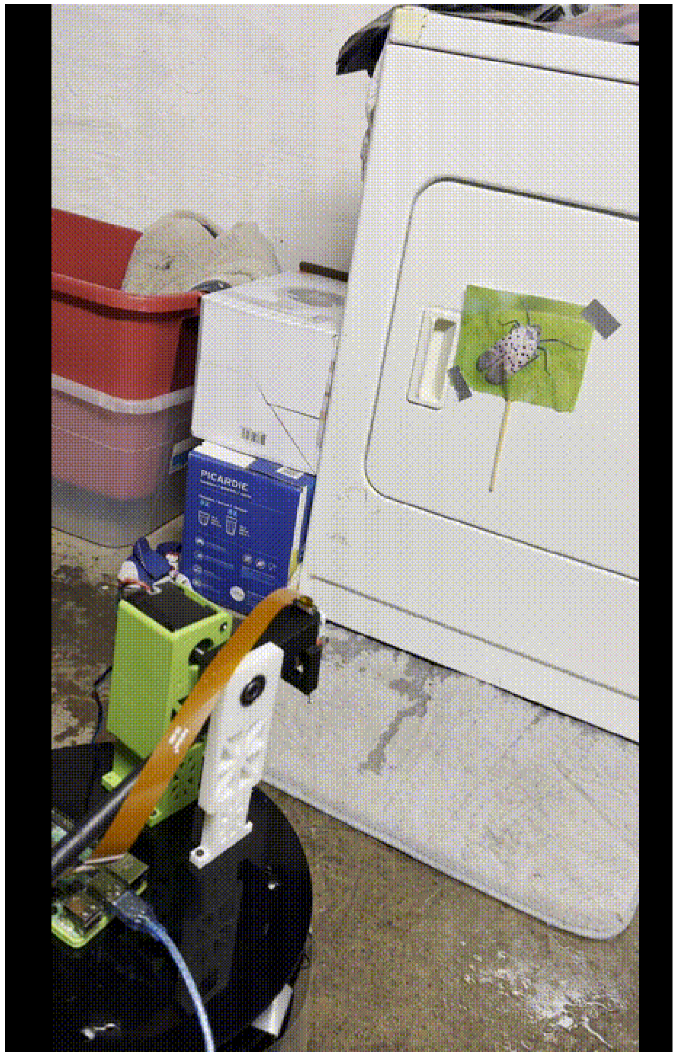


Figure 39: Short clip of our final design detecting an image of a lantern-fly, and dispersing water directly at it.

Final Design Results:

Final prototype testing included 3 main tests:

- Initial Weight Sensing Test
- Tracking Test
- Shooting Test

These tests are done in a sequential order and have to be completed in sequential order before continuing. In the initial weight sensing test, we review if the weight sensing capabilities work while in the surveillance state. This test confirms if both systems can work simultaneously while using an arduino that works sequentially. This test is done without the water and with water at different levels. All 4 levels were able to work, and indicated that we could move on to the tracing tests.

For the tracking tests, lantern fly pictures were placed within the target range and we observed if the robot would focus on the target center before returning to its original surveillance state. Three variations of the test were done. The first is a picture 4 inches to the right of the camera, then 4 inches to the left, then two pictures at the same time at both sides. Since multiple trials were conducted, the vertical offset was randomly chosen during each test. It was evident that lighting and camera performance was a huge constraint. Specifically, the auto focus feature would struggle in certain spots of the camera and not be able to identify targets as lantern flies. All tracking final positions did not exactly hit the centroid, each having a fair amount of horizontal offset ranging from 1-2 inches and minimal vertical offset to the camera centroid. The feedback loop did improve accuracy by a large margin of about 2-3 inches, especially when the bounding box was large due to picture size. Because of these issues, testing a picture at both sides was ineffective but testing two pictures on the more accurate side of the camera led to fairly consistent identification and tracking. Overall, the identification was successful for about 60% of the time, with the right side of the camera being less accurate with only about 20% of attempts being successful.

Finally, we conducted the shooting tests that aimed at targets from trials that were consistently identified. Initially, the targets missed due to some assumptions that needed to be fixed. The main assumption is the offset of the nozzle to the camera, which needed to be evaluated visually before it could be corrected. Although the correction value changes based on distance, a movement of 5 degrees generally led to the most consistent hits at 4 out of 5 targets hit. The larger pictures had a higher miss rate due to difficulty finding the center compared to smaller pictures. In practice this isn't an issue due to the size of lantern flies compared to the pictures. In all tests where humans were present in the camera range, the robot did not shoot.

11. Conclusions

As a team, our collective experience throughout the development of this project has been quite enlightening, offering us a lot of opportunities to learn and adapt in order to make the project a success.

During the design process, having a clear and concise design was pivotal to ensure the effective development of our project. However, the absence of a full-system CAD slowed us down in the beginning, forcing us to play catch up towards our development cycle. Additionally, as we began integrating these various technologies, we realized that our initial research was simply not enough. For instance, a deeper understanding of computer vision would have been greatly beneficial in saving us time throughout the entire project. If we had that time saved, we may have been able to implement localization techniques to ensure correct movement, improved on our overall design, or even added additional functionalities into the robot.

Another instance of this lack of research, was in choosing to do stereo cameras with the Raspberry Pi. When we chose to use a Raspberry Pi as our computing platform, we had assumed that we would have stereo cameras to enable us to do some basic projectile motion to ensure accurate shots. However, when we came to integrate the camera with the Raspberry Pi is when we realized that stereo vision support for the Raspberry Pi Model B was depreciated (there is support for other modules though). This forced us to pivot towards having no depth sensing, reducing our project's overall effectiveness. Overall, investing more time in understanding these core technologies initially could have enabled innovation, better functionalities, and a more efficient project trajectory within our time constraints.

In terms of our project planning, we should have followed our Gantt chart more religiously to ensure that our project remained on track and adhered to the proposed timelines. While the Gantt chart provided a very structured roadmap for our project milestones, there were still some instances where we deviated from the planned timeline due to adjustments in priorities. This divergence would typically result in tasks having to be overlapped or just pushing of deadlines which naturally resulted in delays towards implementing our project. Therefore, upon reflection, we found that it would have been important to just dedicate ourselves to our Gantt chart and only pivot when there was no other choice, instead of out of convenience.

Moreover, during the integration phase, we encountered unexpected challenges with our motor drivers. Initially, we struggled for two days to identify why the motors weren't functioning properly, only to realize that the root cause was insufficient amperage. This setback significantly delayed our integration process and resulted in missed opportunities for testing and refinement. Knowing our product's power requirements beforehand could have been immensely beneficial, allowing us to anticipate and resolve such issues swiftly. A comprehensive understanding of our product's electrical needs in advance would have streamlined our debugging process, ensuring smoother integration and potentially preventing unnecessary downtime.

Overall, our project journey was a very enriching learning experience, emphasizing the critical significance of meticulous design and in-depth research. Initial setbacks stemming from the absence of a full-system CAD and the misjudgment on Raspberry Pi's stereo camera support hindered our progress. A deeper grasp of foundational technologies could have propelled innovation and enhanced functionalities, and strict adherence to our Gantt chart for project planning would have curbed delays caused by shifting priorities and task overlaps. However, we were still able to overcome these challenges and gained the experience necessary to tackle these problems should they come up in the future. These lessons underscore the importance of careful planning, comprehensive research, and preemptive technical understanding for smoother project execution in future endeavors.

12. References

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13. Appendices

Concept Generation Cont.:

Sub-System Concepts Cont.:

Identify Targets (Object Classification):

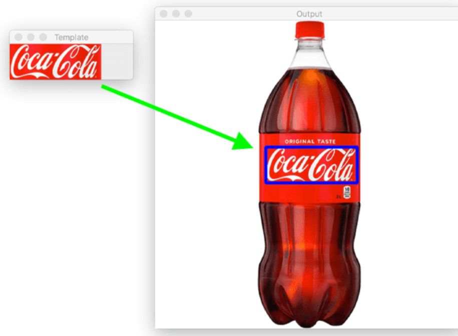

Figure 16:
Template Matching Approach

Our other object classification concept was to use a simple template matching algorithm to identify the lantern flies. For instance, we would take an image of a lantern fly and then go through the image we want to classify and simply compare the pixels. We can then measure the similarity between the template image and the object to be classified to identify whether the object matches the template image. Overall, this algorithm is simple to implement, however, it isn't as robust as our methods since it does not factor in any environment variables such as illumination and occlusion.

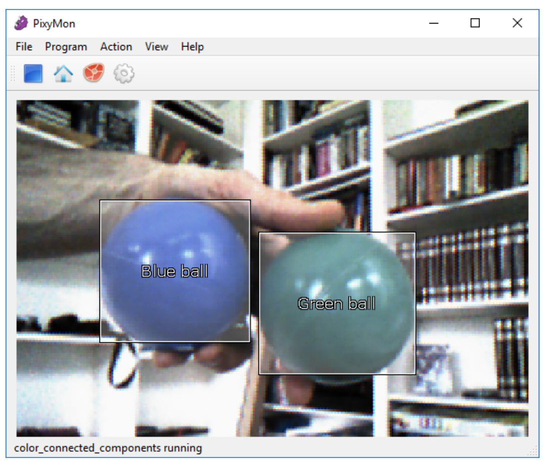

Figure 17:
Color-Matching Approach

Lastly, our last identification concept was to use Pixy2 to implement a simple color-matching algorithm to identify the lantern flies. The Pixy2 camera allows us to categorize certain color hues with objects and therefore perform object identification based on the color. Therefore, we would simply identify the main color and hue for lantern flies and then encode that color to mean a lantern fly. This concept would work for simple object classification, however since it only relies on color matching, it can easily lead to misidentification of objects with similar hues. For example, if someone's shoes match the lantern fly's color, it would be classified as a lantern fly and then shot at. As such, this concept is not as robust as the data-driven approaches we outlined for object classification.

Track Targets:

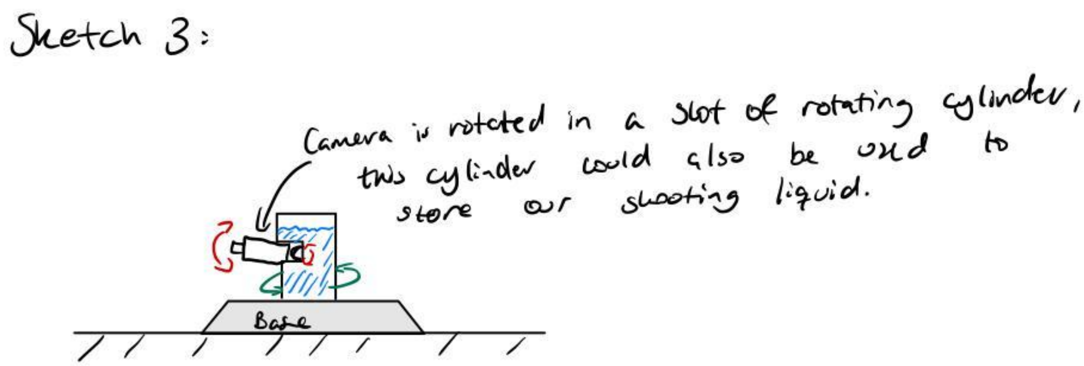

Figure 18:
Third Sketch for the Track Targets subsystem.

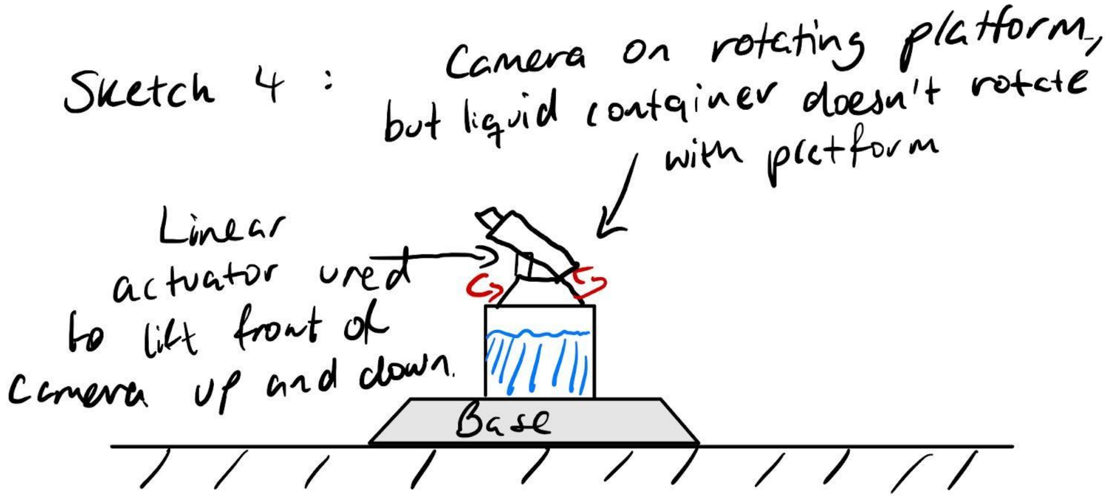

Figure 19:
Fourth sketch for the Track Targets subsystem.

Storage of Materials:

Figure 20:
Pressurization (If need) Method Concept.

In the upper part of the figure, there is a refillable tank made of stainless steel. The lower part of the figure shows a method of manually pressurizing the tank after filling it. The purpose of this concept is to enable the nozzle to spray out the liquid quickly and smoothly. However, we will not need to pressurize the container if the performance of the electric pump is satisfactory.

Shooting Liquids:

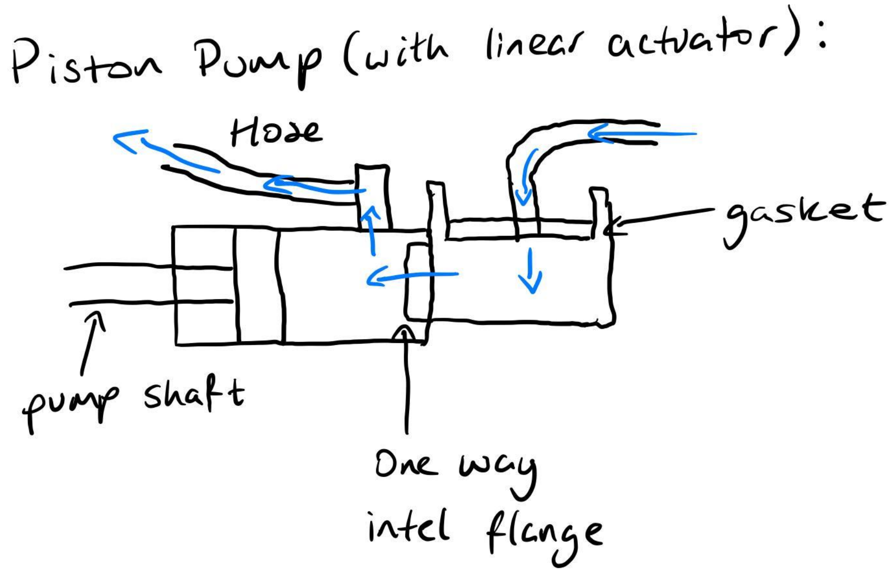

Figure 20:
Piston Pump (with linear actuator)

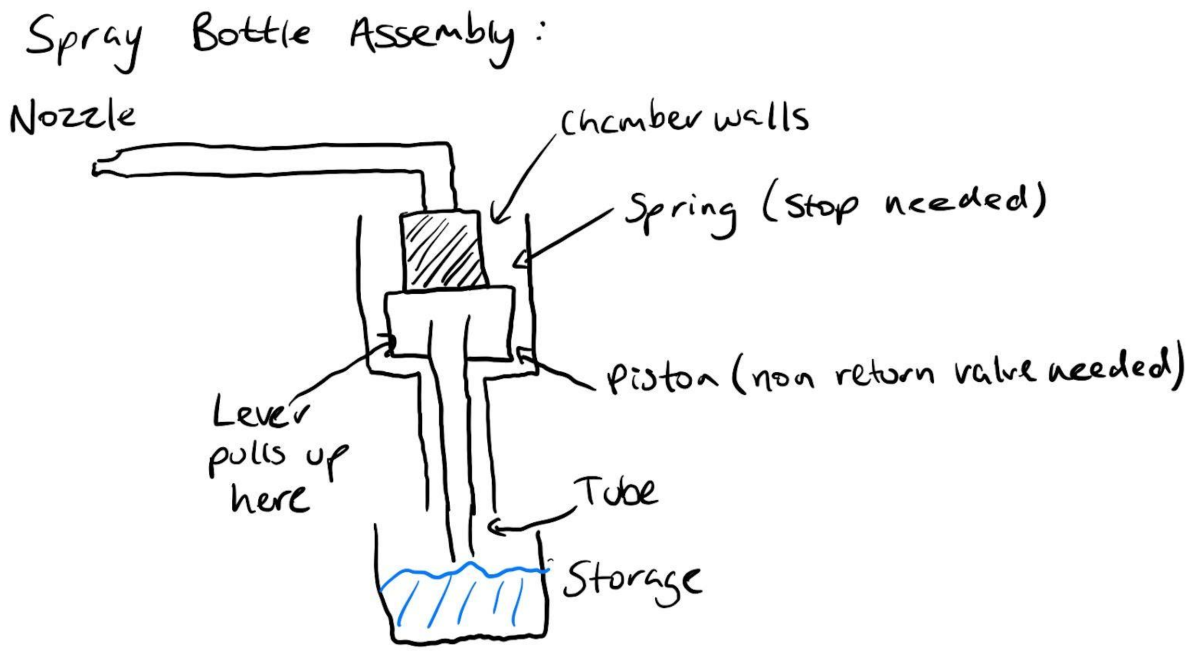

Figure 21:
Spray Bottle Assembly