Dodgeball Bots

ECE 445 Design Document

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4/14/25

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1 Introduction

1.1 Problem and Solution Overview

The traditional sport of dodgeball, while popular, faces significant limitations in terms of accessibility and safety. Since sport requires two teams to play, it takes at least two people to swim, and the high-speed throws pose a risk of injury, especially to vulnerable areas. Recently, there have also been new technological developments exploring new forms of dodgeball play, such as augmented reality (AR) [1] and motion tracking devices [2] that attempt to improve the sport but also present new obstacles. Augmented reality relies on controlled environments and wearable sensors, limiting spontaneity, while motion tracking systems perform poorly in terms of latency and accuracy under variable lighting conditions. There are still a number of issues that need to be addressed in developing a robotic device platform that can mimic the mechanics of a dodgeball game while ensuring accuracy and safety, including instant target detection, turret mobility, and more.

In response, we propose an improvement program that aims to address these challenges by integrating thermal cameras, mechanical turrets, and an autonomous robotic system with AI modular design. For immediate target detection, unlike AR or motion tracking, Dodgebot employs a thermal camera compatible with the Jetson Nano for real-time body detection without relying on wearable sensors. For the motorized turret, the Arduino-driven 360° turret module allows for full rotation while avoiding wire entanglement to ensure unrestricted movement. The firing mechanism utilizes dual counter-rotating motors to propel the projectile, reducing the risk of injury by controlling speed. The solution is designed to be powered by a 48V max mobile power supply, ensuring portability and scalability. This approach improves previous systems by combining accessibility, environmental adaptability, mechanical precision and safety to provide a novel solution.

1.2 Visual Aid

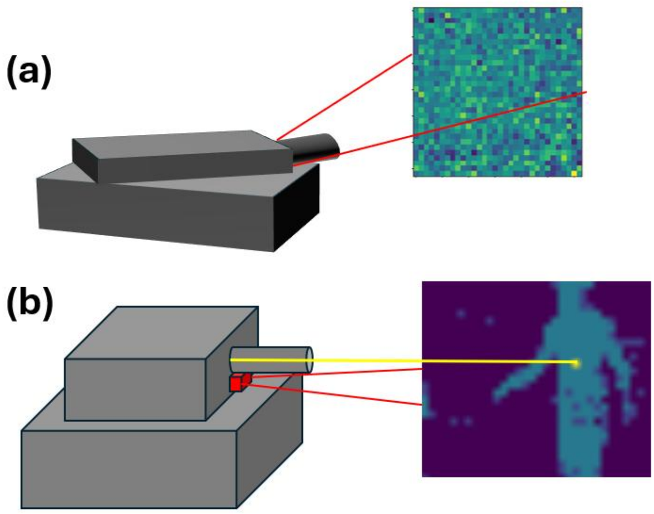

Figure 1. The operation mechanism of the robot. During (a), the robot scans the environment ahead of the robot using a thermal camera attached to the underside of the gun barrel (red box, with red lines as its view area). If a target is not seen, it will rotate to a new direction. If a target is detected, then the turret aligns to the center mass of the object and immediately fires.

The robot will function as shown in Figure 1. On an ambient environment, there will only exist small deviations in temperature between each pixel of the thermal camera. Hence, if such were to occur, the robot (controlled through the ESP8266 MCU) will deem the target non-existent in this context. If so, the robot will rotate to a new firing position, to which if an object of appreciable size (which will skew the temperature measurement) is detected, the MCU will first calculate the center of the 'blob,' and then aligns the turret to the object's center. It will then immediately fire once the gun is aligned to be about the center of the object (not necessarily need to be precisely in the middle).

1.3 High-level requirements list

The following are the requirements to which will be evaluated against the finished design:

- The turret module should be able to rotate fully to 360 degrees once within 20 seconds. Hence, wiring must be done inside the robot to ensure that it will not be entangled when the turret rotates.
- The firing mechanism should be able to fire without misfiring >95% of the time.
- The robot must achieve ⩾80% firing accuracy when targeting moving humans within a 5-meter range under standard (flat terrain, good visibility) conditions.
- The machine vision classification should achieve accuracy of 80%.
- The whole design should be modular, except power delivery, which may require external outlets.

2 Design

2.1 Modular Block Diagrams

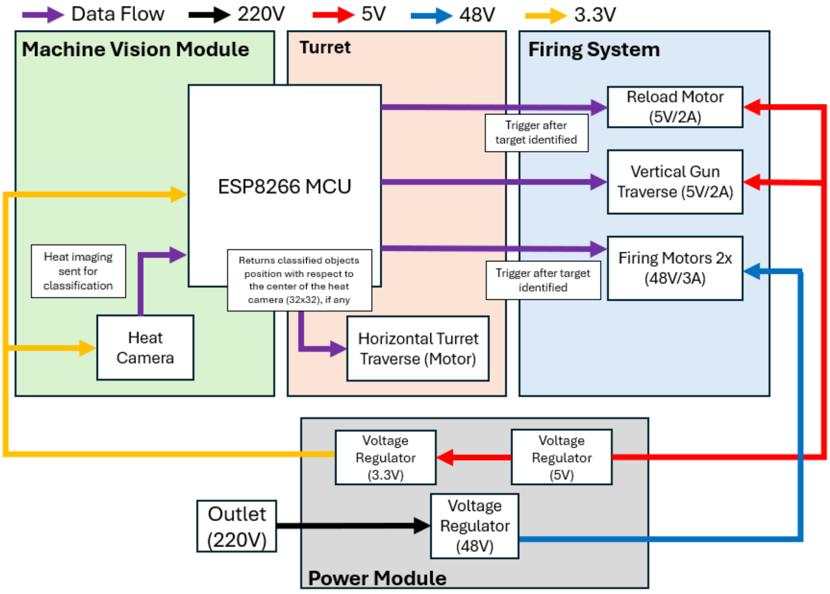

Figure 2. The block diagram of the robot. Note that this is slightly different from the proposal and is reflected in the new information that we received during the creation of the robot. In particular, as the object detection is very light, we can utilize the ESP8266 MCU to do the calculations while simultaneously controlling the motors.

The block diagram is shown in Figure 2. The block diagram shown is an improved version of the original block diagram shown in the proposal. In this case, as we only conduct simple row and column averaging of the camera's data (which is only 32 by 32 pixels), the whole algorithm can be made fit within the ESP8266 memory limit. ESP8266 is used primarily because the heat camera we use, RT-Thermal, connects through Wi-Fi, which is supported by ESP8266. The ESP8266 also controls the movement of the other functional motors, which is to be described in Section 2.3.

2.2 Physical Diagrams

The 3D design of the device is shown in Figure 3. The machine fires a tennis ball, with a diameter of 63.5 mm, hence the turret is made to be slightly larger than 20 cm to accommodate both the tennis ball, and the two firing motors. The design is slightly different from the previous design made in the proposal, as we now use a servo (with weight limit of 25 kg) to lift the gun up and down. The reload system (i.e., the L-tube and the reload motor) is attached to the gun. As a result, the magazine will be attached to the reload tube (and hence it is not attached to the turret enclosure). Detailed explanation of the design is covered in Section 2.3.

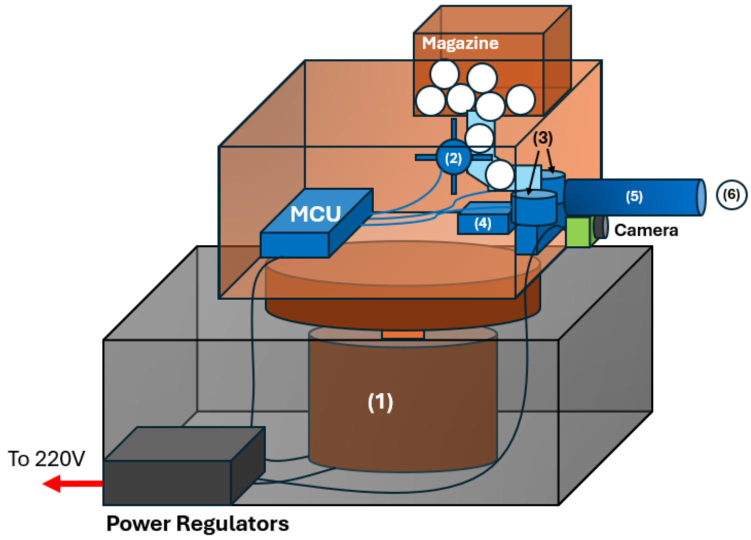

Figure 3. The 3D design of the robot. (1) is the turret traverse motor, (2) is the reload motor, (3) are the firing motors, (4) is the vertical traverse motor, (5) is the gun barrel, and (6) is the fired ball. The layout of the components are slightly altered from the proposal, with (4) now located at the back of the firing motor, and the absence of the GPU unit, as per the current model.

2.3 Block Designs

2.3.1 Machine Vision Module

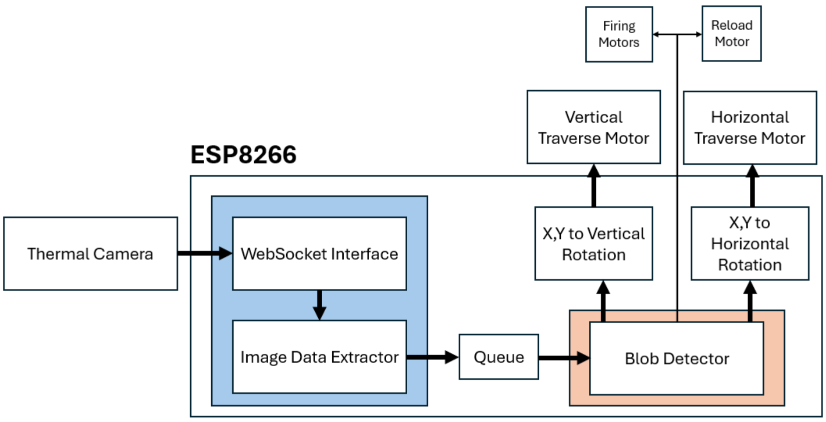

Figure 4. The block diagram of the machine vision module.

This module consists of a thermal camera and an ESP8266 to perform image classification, with the block diagram shown above. The camera is mounted on the gun barrel; hence it is aimed exactly where the gun is aiming at. On a specific viewpoint, the ESP module will first identify objects with heat signatures higher than the ambient environment. We implement this by calculating the difference in temperature between one pixel and its neighboring pixel and determining if this is a possible target if the difference is substantial. Note that the data retrieved from the camera in its raw form is in the ranges 2500-3000, so to determine the temperature difference, we calculate whether the difference between the maximum and minimum value is 105. From our experience, the body temperature of a human is typically high enough to show this anomaly to the surroundings, and is typically large enough, which will be helpful so that the ESP does not identify other object besides humans. If it is a target, this module will instruct the ESP (turret module, see Section 2.3.2) to traverse the turret towards the target, reload and fire the gun. This is done by first determining the center of the target through the algorithm described in the flowchart below. Then, we determine the center offset from the center of the camera and then instruct the turret to traverse towards the object's centerpoint until the offset becomes zero. To calculate the amount of rotation needed, we do a tabulation of values. We first determined the angle needed to offset the camera by one, two, three, and up to 16 pixels. This way, no calculation is needed, and the ESP can refer to this value table to determine how far to rotate. Otherwise, it will instruct the Arduino to rotate the turret to a new viewing point for image classification.

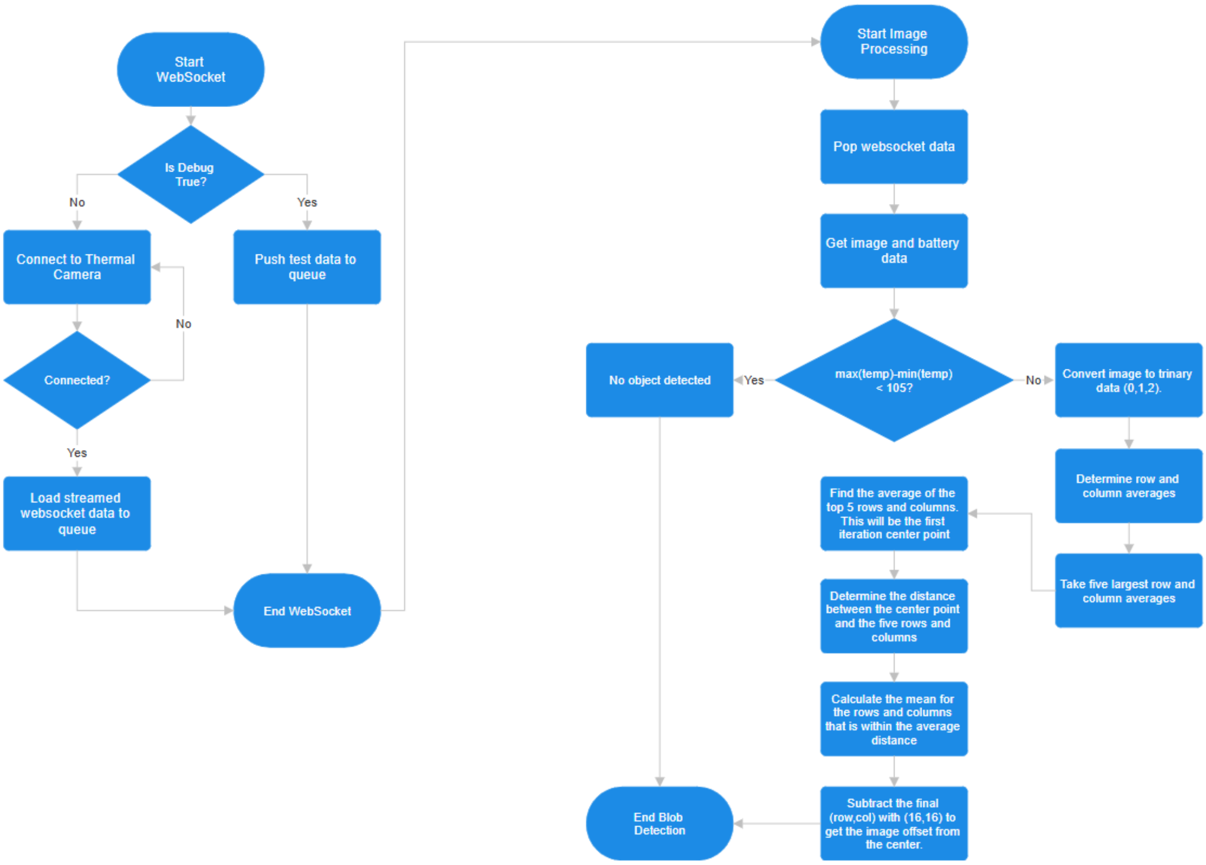

Figure 5. The flow chart of the machine vision module.

Requirement	Verification
<u>Image Classification and Target</u> 1) When the absolute difference between a pixel and its neighboring pixels exceeds 105, the system should flag the central pixel as a candidate thermal anomaly and initiate confidence level calculation. 2) Within a distance of 5 meters, a thermal anomaly pixel is classified as valid when the MCU return the centroid position.	1) a. In an online environment, set the computer to output "Candidate Anomaly" when a candidate anomaly is marked. b. Input a matrix of 32 x 32 pixels into the computer, with the center pixel at a typical human temperature and neighboring pixels at 0°C. c. Record whether the system outputs "Candidate Anomaly".

3) Once a valid pixel is detected, the system should transmit a command containing the target coordinates to the Arduino within 1s. 4) If no target is detected, the system should rotate the turret clockwise by 30° (±2°) and then initiate a new classification cycle within 1s.	d. Enter a 32 x 32 pixel matrix into the computer with all pixels at 25°C, this can be done by placing the camera lens directly on top of someone's arm for example. e. Record whether the system outputs a "Candidate Anomaly". f. Perform at least 3 validations per group. 2) a. Prepare a tester to stand within 5 meters of the system and take at least 5 sets of images. b. Prepare a piece of paper similar in shape to the tester to be fixed within 5 meters from the system and take at least 5 sets of images. c. Record the number of times the system identifies the object. d. The F1-score (2 × (Precision×Recall) / (Precision+Recall)) of the system for the classification results should be greater than 80% as a composite metric. 3) a. In the online environment, set the computer output the time at this point (T1) after sending coordinate. b. Input an image with a valid object into the MCU. c. Use an oscilloscope to monitor the turret motor output voltage, with the oscilloscope input and output connected to both ends of the motor. When the motor output voltage is greater than 5V, record the time at this point (T2). d. Make at least 3 measurements. The average time difference between T1 and T2 should be less than 1s. 4) a. Connect the rotary potentiometer to the turret motor so that the motor rotation can drive the potentiometer knob. The three pins of the potentiometer are connected to VCC (24V ± 3V), Arduino analog input (A0) and GND (less than 1v). b. Input an image to the computer with less than 70% confidence, then the motor should rotate clockwise.

	c. Use the Arduino to read the analog value (0-1023) via analogRead(), map it to an angle (0°~300°), and record it. d. Take at least three measurements. The rotation angle should be between 28° and 32°.

2.3.2 Turret Module

The turret module houses the ESP microcontroller, which controls the turret traverse and the gun firing system (in the firing system module, see Section 2.3.3). To rotate the turret, the ESP MCU (from machine vision module, Section 2.3.1) will send instructions to both the horizontal and vertical traverse motors to rotate the turret and elevate the gun so that the target is centered. The gun elevation is adjusted with accordance to the target range, as the target is further away, it will occupy less of the total pixel area, which means the gun must compensate with a higher elevation. The elevation to pixel occupation relation is tabulated manually. If no target is detected, it will instruct the Arduino to rotate the turret to another angle for image scanning by the machine vision module. To fire the gun, the Arduino will activate the reload motor once to allow a single bullet (tennis ball) into the chamber, and the firing motor. When the bullet enters the chamber, the bullet will be in contact with the firing motor (which is rotating in-plane, one clockwise and another counterclockwise), which will launch the bullet outwards. The machine fires a total of 5 bullets fired, to which the machine will then stop firing. After the machine stops firing, the ESP will rotate the turret to another viewpoint for classification, return the gun elevation to normal, and switches off the firing motor.

Requirement	Verification
1) The vertical traverse servo should be able to aim up to 20° (±2°), and it should hold at this position at least 20 seconds while under power. 2) The vertical traverse servo should aim up according to the tabulated values. 3) The vertical traverse servo should return to neutral (0° (±2°)) after firing within 1 second. 4) The horizontal traverse motor should rotate 360° (±2°) once within 20 seconds. 5) The horizontal traverse motor should turn according to the tabulated values. 6) The horizontal traverse motor should rotate 30° (±2°) clockwise when no target is detected.	1) a. We manually program the ESP module to lift the turret by 20° (±2°). b. We measure the angle of inclination with angle ruler and verify it is 20° (±2°). c. We let the servo hold this position. If the servo is able to hold beyond 20 seconds, this test will be count as successful. 2) a. We manually program the ESP to aim by 1, 2, 3, up to 16 pixels. b. The vertical traverse servo should raise the gun to an angle (±2°) according to the tabulated values. c. Note that the tabulation assumes the target is at a 5 meters distance. 3) a. We mock this test by assuming that the

	signal for the reload motor sent to the ESP has been sent. b. The ESP then must return the vertical traverse servo to 0° (±2°) within one second. When the motor starts working, a high-level signal (>5V) is sent to the input pin of the ESP, and the trigger is monitored using an LED or Arduino serial monitor. the timing starts when the LED is lit or receives feedback from the Arduino serial port until the ESP resets the vertical traverse servo to 0° (±2°) . The time taken should be less than 1 second. c. After the servo stops rotating. Ensure that the angle now is set to zero. 4) a. We manually program the ESP to instruct the horizontal traverse motor to rotate by 360° (±2°). One test in clockwise direction and another in anticlockwise direction. b. We start timing after an LED signal (or Arduino's Serial Monitor) report that the turret will begin to move. c. We verify that the motor turns within 20 seconds, and that it turns as according to the programming (i.e., turns clockwise when instructed to turn clockwise). 5) a. We manually program the ESP to aim by 1, 2, 3, up to 16 pixels horizontally. We may conduct the test twice, first 1-16 pixels to the left, then 1-16 pixels to the right. b. The horizontal traverse motor should rotate the turret to an angle (±2°) according to the tabulated values. c. Note that the tabulation assumes the target is at a 5 meters distance. 6) a. Load a test image that has no target. b. Once the ESP detected that there is no target, proceed to turn the turret by 30° (±2°) clockwise.

	c. Verify that the rotation indeed amounts to 30° (±2°) by angle ruler.

2.3.3 Firing System Module

The firing system mainly consists of motors which controls the bullet (tennis ball, about 65 mm) reloading mechanism, the bullet firing mechanism, and the gun elevation mechanism. The bullet reload mechanism is controlled by a motor with extended spokes (reload motor), which regulates ball intake into the chamber, and making sure that only one ball is loaded into the machine at a time. The firing mechanism consists of two horizontal motors placed to each other, with a gap that barely fits the bullet diameter. The two motors rotates in opposite directions, with 6000 RPM and torque to ensure that the ball does not get jammed in the chamber, and that the ball can be propelled at high speed. When the ball touches the motors, the ball will be fired out from the gun shaft, and outwards to the surroundings. Finally, the elevation mechanism is controlled by a single servo, capable of lifting 25 kg, which is attached directly to the gun (gun barrel and the two firing motors), and the reload tube. The reload mechanism loads 5 balls in total. To keep track of the number of balls fired, we count the number of revolutions of the reload motor. After it reaches 5 revolutions (360*5=1800 degrees), it will stop, as it has fired 5 balls.

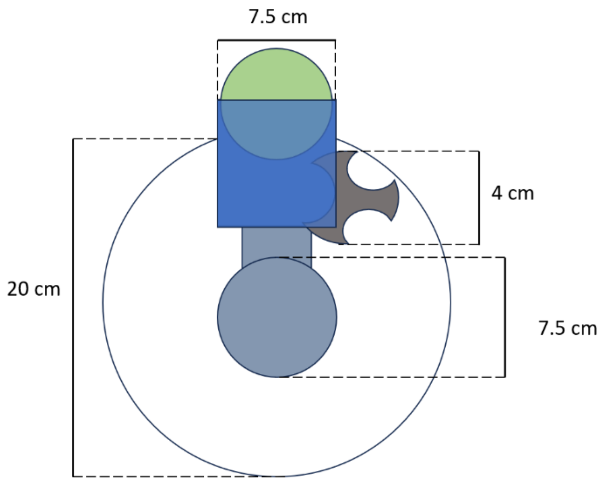

Figure 6. Reloading Mechanism (top-down view)

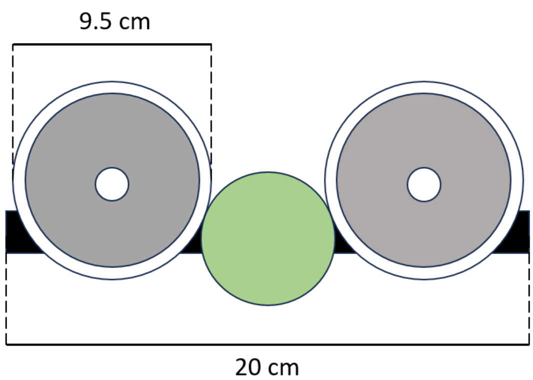

Figure 7. Firing System Mechanism

Requirement	Verification
1) The reload motor should only trigger when the blob detector detects an object 100% of the time. 2) The reload motor should only load one ball at a time, fire 5 balls within 10 seconds and 1 ball every 2s (±0.2s). The machine then stops firing until a new target is obtained. 3) The reload mechanism should not fail at least 90% of the time. Failing means the tennis ball is not removed from the machine by the firing motors (this includes jamming, or weapon misfires). 4) The firing motor should launch the ball at least 5 meters forward 80% of the time. 5) The firing motor should only trigger when a valid object is detected.	1) a. Load an image data that either contains nothing or a valid target. b. Once the machine identifies this target, it should start reloading the motor. If no target is detected, then it should not start the motor. c. Note that the reliability of this test depends on the classification quality of the blob detector. Hence, this test is deemed successful if the reload motor turns on as what the ESP MCU instructs, whether a target is actually there or not. 2) a. We load an image containing a valid target data. b. Once the robot detects the image, we start counting using a timer. This can be done by triggering the LED built in with the ESP, which will turn on after the target is identified. c. After the timer starts, we count the amount of time needed to load 5 balls separately. We also determine the total amount of time needed to fire all five balls. We measure the reload speed of each ball also to ensure that the reload is uniform. d. After shooting five balls, the machine shall go to sleep for 5s (±0.2s), and at this point the reload motor should completely stop. 3) a. We load two separate images with valid targets. b. Assuming requirements No.2 is met, then after the test ends, the machine should only misfire at most once. 4) a. Launch 10 balls from the machine. Record every launch to ensure the precise position hits the ground by tape measure. b. After knowing the landing position, we

	measure the shortest distance to the center of the gun (i.e., the initial point of launch) by tape measure. 5) a. Load an image data that either contains nothing or a valid target. b. Once the machine identifies this target, it should start the firing motor. If no target is detected, then it should not start the motor. c. Note that the reliability of this test depends on the classification quality of the blob detector. Hence, this test is deemed successful if the firing motor turns on as what the ESP MCU instructs, whether a target is there or not.

2.3.4 Power Module

This module provides power to the motors and ESP MCU. It will be powered by a wall outlet which will be distributed to all the devices on the system using voltage regulators. For large powerful motors (i.e., to rotate the turret base, elevate the gun (as it also carries the firing motors), and the firing motors), the power requirements are at 24V/3A, 5V/2A, and 48V/3A respectively. For the ESP module (3.3V/200mA), it will be powered with a 5V to 3.3V (like the AMS1117-3.3) voltage regulator.

Requirement	Verification
1) The wall socket should be capable of providing a voltage range of 0-48V via a voltage regulator, with an allowable deviation of ±5%. 2) The power supply module can operate within the current range of 0 to 3A, and the current provided to each part should not exceed the maximum current that the part can withstand.	1) a. Connect the voltage regulator to the wall socket input. Use its control interface to set the voltage controller to output 3.3V, 5V, 24V and 48V respectively, allowing a range error of 5%. b. Measure the output voltage across the voltage regulator using a calibrated multimeter. c. All outputs should be maintained within ±5% of the target voltage. 2) a. Connect the voltage regulator to the wall socket input. Use its control interface to set the voltage controller to output the rated voltage of the components respectively, allowing a range error of 5%. b. Connect each component to the voltage

	regulator respectively through the designed circuit. c. Measure the output current at both ends of the component using a calibrated multimeter. d. All output currents should be within the range of 0 to 3A ($\pm$5%) and not exceed the rated current of the component

2.4 Tolerance Analysis

During our feasibility analysis, we determined that the gun module will be the hardest to implement, as it requires tight synchronization between the motors, a sturdy chamber to house the moving parts (i.e., motors) and making sure the gun shaft can elevate/depress freely while still being attached with the firing motors. Here, we consider how fast the ball should be propelled such that we can consider the ball hitting a target 5 meters away at maximum elevation (10 degrees). Assuming our initial velocity is v_i, our ball trajectory can be modeled as (1):

$$0 = v_i \sin 10^\circ - \frac{1}{2} g t \tag{1}$$

Where *t* is the time of which the ball has reached the ground ($t > 0$):

$$t = \frac{2 v_i \sin 10^\circ}{g} \tag{2}$$

Assuming *t* is also the time the ball took to travel 5 meters:

$$\frac{5}{v_i \cos 10^\circ} = \frac{2 v_i \sin 10^\circ}{g} \tag{3}$$

Numerically evaluating (3) gives the initial velocity to be:

$$v_i \approx 12 \frac{\mathrm{m}}{\mathrm{s}} \tag{4}$$

Hence, we need to achieve an initial velocity of 12 meters/second. Now consider the rotational energy of the two motors:

$$E_{\text{total}} = 2 \cdot \frac{1}{2} I \omega^2 = \frac{1}{2} M R^2 \omega^2 \tag{5}$$

We now constrain the mass of the wheel (*M*) to be 400 grams. Assuming a 6000 RPM motor, then:

$$E_{\text{total}} = \frac{1}{2} 0.4 \cdot R^2 628.32^2 \tag{6}$$

Hence:

$$E_{\text{total}} = 78956 R^2 \tag{7}$$

We now assume that 40% of the energy is converted into the ball's translational energy, with the ball mass of 56 grams (assuming the same mass as a regular tennis ball), giving a velocity of:

$$v = 1062 R \tag{8}$$

Then, the minimum radius of the ball must be:

$$R = \frac{12}{1062} = 9.4 \text{ cm}$$

Which is within reasonable range for the propelling wheel. This radius can be further decreased if we increase the mass of the rotating wheel, but this calculation nevertheless shows a good indication of our design criteria.

2.5 Schematics and Board Layout

As seen in Figure 8. The tennis ball used in this design has a measured diameter of approximately 65 mm. The two grey circles with white outer rings represent the main wheels driven by motors, which are used to launch the ball. The large transparent circle indicates the ammunition box, which stores the tennis balls before they enter the launching mechanism. In Figure 9. The launching motor is highlighted in dark grey. Smaller motors in comparison, such as the reloading motor and the angular motor used to adjust the firing trajectory, are shown in purple.

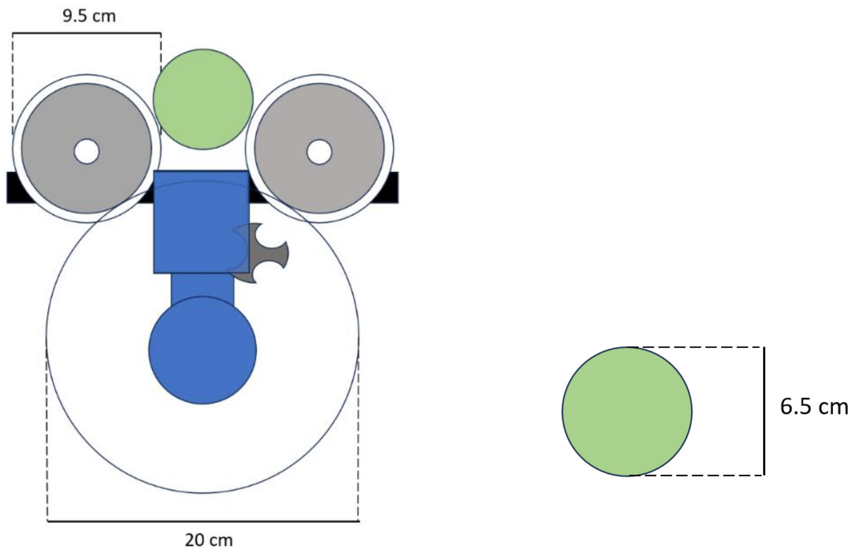

Figure 8. Top view of the DodgeBot mechanism with ball sizing

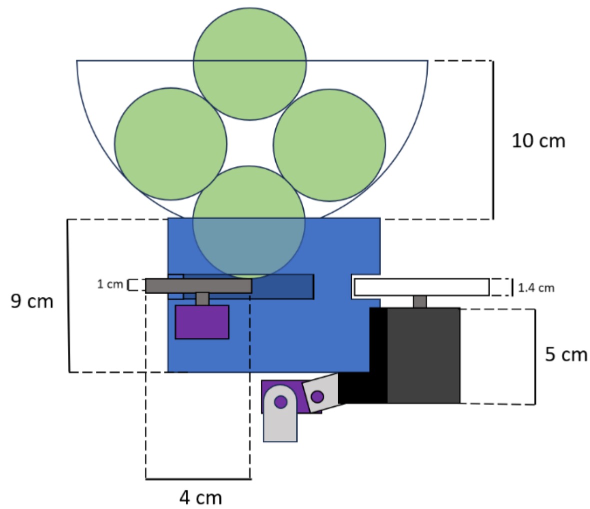

Figure 9. Side view of the DodgeBot mechanism

Circuit wise, the implementation will be very simple: cable connections between servos and motor drivers are made directly to the ESP module (through soldering). For the firing motor wirings, we follow the datasheet of the AK300S motor driver [1]. The wirings are shown in Figure 10. Note that for the Figure 10 (left), an extra wiring is done from GND to CCW so that the motor turns in the CCW direction, which is required to propel the ball forward.

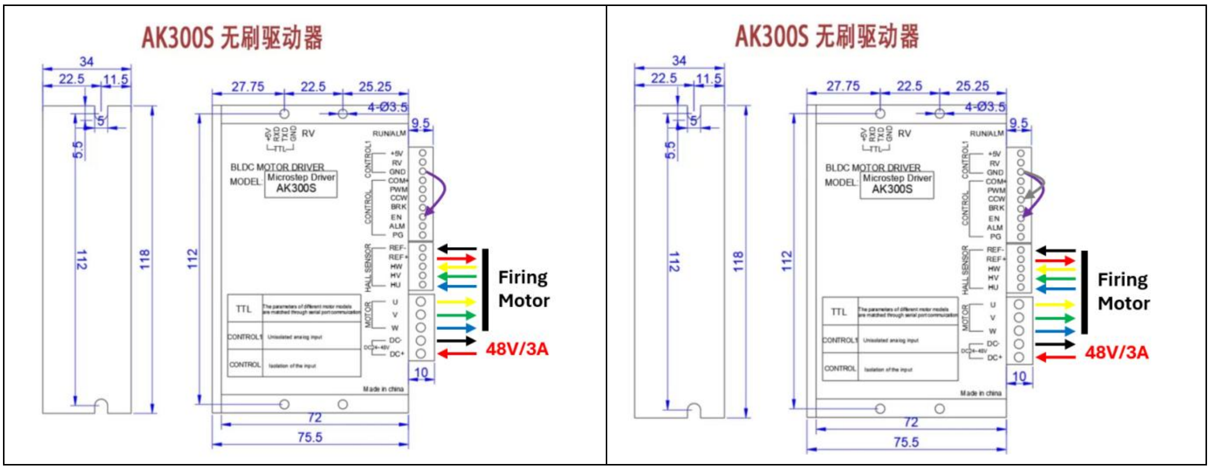

Figure 10. The datasheet and wiring of the AK300S motor driver, used to interface the firing motor with the ESP MCU.

2.6 Software

The whole system used to control the motors are as shown in Figure 11. In this case, the software is loaded by the ESP MCU every boot and will run indefinitely. The system first tries to connect to the Thermal camera Wi-Fi hotspot. If unsuccessful, it will try again after 5 seconds, but if successful, it will start reading the camera's data. Two of the most important data is read at this stage, the image data and the camera's battery data. While the camera does not offer a 0-100 scale for its battery level, from experience we noticed that a battery of <3.7V will result in a camera shutdown. Therefore, if the camera battery's voltage reaches 3.7V, our ESP MCU will trigger a warning LED light indicating that the camera's battery is running low. It will then proceed to process the camera's image data, and depending on whether a target is there or not, it will trigger the following motors in sequence:

Firing motors → Vertical and horizontal traverse motors → Reload motor

Then, the reload motor starts loading 5 balls. To count the number of balls loaded, the reload motor will slowly rotate from 0 degrees to 360*5 = 1800 degrees. After which, the reload motor stops, and shuts down all the related motors. It will then scan the surroundings again to acquire a new target. If no target is detected, it will rotate by 30 degrees CW to search for a new target.

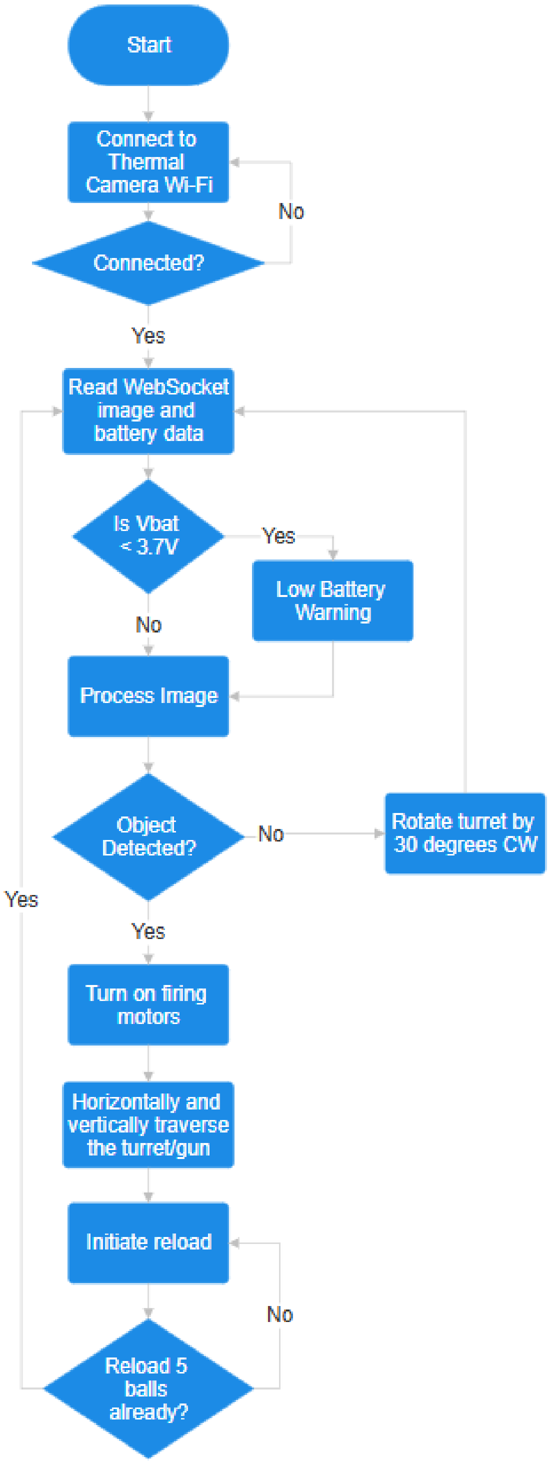

Figure 11. Flowchart for the software systems.

3 Cost

No.	Item Description	Quantity	Price (¥)
1	Pocket-size Thermal Imaging Device (Black)	1	299
2	Star-Shaped Coupling D25 L30	2	24
3	Heavy Duty Iron Caster Wheel (4-inch, 12 holes)	2	22
4	Hex Socket Bolt M22×50 (8.8 grade, 2 pieces)	1	6,24
5	Plum Coupling Star Type D40 L45	2	40
6	Plum Coupling Star Type D45 L55	1	30
7	Aluminum Profile 4040 – 2020L Type	1	16,19
8	T-slot Screw + M5 Nut Set	1	1,6
9	Spring Plate Nut for Aluminum Profile (20 pcs)	1	2,4
10	2020 Corner Brackets for Aluminum Profile	1	0,58
11	Hinged Connector (Zinc Alloy, 20 Series Slot)	1	0,6
12	Stepper Motor Mount Bracket for 42/57/60/80 size motors	2	36
13	Plum Coupling Star Type D45 L55 (duplicate)	1	30
14	EVA Foam Balls (Photography Prop – 6 pcs)	1	11,8
15	4-inch Silent Swivel Rubber Wheel (TPR)	2	37,2
16	Brushless DC Motor Kit 57BLY55-48V-100W	2	493
17	UPVC Pipe + 90° Elbow (DN80, 90mm diameter)	2	27,19
18	MG996R Metal Gear Servo Motor (360° rotation)	1	14,81
19	Dual-axis Servo Motor Set 25kg (RDS3225)	1	105
20	Drive Wheel (95mm diameter, 8mm inner)	2	54
21	Acrylic Transparent Dome Cover (200mm)	1	31
22	Stainless Steel Coupler (Double-hole, 3–6mm)	1	7,84
23	Shaft Collars with Hex Set (10pcs + 5 Handle Tools)	2	11,07
24	Short Solid Stainless Steel Rod (Φ3×200mm, 5pcs)	1	2,67
25	acrylic L tube (custom made)	1	320
Total		**34**	**1624,19**

Our labor cost from Feb1 to Apr 18 is:

Name	Hours Worked	Hourly Rate (USD)	Total Cost (USD)
Loigen	200	20	4000
Jaden	200	20	4000
Liikoya	150	20	3000
Jenna	100	20	2000
Isaac	50	20	1000

Items reimbursment = **¥ 1624.19**

Labor cost = $ 14000

4 Schedule

Week	Tasks	Member
25 April	Finish 3D printing and assembling the reload mechanism. This includes the L-tube and reload motor mount connection	Jaden, Loigen
	Design and build the foundation for the gun to rest to. It will be attached to the vertical traverse motor.	Jenna, Qingyan
	Investigate power delivery mechanism for our motors and MCU. This includes ordering components.	Isaac, Loigen
2 May	Build the turret casing, which also includes the magazine that connects to the reload mechanism. This case will be connected to the base that Qingyan made the week before.	Jaden, Jenna
	Attach turret traverse motor to the base of the turret.	Qingyan
	Map out and create wirings for the power delivery system. Test using a multimeter to ensure that the voltage output is what we expected.	Isaac, Loigen
9 May	Assemble power wirings to the motor and ensure that motors are correctly powered.	Isaac, Loigen
	Create the base that encapsulates the turret traverse motor.	Qingyan, Jenna
	Create barrel for the gun component and attach heat camera to the gun.	Jaden
	Program the MCU to traverse the turret and elevate the gun according to the rules in Section 2.3.2.	Loigen

5 Ethics and Safety

The Dodgebot system presents important safety and ethical concerns related to projectile impact, robotic movement, and user privacy. Ensuring safety and responsible use is a priority throughout development and deployment.

One of the biggest concerns is preventing injuries from projectile impacts. To keep the system safe, Dodgebot will use soft, foam-coated balls and limit their speed to prevent excessive force. These safety measures align with **IEEE Ethics Guideline [4]**, which prioritizes public safety, and **ASTM standards**, which ensure that projectiles remain safe for recreational use.

Another risk is the movement of the rotating turret. If it moves too fast or unpredictably, it could cause accidental hits or mechanical hazards. To prevent this, the system will have controlled rotation speeds, limited to 18 degrees per second, and internalized wirings to prevent tangling with outside objects. Additionally, **OSHA safety guidelines [5]** will be followed to minimize mechanical risks.

Privacy is also a concern because Dodgebot uses thermal imaging to detect players. To protect user data, the system will not store any images, and all processing will happen in real-time. Players will be required to give consent before tracking begins. These steps follow the **ACM Ethics Guideline [6]**, which focuses on protecting personal privacy.

An additional concern is **detection reliability based on camera limitations**. To ensure Dodgebot only operates where accurate sensing is possible, we will implement a physical detection zone that matches the effective viewing cone of the thermal camera. Because the camera cannot reliably detect targets beyond a certain distance or angle, the system will automatically disable tracking and firing when a target moves outside this cone. This prevents unintended behavior, and follows **IEEE Code of Ethics [1]**, which prioritizes system safety.

Furthermore, there are concerns on privacy, since we are using a thermal camera. Under the EU's GDPR [1], thermal imagery containing biometric or health data qualifies as personal data, triggering requirements for lawful basis, data minimization, and secure handling. IEEE's CertifAIEd™ Privacy [2] specification outlines that data processing should be limited to legitimate ends, with transparent policies and protection against unauthorized disclosure. In this case, we do not save any form of imaging data. While the image is kept in a queue system, the data of the image will be "destroyed" after the image is processed as to make room for new data. In the case where the machine stops while still having some picture data in the queue, the image is destroyed once the system shuts down and is not stored in any non-volatile memory.

By following industry standards, legal regulations, and university policies, Dodgebot will be a safe, ethical, and responsible system that ensures fair and secure gameplay for all users.

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