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Contents

1. Introduction

The game *Dodgeball* is a game that traditionally requires two opposing teams, where the attacking team tries to hit the opponent (i.e., the defending team) by throwing balls against them. While the game is relatively simple, the current state-of-the-art explores alternative to the traditional dodgeball format such as augmented reality (AR) dodgeball [1], motion-tracking dodgeball [2], and *dodgebots* (a combination of "dodgeball" and "robot"), which will be the primary discussion of this proposal. This section serves to introduce the *dodgebot* concept, along with specific set requirements that determine the final design feasibility. Section 1.1 explains the underlying problem that leads to the *dodgebot* concept, Section 1.2 details the solution to Section 1.1, and Section 1.3 outlines the specific requirements that the design must achieve to fully solve the problem statement.

1.1 Problem

While traditional dodgeball remains a popular sport, its physical demands and safety risks limit accessibility. Players with mobility challenges often cannot participate, and high-velocity throws raise concerns about injuries, especially among younger players. Recent attempts to modernize the games such as augmented reality (AR) systems or motion-tracking setups have introduced new hurdles. For example, AR setups depend heavily on controlled environments and wearable tech, which restrict spontaneous gameplay. Motion-tracking systems, meanwhile, often lag in fast-paced scenarios and struggle with accuracy under variable lighting [3]. These solutions also fail to replicate the physical interaction that defines traditional dodgeball.

A key unresolved challenge lies in developing an autonomous robotic system that safely emulates dodgeball's core mechanics while being inclusive and reliable. Existing robotic platforms face issues like inconsistent target detection in real-world settings, mechanical limitations in turret rotation, and frequent misfires during projectile launches. The dodgebot project tackles these gaps as to be discussed in Section 1.2.

1.2 Solution

The proposed dodgebot system addresses the limitations of traditional and modern dodgeball variants by introducing an autonomous robotic platform that combines adaptive thermal imaging, precision targeting, and modular design. The following are the several cores features we have chosen to implement:

1. **Adaptive Thermal Imaging**
   The machine vision module employs a thermal camera paired with a Jetson Nano for real-time target detection. By analyzing temperature differentials, the system identifies human targets with ≥70% confidence, ensuring robust performance under variable lighting and dynamic conditions. This eliminates reliance on controlled environments or wearable sensors, addressing the shortcomings of AR and motion-tracking systems. The system also determines the approximate range of the target from the machine based on how large is the target signature, to which allows the appropriate gun elevation to be used to hit the target.

2. **360° Turret Rotation**
   The turret module, controlled by an Arduino, enables full rotational mobility within 20 seconds. Internal wiring prevents entanglement during rotation, ensuring unrestricted movement. The turret's elevation mechanism adjusts the firing angle incrementally (up to 10∘) to deliver a burst of projectiles, enhancing engagement dynamics.
3. **High-Reliability Firing System**
   The firing mechanism utilizes dual counter-rotating motors to propel tennis-sized balls at a rate of 1 ball/5 seconds, achieving ≥95% firing reliability. The ball chosen is lighter than a typical tennis ball, to minimize injury risks, while still maintaining its large appearance to make dodging easier.
4. **Modular and Self-Contained Design**
   The dodgebot operates independently, requiring only two batteries. This eliminates external dependencies, ensuring portability and future expansion in the robot mobility.

1.3 High-level Requirements List

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

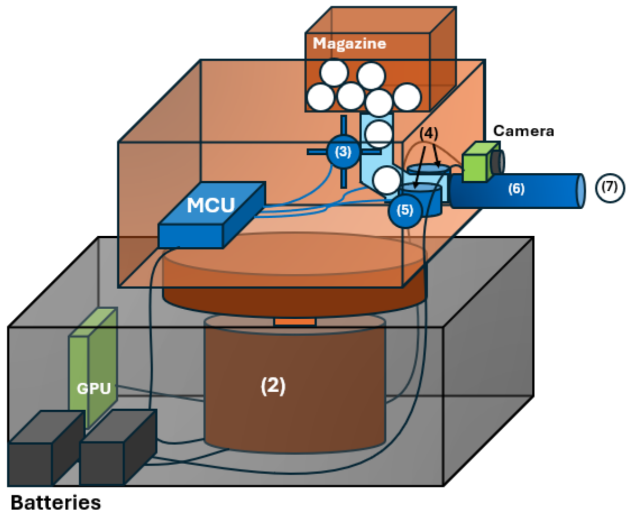
- The turret module should be able to rotate fully to 360 degrees within 20 seconds. Hence, wiring must be done inside the robot to ensure that it will not be entangled when the turret rotates.
- The firing mechanism should be able to fire without misfiring >95% of the time.
- The robot must achieve ≥80% firing accuracy when targeting moving humans within a 10-meters range under standard (flat terrain, good visibility) conditions.
- The machine vision classification should achieve accuracy of ≥80%.
- The whole design should be modular, that is no external connection. Power is done with batteries.

2 Design

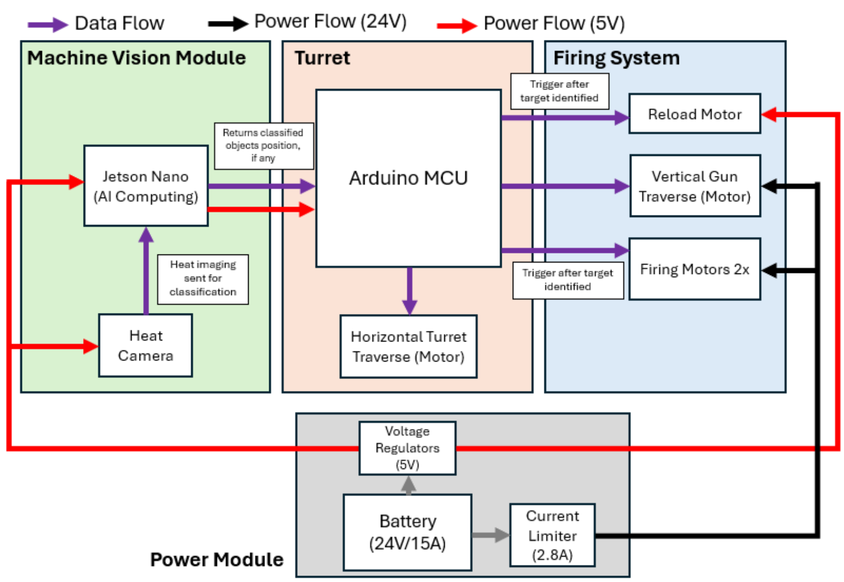
The following section presents in detail the schematic of the design.

2.1 Block Diagram and Systems Overview

The 3D schematic of the robot is shown in Figure 1 (a), and the detailed schematic of the robot's components is shown in Figure 1 (b).



(a)



(b)

Figure 1. (a) Shows the 3D schematic of the robot, with (1) as the PSU, (2) the turret (orange rectangle) horizontal traverse motor, (3) the reload motor, (4) the firing motor, (5) the vertical gun traverse motor, (6) is the gun shaft, (7), is the fired projectile. (b) Outlines the schematic for all the modules required to achieve the design.

2.1.1 Machine Vision Module

This module consists of a thermal camera and a *Jetson Nano* computer to perform image classification. The camera is mounted on the gun barrel; hence it is aimed exactly where the gun is aiming at. On a specific viewpoint, the computer 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 exceeds 20°C. Since we train this machine with regards to humans (at distance up to 10 m), the computer will only classify these anomalies as a valid target if it shows >70% confidence in its estimation. If it is a target, this module will instruct the Arduino (turret module, see Section 2.1.2) to traverse the turret towards the target, reload and fire the gun. Otherwise, it will instruct the Arduino to rotate the turret to a new viewing point for image classification.

2.1.2 Turret Module

The turret module houses the Arduino microcontroller, which controls the turret traverse and the gun firing system (in the firing system module, see Section 2.1.3). To rotate the turret, the Jetson Nano (from machine vision module, Section 2.1.1) will instruct the Arduino 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 (a weighted ping-pong 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 Arduino will rotate the turret to another viewpoint for classification, return the gun elevation to normal, and switches off the firing motor.

2.1.3 Firing System Module

The firing system mainly consists of motors which controls the bullet reload 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 high 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 motor, which is attached directly to the gun (gun barrel and the two firing motors). This motor elevates or depresses the shaft, which is independent of the rest of the reloading system, as to not overcomplicate the elevation/depression process.

2.1.4 Power Module

This module provides power to both the motors, Jetson Nano, and the Arduino. It will be powered by two 12000 mAh batteries (24V/15A) 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/2.8A, which requires a current limiter. For the reload motor and Jetson Nano (5V/2A), it will be powered with a 5V voltage regulator. The Arduino is powered through USB connection from the Jetson Nano to the Arduino to simplify design.

2.2 Subsystem Requirements

2.2.1 Machine Vision Module

The machine vision module must satisfy the following:

- Systems should identify correctly targets 80% of the time.
- If multiple targets are detected, it should select a target that has a higher confidence rate.
- The system needs to correctly relay the x-axis and y-axis offset of the target from the center pixel for targeting.

2.2.2 Turret Module

The turret module must satisfy the following:

- Able to rotate a full 360 degree turn without causing damage to other components (e.g., tangled wires) within 20 seconds.
- Using the x-axis offset data, the Arduino should be to turn the turret such that the gun (located at the center of the turret) can aim towards the center of the target.
- The turret module should have a magazine box on the top with easy access inside to reload the ball.
- The Arduino should initiate the correct firing sequence (which amounts to one burst):
    1. Turn on the firing motors.
    2. Rotate the turret using the horizontal turret traverse motor to align the target horizontally and then use the vertical gun traverse to align the target vertically. The target is aligned with respect to the center of the camera's image pixel.
    3. Load one ball into the chamber. A local variable in the Arduino increments by one after the motor has finished rotating. This local variable will be used to count the number of balls fired. Within five seconds, the ball must have been fired.
    4. Repeat steps 2 and 3 until the local variable counts until **5**, i.e., the number of balls that has been shot.
    5. Turn off the firing motors and reset the elevation angle to zero.

2.2.3 Firing Module

The firing module must satisfy the following requirements:

- The gun should reliably fire at least 95% of the time.
- The whole firing system should accommodate projectiles of a ping-pong ball size.
- The rate of fire for one burst is 1 ball/ 5 seconds, and one burst should amount to 5 balls in total. We expect that the machine will fire 5 balls about 90% of the time, and even if extra balls are found to have entered the chamber, the standard deviation should amount to be +/- 1 ball.

2.2.4 Power Module

The power module must satisfy the following requirements:

- Provide a 2.8A of current while maintaining 24V DC under maximum load (simultaneous horizontal turret traverse, vertical gun traverse, and the firing motors running).
- Provide 5V/2A DC for both the reload motors and Jetson Nano.
- A battery lifetime of minimum 30 minutes, ideally 1 hour.

2.3 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 modelled 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:

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

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.

3. 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. This safety measures align with IEEE Ethics Guideline [1], 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, as we limit it to 18 degrees per second and internalized wirings (as to prevent it getting tangled with outside objects). Additionally, OSHA safety guidelines [2] will be followed to minimize 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 have to give consent before tracking begins. These steps follow ACM Ethics Guideline [3], which focuses on protecting personal privacy.

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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