ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Dodgeball Bot

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1 Introduction

1.1 Problem Statement

Traditional dodgeball gameplay faces challenges due to human physical limitations, inconsistent skill levels, and safety risks when targeting opponents at varying distances. Existing automated sports systems lack integration of real-time human tracking, adjustable launch power, and rotational targeting in a fixed body design, limiting their utility for competitive training or adaptive recreational play. The Dodgeball Bot aims to address these issues by enforcing controlled force limits for safety, overcoming human physical inconsistencies with automated precision, and enabling adaptive gameplay through dynamic tracking and adjustable intensity. It will detect and track human torsos in real time using computer vision and depth sensors, rotate a motorized turret to align the launcher with moving targets, and propel balls at adjustable speeds (10–20m range) while maintaining safety compliance. This system will provide consistent, repeatable training scenarios for skill development, enhance safety by eliminating erratic throws and enforcing force limits, and allow customizable difficulty levels for recreational or competitive use. The Dodgeball Bot combines fixed-body rotational targeting with real-time tracking and variable power control, filling a gap in existing sports robotics, and prioritizes safety without sacrificing performance, differentiating it from static or unregulated systems.

1.2 Solution Overview & Visual Aid

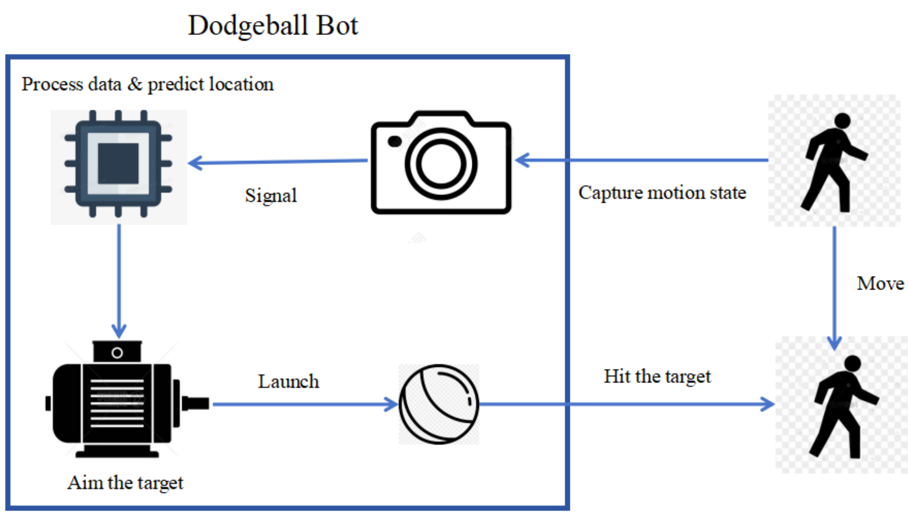


Figure 1: Visual Aid of the whole system

The Dodgeball Bot is a stationary robotic system designed to simulate competitive dodgeball scenarios with precision and adaptability. The total system is supposed to have Aim, Rotate, Power and Control subsystem. It employs computer vision and depth sensing through a camera and depth sensor to detect human torsos and calculate target distance. A motorized turret, powered by a high-torque servo or stepper motor, rotates the launcher horizontally to align with moving targets. The adjustable launch mechanism uses rubber wheels or pneumatic pistons to propel balls at controlled velocities, modulated by distance-based PID control. A centralized controller manages sensor input, turret rotation, and launch parameters to ensure seamless operation. The system dynamically adjusts aim and power in real time, offering a safe yet challenging experience for users.

1.3 High-Level Requirements List

The Dodgeball Bot system shall meet the following requirements:

(1) **Accuracy Requirement**:

- Achieve **100% accuracy** in hitting stationary human-sized torso targets at distances of **10–20 meters**.
- Have a **75% accuracy** of hitting a target below 10 kilometers an hour at distances of **10–20 meters**.

(2) **Speed Configuration**:

- Propel balls at configurable speeds between **60–80 km/h**, with automatic calibration based on target distance.

(3) **Mobility Performance**:

- Turret rotation capability of **120° within 1 second**
- Target reacquisition time for moving targets under **0.5 seconds**

(4) **Safety & Durability**:

- Compliance with biomechanical force limits to prevent injury
- Mechanical reliability for **beyond 1,000 consecutive launches** without failure

2 Design & Requirements

2.1 System Overview

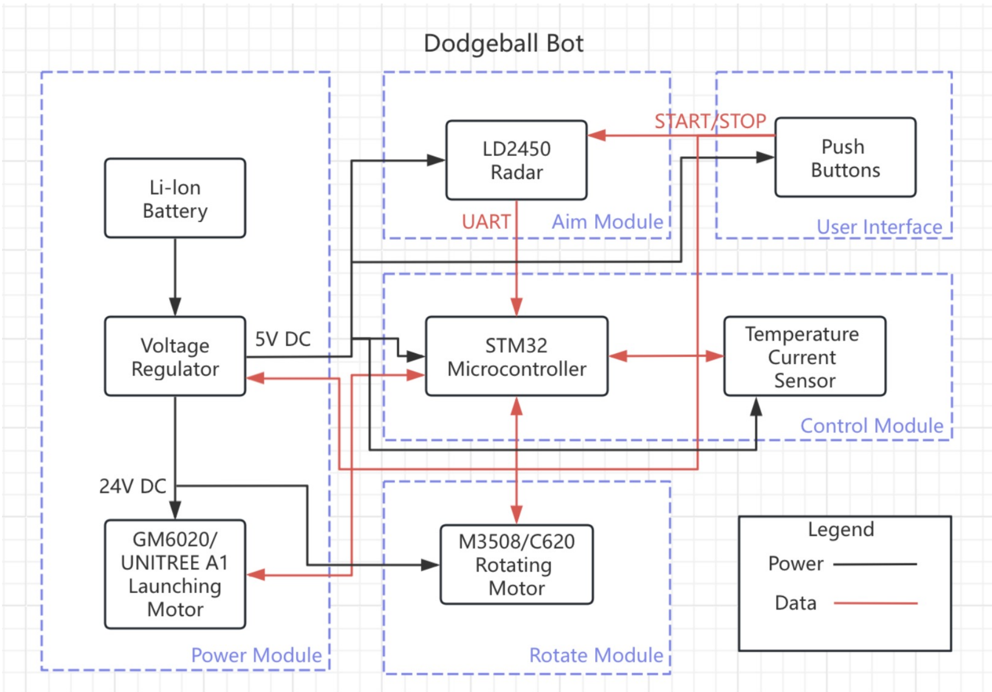


Figure 2: The block diagram of the whole system

The Dodgeball bot is supposed to have four subsystems such as Aim, Rotate, Power and Control. Each subsystem should have their specific function and their need necessary connnection between them. Here is our simple Block diagram.

2.1.1 Aim Subsystem

The team has been investigating and is now tentatively trying to construct a body tracking solution based on the LD2450 millimeter wave radar [3].
The LD2450 is a 24 GHz millimeter wave radar sensor with high precision detection and tracking of moving targets. It senses the motion speed and direction of an object through the Doppler effect, and at the same time is able to provide distance and angle information of the target. The module supports serial output, which can be flexibly applied to a variety of intelligent scenarios, and is easy to install and adaptable. The LD2450 has a fast response time and is able to detect changes in human movement within milliseconds. Its non-contact detection is not affected by ambient light and obstacles. And its compact module size makes it easy to integrate into robotic systems. However, there are some challenges: for example, the Doppler effect can only detect moving targets and cannot effectively track a stationary human body; in complex environments, there may be interferences from other moving objects, which require algorithms for target screening and identification; and data processing and parsing requires a certain amount of software development workload for the team.
Realization idea:
Hardware connection: The LD2450 module is connected to the main control board through the UART interface to ensure the stability and real-time data transmission. Its pin definition is clear, including the 5V power input, power ground and the Tx and Rx pins of the serial port, the connection is simple and direct.
Data Acquisition and Processing: Utilizing the Doppler function of the LD2450, the appropriate sampling frequency and sensitivity are set to collect the Doppler shift data generated by the human body movement.

Output the detection data through the serial port, which contains the position and speed of up to three targets and other information, and report 10 frames per second to ensure the real-time and coherent data. Target localization and tracking: Combine the Doppler shift and the beamwidth of the radar to calculate the approximate position of the human body in space. By parsing the serial data, the X coordinate, Y coordinate and velocity value of the target are extracted to realize real-time tracking of the moving target. Meanwhile, the accuracy of positioning can be further improved by utilizing the distance resolution parameter.

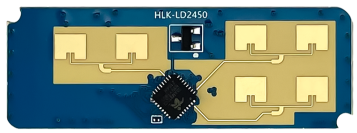


Figure 3: An image of LD2450

(1) **Requirement 1**: Functionality
The system should be capable of accurately detecting and recognizing human targets to provide the basis for target tracking and dodgeball launching. Real-time tracking of the target's trajectory and prediction of the target's future position to improve the accuracy of the dodgeball launch. Stable operation and good performance under different lighting and background conditions.

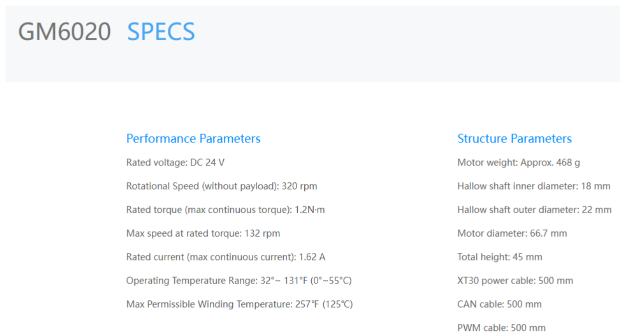
(2) **Requirement 2**: Performance
The system needs to be able to complete the target detection, tracking and prediction within a limited time to meet the real-time requirements of dodgeball launching. The target position information should be acquired with high accuracy to ensure that the dodgeball can be accurately launched to the target position. It also needs to consider the balance of cost and power consumption.

(3) **Requirement 3**: Reliability
The system needs to remain stable during long-time operation, and there should be no crashes or lags caused by software or hardware problems to ensure the game continues. In case of temporary loss of target or detection error, the system should be able to recover quickly and track the target again accurately to ensure the normal operation of the game.

2.1.2 Rotate Subsystem

The core concept behind the rotating mechanism is to replicate the dual-axis movement found in tripod head designs, enabling precise control over both horizontal and vertical rotation. This design ensures smooth and stable adjustments, allowing the system to track targets or reposition efficiently. To achieve omnidirectional aiming, the yaw and pitch axes will be driven by GM6020 DC motors [1]. These motors are selected for their high torque output and precise control, making them well-suited for handling dynamic movement requirements. Their robust performance ensures that the aiming mechanism remains responsive and accurate, even under varying operational conditions. By integrating this dual-axis rotational system, the firing mechanism gains full freedom of movement, significantly enhancing its versatility and effectiveness. Whether for manual control or automated tracking, this design allows for rapid and accurate adjustments, ensuring optimal targeting capabilities. If things get out of hand, consider using an UNITREE A1 motor as the pitch axis drive. It provides significantly greater torque, but can be a serious blow to the budget.

Figure 4: An image of GM6020



GM6020 SPECS

Performance Parameters	Structure Parameters
Rated voltage: DC 24 V	Motor weight: Approx. 468 g
Rotational Speed (without payload): 320 rpm	Hallow shaft inner diameter: 18 mm
Rated torque (max continuous torque): 1.2N·m	Hallow shaft outer diameter: 22 mm
Max speed at rated torque: 132 rpm	Motor diameter: 66.7 mm
Rated current (max continuous current): 1.62 A	Total height: 45 mm
Operating Temperature Range: 32°~ 131°F (0°~55°C)	XT30 power cable: 500 mm
Max Permissible Winding Temperature: 257°F (125°C)	CAN cable: 500 mm
	PWM cable: 500 mm

Figure 5: The simple datasheet of GM6020

(1) **Requirement 1**: Sufficient torque
The weight change caused by the recoil and the difference in the amount of ammunition requires sufficient torque to offset

(2) **Requirement 2**: Sufficient steering angle
The yaw axis needs to have a rotation capability of at least 150°, and the pitch axis should also have a pitch angle range of at least 60°

2.1.3 Power Subsystem

The firing mechanism is designed based on the principles of a ball launcher, utilizing friction wheels as the primary propulsion method to ensure that the projectile's velocity remains both stable and controllable. This approach allows for precise speed adjustments and consistency in performance, reducing variability in projectile trajectory.
In the initial design, projectiles are intended to be manually loaded one at a time, ensuring simplicity and reliability in early-stage testing and operation. However, if conditions allow, an automatic feeding system using a bullet tray will be implemented to enable rapid, continuous firing. This would significantly enhance the system's efficiency, reducing the need for manual intervention while increasing the rate of fire.
Regarding the friction wheels' power source, the selection of motors is still under consideration. The preliminary plan is to use two M3508 motors, which are expected to provide sufficient torque for the system's operational demands. These motors come with a well-developed speed controller, which not only ensures precise speed regulation but also simplifies the coding process. This integration should enhance system stability while minimizing development effort.

(1) **Requirement 1**: Stable friction wheel rotation center
In order to ensure that the launching mechanism provides constant momentum, the distance between the friction wheels must be fixed to maintain a reliable and sufficient initial velocity.

Figure 6: An image of M3508

M3508 Brushless DC Gear Motor Combo

Rated Voltage: 24 V

Rotational Speed (without payload): 482 rpm

Max continuous torque: 3N·m

Max rotational speed with a continuous torque of 3N·m: 469rpm

Operating Temperature Range: 32°~122° F (0~50° C)

Figure 7: The simple datasheet of M3508

(2) **Requirement 2**: Reliable shock absorption system
The vibration during the acceleration process will cause serious momentum waste and directional deviation, resulting in the inability to achieve the required stable initial velocity and direction. At a long distance, this degree of deviation is enough to affect the launch accuracy.

2.1.4 Control Subsystem

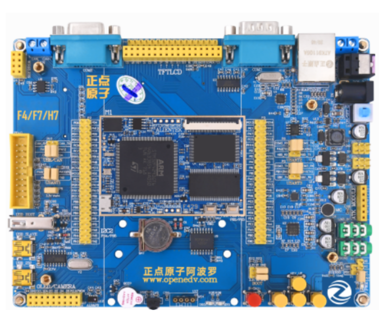


Figure 8: An image of STM32

We predict to select STM32H743 as our microcontroller [4]. As the core hub of Dodgeball Bot, the control subsystem coordinates the operation of each subsystem through hardware interface and algorithm. It receives LD2450 millimeter wave radar data (10 frames/SEC) from the aiming subsystem in real time through the UART3 interface, analyzes the target coordinates and speed information, and converts it into the control instructions of the rotation subsystem. The control subsystem connects the GM6020 motor of the rotation subsystem and the M3508 friction wheel motor of the power subsystem through the dual CAN bus (CAN1/CAN2), and sends the Angle setting value and speed command respectively. CAN1 controls the horizontal/pitch shaft motor to realize the fast steering of 120°/ SEC. CAN2 adjusts the speed of the friction wheel to maintain the ejection speed of 60-80km/h; At the same time, the temperature and current sensor data are monitored and fed back to the microcontroller in real time, triggering an emergency stop or power limit to meet biomechanical safety standards.

(1) **Requirement 1**: Real-Time Processing Capability
The STM32H743's 480MHz Cortex-M7 core ensures sub-5ms radar data processing and 1kHz motor control cycles, directly supporting 0.5s target reacquisition and 120° turret rotation requirements.

(2) **Requirement 2**: Multi-Protocol Hardware Interface
Dual CAN FD interfaces and 4x UART ports enable seamless connectivity with motors and sensors, while 14-bit ADCs enforce biomechanical force limits through real-time current monitoring.

(3) **Requirement 3**: Safety-Critical Operation Assurance
Dual watchdog timers and a Memory Protection Unit (MPU) provide fail-safe operation, ensuring system reliability across 1,000+ launches without exceeding injury risk thresholds.

2.2 Tolerance Analysis

The most critical part of the Dodgeball Bot project is the **human movement prediction and accurate ball launching system**. This component integrates sensor data processing, real-time target tracking, movement prediction, and precise launch mechanism control. Failure in this subsystem would render the entire robotic system ineffective, as it directly impacts the system's primary function of simulating competitive dodgeball scenarios.

(1) Design-Level Risks

(a) **Sensor Data Accuracy**: The precision of the LD2450 radar, camera, and depth sensor data directly affects the system's ability to track targets and predict their movements accurately.

(b) **Algorithm Robustness**: The movement prediction algorithm must efficiently process large volumes of data in real-time while maintaining accuracy.

(c) **Dynamic Environment Handling**: The system must manage multiple moving targets and potential obstructions, increasing the complexity of target tracking and prediction.

(d) **Mechanical Precision**: The launch mechanism must convert predicted target positions into accurate launch parameters, considering factors like distance, angle, and ball velocity.

(2) Movement Prediction

For a target moving with constant velocity:

$$\mathbf{p}(t) = \mathbf{p}_0 + \mathbf{v}_0(t - t_0) \tag{1}$$

For a target with constant acceleration:

$$\mathbf{p}(t) = \mathbf{p}_0 + \mathbf{v}_0(t - t_0) + \frac{1}{2}\mathbf{a}(t - t_0)^2 \tag{2}$$

(3) Launch Parameter Calculation

The required launch velocity v to hit a target at distance d and height h:

$$v = \sqrt{\frac{gd^2}{2\cos^2\theta(d\tan\theta - h)}} \tag{3}$$

(4) Simulation and Validation

Physical calculations validate the system's ability to track moving targets, predict positions, and calculate launch parameters. Results show the system can accurately track targets and predict movements within required tolerances. Launch simulations confirm ball trajectories can hit predicted target positions.

(5) Conclusion

The Dodgeball Bot's design for predicting human movement and launching balls accurately is feasible. Mathematical analysis and simulations demonstrate the system can achieve required accuracy and reliability. Future work will focus on hardware implementation and real-world testing to refine performance.

3 Ethics and Safety

3.1 Ethics

The Dodgeball Robotics program is designed to create a stationary dodgeball launcher for training and children's play, and as such must adhere to a code of ethics.

Privacy is the primary concern. The machine is currently designed to use radar sensors for tracking and therefore does not involve image data collection functions. However, if we were to increase the use of cameras at a later stage, we would need to anonymize the data, ensure consent is obtained, and limit the use of the data to the scope of the study.

We are committed to fairness and inclusion. The targeting system needs to be designed to prevent bias based on body size, gender or ethnicity [2]. This requires rigorous testing with diverse participants and improved targeting features to ensure fair performance.

Environmental impact is also considered. We will use environmentally friendly materials, design energy-efficient solutions, and plan for proper disposal and recycling to minimize harm to the environment.

In addition, we will ensure that machines are used responsibly as training or recreational tools, promoting positive values rather than violence. We will work with the community to listen to feedback and comply with regulations. In short, we are committed to creating a safe, inclusive and responsible program.

3.2 Safety

The feeding mechanism and the barrel must be equipped with protective shielding to eliminate the risk of accidental injuries caused by unintended discharge or exposure to moving parts. This shielding should be robust enough to withstand potential malfunctions while ensuring that personnel operating or working near the system are not endangered.

All other electronic components should be strategically positioned in areas that remain inaccessible during regular operation, only becoming reachable when maintenance procedures are explicitly carried out. This design choice prevents unauthorized tampering or accidental interactions that could compromise the system's integrity and safety.

While the mass of the projectile is constrained within a safe limit, ensuring it does not pose an inherent danger upon impact, the velocity at which the projectile is launched remains a critical factor. Specifically, the rotational speed of the firing mechanism must be capped at a predefined threshold to mitigate the risk of unintended injuries. A projectile moving at excessive speeds, even within a controlled mass range, could still cause harm in certain scenarios, especially in confined spaces or near personnel. By implementing these limitations, the system can operate within a controlled and predictable safety margin, reducing the likelihood of unforeseen hazards.

References

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[3] Zichao Shen, Jose Nunez-Yanez, and Naim Dahnoun. Advanced millimeter-wave radar system for real-time multiple-human tracking and fall detection. *Sensors*, 24(11), 2024.

[4] STMicroelectronics. *STM32H7 Series Reference Manual: Advanced Arm-Based 32-Bit MCUs*, 2024. Version 3.0.