

Project Proposal: Autonomous Ammunition Loading and Firing Robotic System

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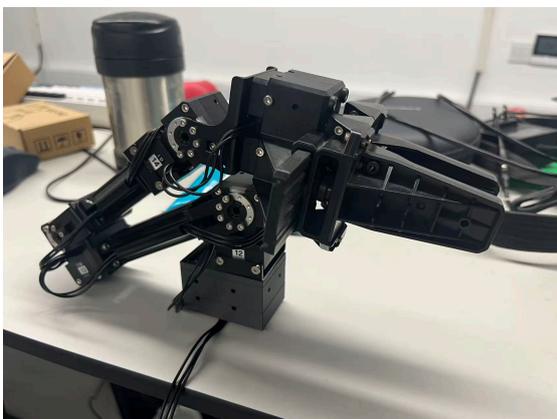
1 Introduction

1.1 Problem Statement

In competitive robotics environments such as the RoboMaster competition, the ability to rapidly and dynamically manage ammunition is a decisive tactical advantage. Current standard loading mechanisms primarily rely on predefined, hard-coded spatial coordinates. These systems are highly susceptible to mechanical jamming and operational failure when projectiles are displaced by robot movement, collisions, or unstructured staging environments. Consequently, there is a critical engineering requirement for an autonomous manipulation system capable of visually identifying, grasping, and loading unstructured ammunition into a launching mechanism in real-time, thereby eliminating the need for human intervention or perfectly aligned staging setups.

1.2 Solution Overview

Our proposed solution is an integrated, fully autonomous robotic arm and launching system. Upon receiving a user-initiated activation command, the system leverages an onboard RGB-D camera feed processed by a lightweight object detection algorithm (e.g., YOLOv5) to accurately determine the spatial coordinates of ammunition scattered within a rear staging zone [1]. An STM32-based central controller computes the necessary inverse kinematics and orchestrates the movement of a multi-axis robotic arm via a CAN bus network [2]. The arm dynamically adjusts its trajectory to retrieve the target projectile, aligns it with a custom loading port, and secures it for the firing mechanism to launch the payload.



(a) Robotic Arm for Ammunition Grasping



(b) Dart Launcher Mechanism

Figure 1: Visual Aid: Hardware components of the autonomous loading and firing system.

1.3 High-Level Requirements

To ensure competitive viability and operational stability, the system must fulfill the following quantitative requirements:

1. **Autonomous Retrieval Rate:** The perception and manipulation subsystems must successfully detect, grasp, and load a randomly placed projectile in the staging area with a success rate of $\geq 80\%$, completing each individual cycle in under 5 seconds.
2. **Launch Execution Reliability:** Once the projectile is successfully grasped and secured into the loading port, the firing mechanism must reliably activate and propel the dart in a general forward direction. The system must achieve an $\geq 80\%$ mechanical discharge success rate without stalling or jamming, independent of ballistic targeting accuracy.
3. **System Endurance:** The combined electromechanical system (including the CAN communication network and motor actuations) must operate continuously for 100 consecutive reload-and-fire cycles without critical software crashes or hardware failures.

2 Design

2.1 Block Diagram

The system architecture is partitioned into four primary modules: Perception, Control, Actuation, and Power. The Perception Module (RGB-D Camera and computation unit) outputs projectile coordinates via UART to the Control Module (STM32 Microcontroller). The Control Module processes trajectory planning and transmits high-frequency torque/position commands via a dual CAN bus to the Actuation Module (robotic arm and launcher motors). The Power Module distributes a regulated 24V DC to the motors and a stepped-down 5V DC to the logic controllers and sensors.

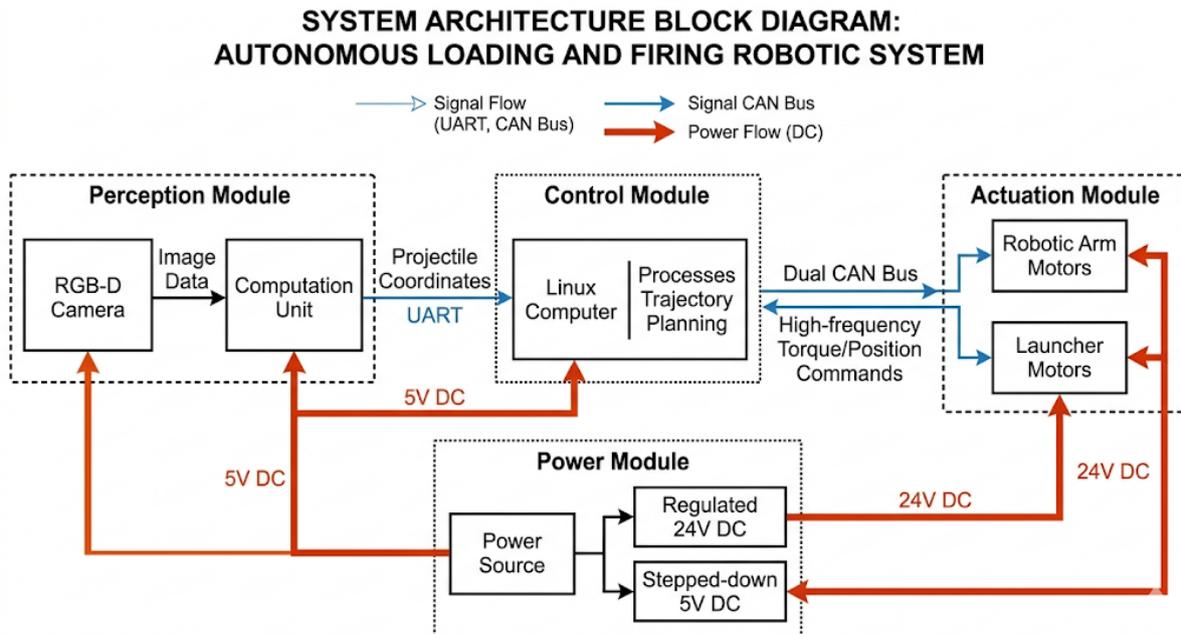


Figure 2: System Architecture Block Diagram: Visualizing the Perception, Control, Actuation, and Power subsystems and their detailed interconnections via UART, Dual CAN Bus, 24V DC, and 5V DC.

2.2 Subsystem Overview & Requirements

2.2.1 Perception Subsystem

This subsystem captures the staging area visually and runs a YOLO-based neural network to identify the bounding boxes and relative depths of the darts.

Requirements	Verification
1. The detection algorithm must identify darts within a 1.5 m unstructured staging radius under standard indoor lighting.	1. Randomly scatter 50 darts within the radius; verify that the software successfully outputs coordinates for ≥ 40 of them ($\geq 80\%$ accuracy).
2. The vision processing latency must not exceed 50 ms per frame to ensure real-time tracking.	2. Record the system timestamp before and after inference over 1000 continuous frames; verify the average $\Delta t \leq 50$ ms.

2.2.2 Control Subsystem

Acting as the logic core, this subsystem utilizes an STM32 series microcontroller to parse visual data into joint angles using inverse kinematics and manages communication protocols.

Requirements	Verification
1. The CAN bus transmission delay between the STM32 controller and motor drivers must be $\leq 10\mu s$.	1. Connect a logic analyzer to the CAN TX/RX lines and measure the time delta between sent and acknowledged packets over 100 samples.

2.2.3 Actuation and Launch Subsystem

This subsystem comprises the physical joints of the RoboMaster-inspired arm (driven by brushless DC motors like the GM6020) and the friction-wheel launching mechanism.

Requirements	Verification
1. The base yaw joint of the robotic arm must be capable of rotating 120° and settling within 1 second.	1. Send a 120° step command via the controller and utilize motor encoder feedback to plot the response, confirming settling time ≤ 1 s.

2.3 Tolerance Analysis

Since the system's primary objective prioritizes retrieval and loading reliability over ballistic targeting, a critical failure point is the positional misalignment of the robotic arm's end-effector during the grasping phase. If the gripper's center deviates from the projectile's center beyond the physical clearance margin, the arm will knock the ammunition away rather than securing it.

The maximum allowable positional error (E_{max}) at the end-effector is dictated by the gripper's maximum opening width (w_g) and the projectile's body diameter (d_p):

$$E_{max} = \frac{w_g - d_p}{2}$$

Assuming a larger dart projectile (approx. 20 cm in length) with a body diameter of $d_p = 40$ mm and a gripper maximum opening of $w_g = 100$ mm, the allowable translational error is $E_{max} = 30$ mm = 0.030 m.

The most significant contributor to this end-effector error is the angular tolerance ($\Delta\theta$) of the base yaw motor. The translational deviation (Δs) at a maximum arm extension length (L) can be approximated by the arc length:

$$\Delta s = L \cdot \Delta\theta$$

Assuming a maximum operational reach of $L = 0.5$ m, maintaining $\Delta s \leq E_{max}$ requires the angular error to be bounded by:

$$\Delta\theta \leq \frac{0.030 \text{ m}}{0.5 \text{ m}} = 0.06 \text{ rad} \approx 3.44^\circ$$

To guarantee the $\geq 80\%$ autonomous retrieval success rate specified in our High-Level Requirements, the closed-loop PID control system must utilize high-resolution encoder feedback to strictly constrain the yaw joint’s mechanical angular tolerance to a conservative $\pm 1.5^\circ$. (Note: Lowering the accuracy constraints translates to a much more feasible mechanical tolerance of $\pm 1.5^\circ$ compared to standard rigid precision systems).

3 Ethics and Safety

3.1 Ethics

As this system involves autonomous targeting and projectile launching, it is imperative to adhere to the IEEE *Ethically Aligned Design* standards [3]. We commit to prioritizing human well-being by ensuring our system is strictly constrained to educational and competitive robotics contexts. The perception algorithm will be explicitly trained to detect inanimate targets (e.g., armor plates, standardized darts) and will feature hard-coded logic to prevent the targeting or tracking of human profiles, avoiding any dual-use applications that could promote violence.

3.2 Safety

The physical safety of operators and bystanders is our primary concern. The friction-wheel launcher will be enclosed within a custom 3D-printed shroud to prevent accidental finger contact with high-speed rotating components. Furthermore, software-level safety limits will be programmed into the STM32 controller to cap the maximum RPM of the firing wheels, ensuring the kinetic energy of the launched darts remains strictly within the safe limits prescribed by RoboMaster competition regulations. An easily accessible hardware emergency stop (E-stop) button will also interrupt the 24V power line to all actuators instantly.

References

- [1] J. Qin and K. Xu, “Design and implementation of automatic assisted aiming system for robomaster ep based on yolov5,” *arXiv preprint arXiv:2312.05055*, 2023.
- [2] Z. Lin, T. Wang, Q. Gao, and Y. Liu, “Design of robot platform based on can bus,” in *2011 international conference on electrical and control engineering*. IEEE, 2011, pp. 645–648.
- [3] R. Chatila, K. Firth-Butterfield, and J. C. Havens, “Ethically aligned design: A vision for prioritizing human well-being with autonomous and intelligent systems version 2,” 2018.