INVERTIBLE CONTROL ANTWEIGHT BATTLE BOT

By

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Abstract

This report presents the design and implementation of an invertible control antweight combat robot. The system utilizes a 6-axis Inertial Measurement Unit and an ESP32 to provide drive logic that is orientation aware. Using a gyroscope and accelerometer, the robot programmatically remaps motor signals to maintain intuitive controls for the operator when the chassis is inverted. The primary weapon is a horizontal spinning bar at the front to deliver powerful blows to the opponents. The 3D printed chassis will be designed with defense in mind, with limited edges, corners, and other vulnerabilities to prevent weapons from damaging or grabbing the robot. At the center, a custom PCB will consolidate power distribution and signal routing, integrating the ESP32 with dedicated motor drivers and voltage regulation circuitry. The design meets all safety regulations and weight class constraints, providing a robust platform that optimizes the operator’s tactical efficiency in competitive environments.

Contents

1. Introduction

This project addresses the technical challenge of designing and building a high-impact antweight combat robot that maintains operational control when the platform is inverted. Beyond the immediate engineering application, this project explores the development of orientation-aware control systems to improve user safety and system reliability. This proposal outlines a dual-sided 2 lb robot that uses an IMU to drive a feedback loop to automatically remap drive logic to the controller, ensuring simple steering in any orientation. The following sections detail the battle-ready systems, including hardware and software subsystems, to construct a highly capable and powerful antweight combat robot.

1.1 Problem

In the high-stakes environment of antweight combat robotics, the margin for error is incredibly thin. All robots must weigh under 2 lb and operate in confined arenas where high-power impacts are common and often result in the robot being flipped or thrown across the enclosure. Many combat robots face a significant tactical disadvantage when inverted. These problems often include having a weapon incapable of operating when inverted, having a drive system that cannot operate inverted, or having a drive system capable of operating inverted but relying on the driver to mentally map inverted controls in real time. For these reasons, many teams choose to build robots with complicated self-righting systems or build defenses to prevent the robot from being flipped in the first place. Any delay in an operator’s reaction time or a failure in the mechanical self-righting system often leads to a knockout, as the opponent can take advantage of the moment of vulnerability.

In addition, many teams compromise the reliability of their robots by over-engineering their drive and weapon systems, leading to complications and electronic failures, particularly when under the stress of impacts. Therefore, there is a critical need for a lightweight but robust solution that simplifies the user experience. By removing the cognitive load of navigating inverted controls or commanding a complicated robot, the operator can focus their entire attention on the offensive strategy and evasive maneuvering. This ensures the robot is a constant threat within the arena and has a strong chance of winning regardless of the design of the opponent’s robots.

1.2 Solution

Our proposed solution is an invertible control ant-weight combat robot designed for maximum offensive output and intuitive operation. The physical architecture of the device will feature a low-profile, rounded chassis with a primary weapon consisting of a double-sided horizontal spinning bar capable of high-inertia attacks. To ensure the robot remains functional regardless of which side is facing up, the drive system will rely on two recessed wheels that protrude very slightly from both the top and bottom of the chassis. This will allow for a “tank-like” differential drive system. When combined with rounded edges to deflect impacts, the robot will maintain mobility and defense in any orientation without the need for any self-righting arms.

The main innovation lies in the integration of a 6-axis Inertial Measurement Unit and a custom PCB powered by an ESP32 microcontroller. The system uses the IMU’s accelerometer and gyroscope data to monitor the robot's orientation in real-time. When the sensor detects that the robot has been flipped, the controls will automatically be inverted via signals sent to the H-bridge motor drivers. The inversion of the control logic will ensure that with the press of the forward input from the laptop, the robot will always move in the direction the weapon is facing. By handling the orientation logic in software, the implementation will achieve a seamless transition that allows for continuous combat effectiveness.

1.3 Visual Aid

The visual representation shown in Figure 1 illustrates the invertible nature of the design. The arrow indicates the robot's wireless control between the ESP32 on the PCB and the operator's laptop. Also, the protrusion of the wheels on both sides allows for ground contact in both the upright and inverted state while also maintaining a very low center of gravity. It is also important to recognize that the top and bottom views are nearly identical, as the direction of rotation for the weapon is the only difference.

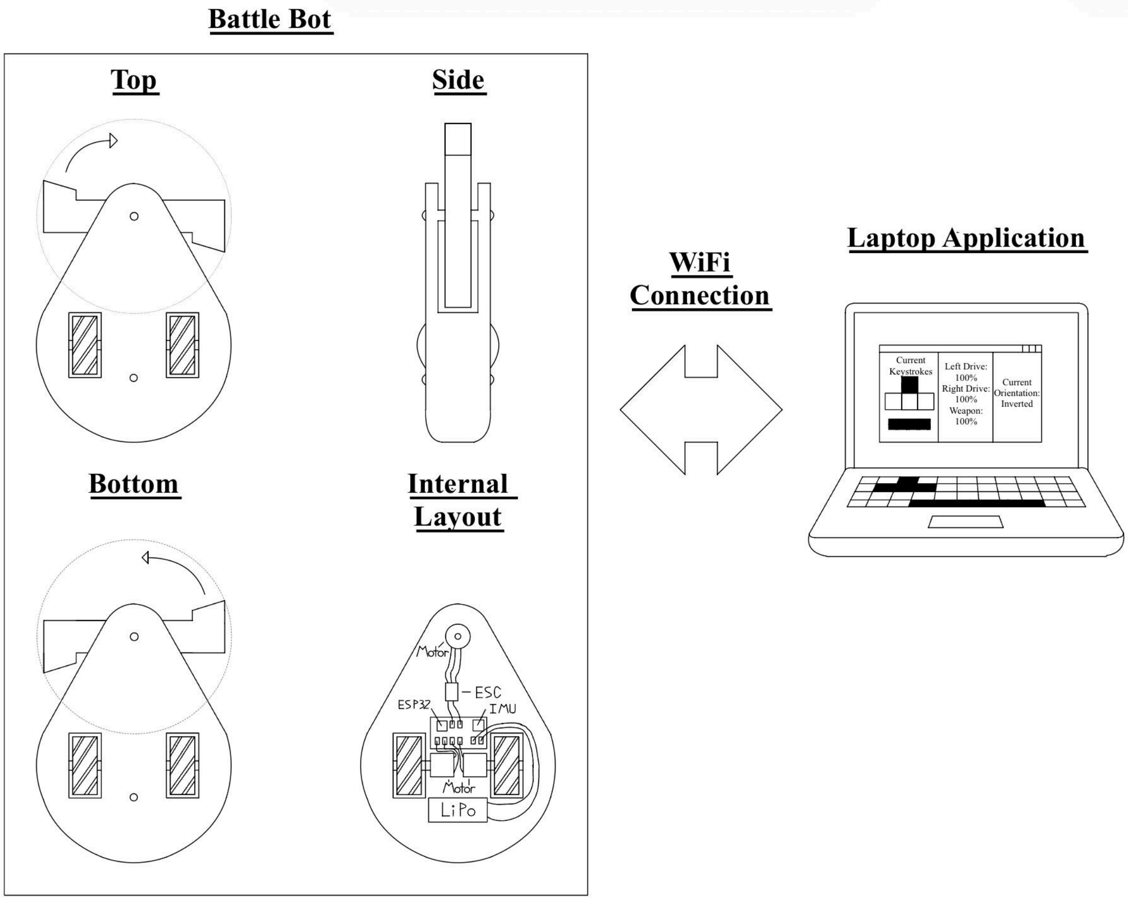

Figure 1: Visual aid of the Invertible Control Antweight Robot. This diagram illustrates the chassis geometry and the wireless connection between the ESP32 and the operator's laptop used to control the robot.

1.4 High-Level Requirements List

To consider our project successful, the antweight combat robot must fulfill the following:

1. The robot must adhere to all of the antweight class specifications, specifically maintaining a total mass less than or equal to 2 lb and ensuring that the kinetic weapon system can be deactivated and brought to a complete rotational stop within 60 seconds of a command or failsafe trigger.

2. The onboard IMU and ESP32 control logic must detect a change in vertical orientation and invert the differential drive motor commands within 300 ms, ensuring that the operator perceives no lag in directional control relative to the new orientation.
3. The horizontal spinning bar must reach a combat-effective rotational velocity within 3 seconds of activation and demonstrate structural integrity to resume full speed rotation following a high-energy impact with an opponent or arena obstacle.

2 Design

2.1 Block Diagram

The system architecture of the combat robot is separated into six unique subsystems, as listed in Figure 2. This diagram serves as the structural map for power distribution and signal routing described in the following sections.

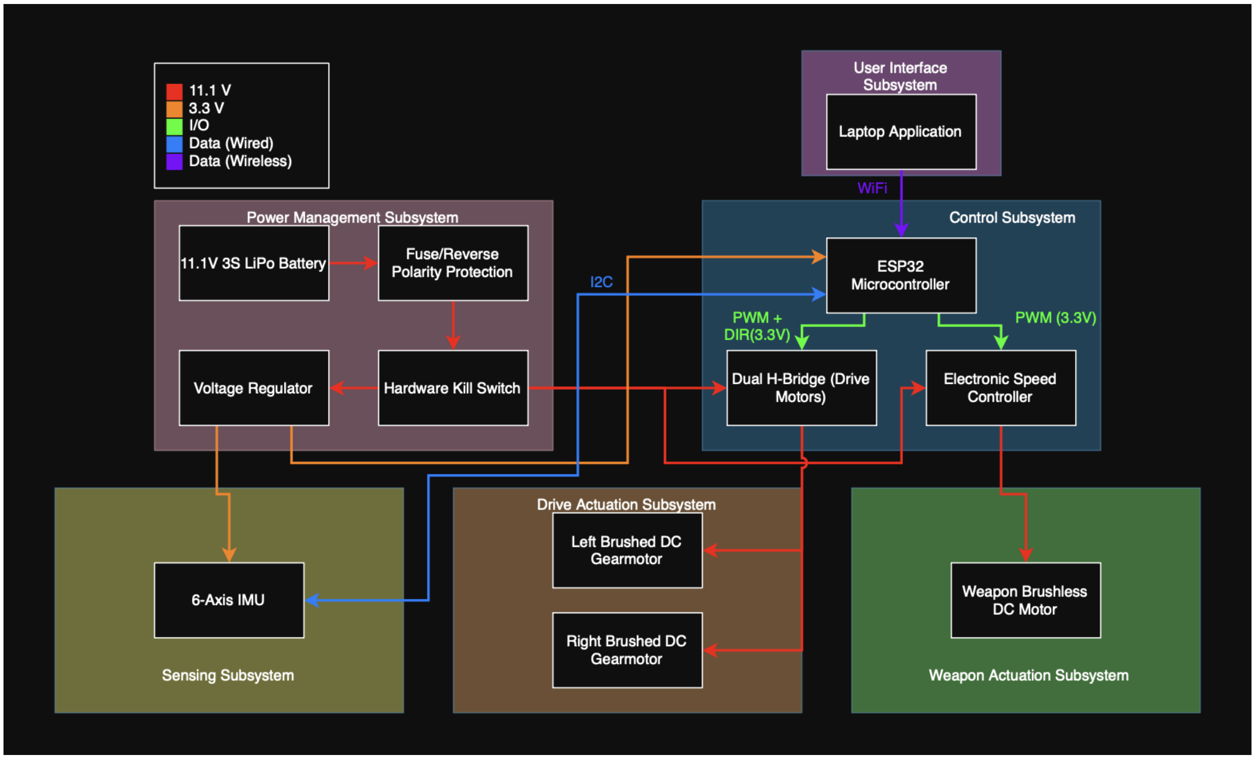

Figure 2 Block Diagram of the Invertible Control Antweight Robot. This diagram ilustrates separation of the robot into six primary subsystems, including the power management, control, sensing, drive actuation, weapon actuation, and user interface subsystems.

2.2 Subsystem Overview

2.2.1 Power Management Subsystem

The Power Management subsystem provides electrical power to all components of the robot. An 11.1V 3S LiPo battery supplies the high-current loads to the drive motors and the weapon motor, while the voltage regulator decreases the voltage down to 3.3V for the ESP32 and IMU. The subsystem includes a reverse polarity protector and a hardware kill switch to immediately disable all motor outputs. This subsystem interfaces directly with the Control Subsystem, Drive Actuation Subsystem, and Weapon Actuation Subsystem by applying the necessary power to all components.

2.2.2 Control Subsystem

The Control Subsystem is centered around the ESP32 microcontroller and is responsible for processing the user inputs and sensor data to generate the motor control signals. It gets wireless commands from a laptop and orientation data from the IMU via WiFi and I2C, respectively. It then generates PWM and directional signals for the dual H-bridge and a PWM signal for the electronic speed controller. This subsystem forms the core logic of the robot and coordinates all of the sensing and communication functions.

2.2.3 Sensing Subsystem

The Sensing Subsystem consists of a 6-axis IMU that provides accelerometer and gyroscope data to determine the orientation of the robot. The IMU communicates with the ESP32 over an I2C interface. This subsystem enables the robot's orientation-aware control logic. It detects when the chassis has been inverted and communicates that information to invert the controls properly. The Sensing Subsystem directly supports the Control Subsystem by supplying the real-time motion and orientation data required for remapping the drive signals on the spot.

2.2.4 Drive Actuation Subsystem

The Drive Actuation Subsystem consists of two brushed DC gearmotors in a tank-style arrangement. These motors are controlled by the dual H-bridge driver that receives its PWM and direction signals from the ESP32. Interfacing with the Power Management Subsystem and Control Subsystem, this subsystem converts electrical control signals to mechanical motion.

2.2.5 Weapon Actuation Subsystem

The Weapon Actuation Subsystem consists of a brushless DC motor driving the spinning bar. The motor is controlled through the electronic speed controller that receives a PWM control signal from the ESP32. Interfacing with the Control Subsystem, this subsystem draws high current from the battery and is activated or disabled based on commands from the Control Subsystem.

2.2.6 User Interface Subsystem

The User Interface Subsystem consists of a laptop application that communicates via WiFi with the ESP32. It allows the operator to send drive and weapon commands to the robot during combat. The laptop will utilize its keyboard as input to control the robot during battle in order to move forward, backward, turn, and spin up the primary weapon. This subsystem is the human-machine interface and is directly connected to the Control Subsystem.

2.3 Subsystem Requirements

2.3.1 Power Management Subsystem

The Power Management Subsystem must provide stable and protected power distribution to all electrical components while complying with ant-weight safety regulations. Failure to maintain voltage regulation or protection would cause microcontroller resets, communication loss, or even motor driver failure.

Functional Requirements:

1. The subsystem must operate from an 11.1V 3S LiPo battery with a full-charge Voltage of 12.6V and a minimum safe discharge voltage of 9.0V.
2. The subsystem must supply unregulated battery voltage in the range 9.0-12.6V to:

    a. Dual H-bridge motor driver
    b. Electronic Speed Controller

3. The subsystem must provide a regulated 3.3V ± 0.1V rail for:
    a. ESP32 Microcontroller
    b. 6-axis IMU
4. The regulator must supply at least 600mA of current at 3.3V.
5. The subsystem must include reverse polarity protection capable of preventing damage if battery terminals are reversed.
6. The subsystem must include an appropriate fuse to interrupt fault currents exceeding safe operating limits
7. The hardware kill switch must physically disconnect battery power to all motor drivers and the Electronic Speed Controller when activated.

Interface Requirements:

1. Battery input: 9.0-12.6 V, DC
2. Logic output rail: 3.3 ± 0.1 V
3. High-current rail: Direct battery voltage
4. The kill switch must interrupt the motor supply path, not just the logic power

2.3.2 Control Subsystem

The Control Subsystem must implement orientation-aware control logic and coordinate all actuation and communication. If orientation detection or PWM signal generation fails, the robot cannot maintain intuitive control when inverted. This goes against the dynamic remapping and combat effectiveness.

Functional Requirements:

1. The ESP32 microcontroller must operate at 3.3V logic levels.
2. The subsystem must receive wireless commands via WiFi from the laptop application with a latency no higher than 100ms under normal conditions.
3. The ESP32 must read the IMU data via I2C at a minimum sampling rate of 100Hz.
4. The subsystem must detect inversion of the robot and remap the drive motor commands within 300ms of orientation change.
5. The subsystem must output:
    a. Two PWM signals of 3.3V for left and right drive motors
    b. Two digital direction signals of 3.3V for the H-bridge
    c. One PWM signal of 3.3V and ESC compatible frequency for the weapon ESC
6. PWM frequency for drive motors must be between 5kHz and 20kHz to ensure smooth motor operation

Interface Requirements:

1. IMU communication: I2C at 3.3V logic
2. H-bridge inputs: 3.3V logic-level PWM and DIR signals

3. ESC input: Standard PWM (2ms pulse width and 50Hz)
4. Wireless communication: WiFi protocol supported by the ESP32

2.3.3 Sensing Subsystem

The Sensing Subsystem must provide reliable orientation detection to enable the control remapping. Incorrect orientation detection would result in wrong control remapping and cause reversed controls.

Functional Requirements:

1. The IMU must operate at a 3.3V supply voltage.
2. The IMU must provide 3-axis accelerometer and 3-axis gyroscope data.
3. Orientation classification must be determined using the acceleration vector direction relative to gravity.
4. The subsystem must provide orientation data to the ESP32 at a frequency of 100Hz or greater.
5. The IMU must maintain functional accuracy of accelerations up to ± 12g.

Interface Requirements:

1. IMU communication: I2C at 3.3V logic
2. H-bridge inputs: 3.3 V logic-level PWM and DIR signals
3. ESC input: Standard PWM (2ms pulse width and 50Hz)

2.3.4 Drive Actuation Subsystem

The Drive Actuation Subsystem must convert control signals into motion while maintaining bidirectional control in both orientations. If bidirectional motor control fails, the robot cannot maneuver or compensate for inversion.

Functional Requirements:

1. The subsystem must consist of two brushed DC gearmotors capable of differential drive.
2. Each motor must support bidirectional operation via the H-bridge driver.
3. The motors must provide sufficient torque to move 2lbs on a flat surface.
4. The subsystem must operate from the 9.0-12.6V battery rail.
5. The subsystem must tolerate stall currents without permanent damage.

Interface Requirements:

1. Control inputs: 3.3V PWM + DIR
2. Power input: 9.0-12.6V battery

2.3.5 Weapon Actuation Subsystem

The Weapon Actuation Subsystem must provide the primary offensive capability. Failure of the subsystem eliminates the robot's primary objective and offensive mechanism.

Functional Requirements:

1. The subsystem must consist of a brushless DC motor controlled by the ESC.
2. The weapon motor must reach operational rotational velocity within 3 seconds of activation.
3. The system must allow a complete shutdown within 60 seconds of a kill command.
4. The ESC and motor must operate from the 9.0-12.6V battery rail.
5. The subsystem must withstand transient current spikes during rapid acceleration and impact.

Interface Requirements:

1. Control input: 3.3V PWM
2. Power input: Direct battery voltage

2.3.6 User Interface Subsystem

The user Interface Subsystem must provide reliable remote operation of drive and weapon systems. Without wireless control and failsafe behavior, the robot cannot be safely or effectively operated.

Functional Requirements:

1. The laptop application must transmit forward, backward, left, right, and weapon activation commands.
2. Wireless communication must operate over WiFi with stable connectivity over 10 meters or less.
3. Loss of communication must trigger a failsafe that disables motor outputs within 1 second.

Interface Requirements:

1. Communication protocol: WiFi
2. Command latency: 100ms or less under normal operation

2.4 Tolerance Analysis

A primary risk in this design is voltage instability on the 3.3V logic rail. When the weapon motor accelerates, stalls briefly on impact, or when the drive motors change direction quickly, large current spikes can cause a temporary voltage sag. If the regulated 3.3V supply drops excessively, the ESP32 may reset. This could cause a temporary loss of communication and orientation-aware control. Consequently, this would compromise the control remapping needed. We can approximate the drop during a transient using the peak current and load impedance.

$$\Delta V \approx \Delta I \cdot \Delta t \ / \ C \ + \ \Delta I \cdot ESR$$

Using the equation derived from Ohm's law as shown above and the fundamental capacitance equation, we can see on the right side of the equation and the left side of the plus sign, if the capacitance drops too low, we could see a huge voltage sag. And all the way to the right, if the ESR (Equivalent Series Resistance) is too high, we would also receive a voltage sag. To tolerate this, the design will incorporate a low impedance under the bulk capacitance on the 3.3V rail. By additionally making sure that the PCB layout is carefully designed to minimize the shared impedance between the motor current paths, we can ensure that transient current demands do not disrupt the stability of control during combat conditions.

5. Ethics, Safety, and Societal Impact

This project has been designed with careful consideration of societal impact, ethical responsibility, and safety, in accordance with ECE 445 course guidelines and the IEEE Code of Ethics [1]. The antweight combat robot addresses an educational and recreational engineering challenge rather than a public-facing issue. As such, its societal impact is primarily educational in nature. It provides hands-on experience in embedded systems, control logic, power electronics, and mechanical design. The project promotes engineering best practices related to system reliability, safety-conscious design, and responsible use of hazardous pieces within a controlled environment. In accordance with IEEE Code Section 1, Rule 1, we hold paramount the safety of the public by ensuring that all high-energy testing will occur within a containment arena [1].

From a public safety perspective, the robot is intended exclusively for use in supervised lab settings and ant-weight combat competitions. The design complies with established ant-weight competition rules [2], which are specifically structured to mitigate risks associated with high-speed kinetic weapons and high-current electrical systems. Environmental and global impacts are addressed through the responsible procurement of components and commitment to recycling LiPo batteries and electronic waste through campus-approved hazardous material programs. No environmental, economic, or global harm is anticipated, as the project does not involve large-scale autonomous control or production.

Relevant engineering standards and guidelines have been incorporated into the design process. Electrical systems adhere to standard low-voltage design practices, including proper current limiting, voltage regulation, and protection against reverse polarity and short circuits [3]. Wireless communication and embedded control logic follow IEEE 802.11 standards to ensure signal integrity and minimize interference with other devices [4]. The project aligns with IEEE engineering standards and ethical guidelines by prioritizing safety, transparency in design decisions, and accountability for system behavior [1].

Ethically, the project raises no concerns related to data privacy, surveillance, or misuse, as it does not collect, store, or transmit personal or sensitive information. There is no human or animal testing involved. All design decisions are made with the intent to minimize risk to operators and spectators [5]. This is to keep it consistent with professional engineering responsibility.

Safety considerations are central to the project design. Electrical safety is addressed through the use of proper battery handling procedures [3] and an accessible hardware kill switch to immediately disable all motor outputs. This design choice prioritizes the safety of the operator and spectators in the event of a control malfunction [1]. Mechanical safety is ensured by enclosing the weapon system within the robot's chassis envelope when inactive and by following competition-mandated weapon spin-down requirements [2]. During development and testing, all laboratory safety protocols will be followed, including the use of protective equipment and controlled testing environments consistent with OSHA safety standards. Collectively, these measures ensure that the project meets the ethical, safety, and professional standards expected of an ECE 445 senior design project.

References

[1] IEEE, *IEEE Code of Ethics*, Institute of Electrical and Electronics Engineers, 2020. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html

[2] Robot Combat Events (RCE), *Antweight Combat Robot Safety and Weapon Regulations*, 2025. [Online]. Available: https://www.robotcombatevents.com

[3] Texas Instruments, *Designing Motor Driver Power Systems for High Transient Loads*, Application Report SLVA959, 2021.

[4] Espressif Systems, *ESP32-WROOM-32 Technical Reference Manual*, Espressif Systems, Shanghai, China, 2023.

[5] D. Jones and M. Ladd, *Introduction to Combat Robotics*, McGraw-Hill, New York, NY, 2015.