ECE 445- Fall 2025

Senior Design Project Document

Antweight Battlebot

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1.Introduction

1.1 Problem

The Project is an Ant-weight, 3D-printed BattleBot for BattleBot Competition, where each team aims to design a robot capable of outperforming the others. The BattleBot must meet specific constraints to be eligible, including a weight limit of under 2 lbs and the use of approved materials such as PET, PETG, ABS, or PLA/PLA+. The robot must be controllable via PC through Bluetooth or Wi-Fi, feature a fighting tool powered by a motor, and allow for an easy manual shutdown for safety. To win the competition, a BattleBot must be designed to either outlast or disable the opponent’s robot, taking into account factors such as durability, maneuverability, and offensive capability to maximize its chances of success.

1.2 Solution

We will build a 2-lb, 3-D printed BattleBot with a front-hinged lifting wedge (shovel) as the weapon to flip and destabilize other robots. The main structure will be ABS for toughness, PLA for non-critical connectors, and PETG around the power system and microcontroller for heat resistance. Control is via PC over Bluetooth using an ESP32-S3-WROOM-1-N16 microcontroller. The bot will have at least three motors: Two DC-powered motors to control the robot's wheels for mobility. One geared lifter motor for the shovel, controlled through H-bridge drivers.

1.3Visual aid

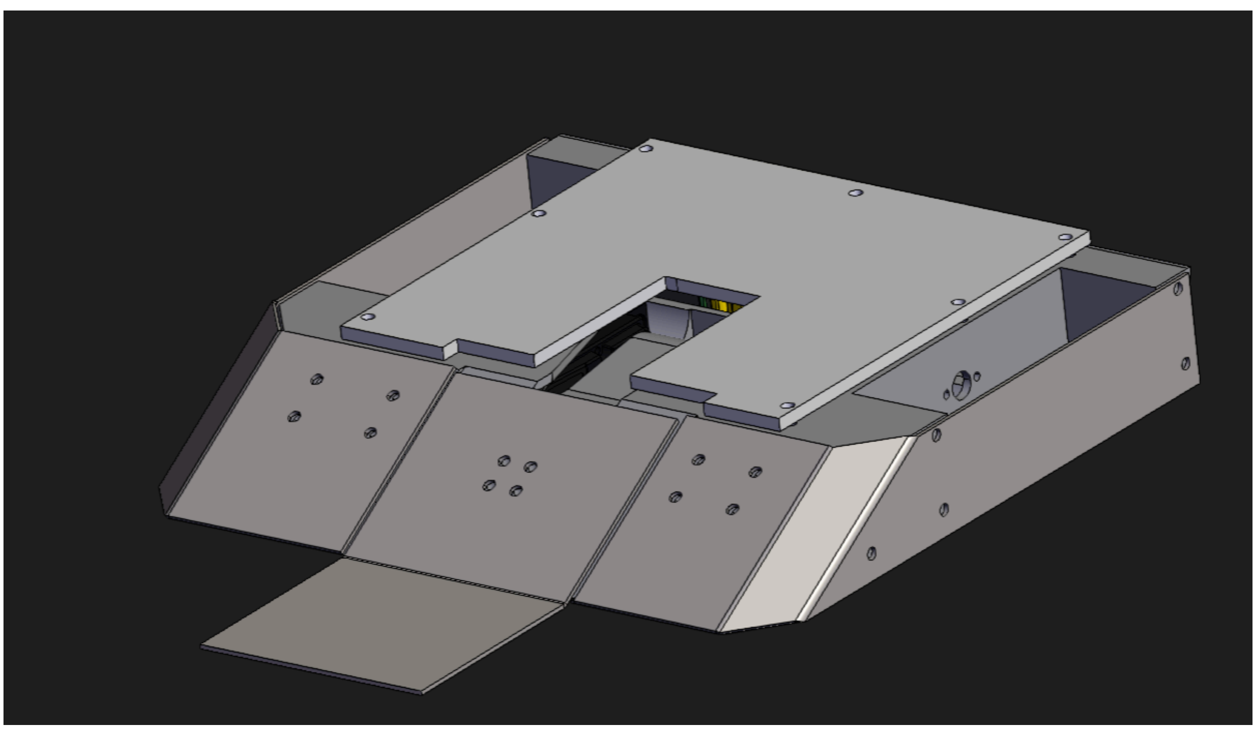

Figure 1:Sample of how the battlebot would look like with 4 wheels and main structure made of ABS

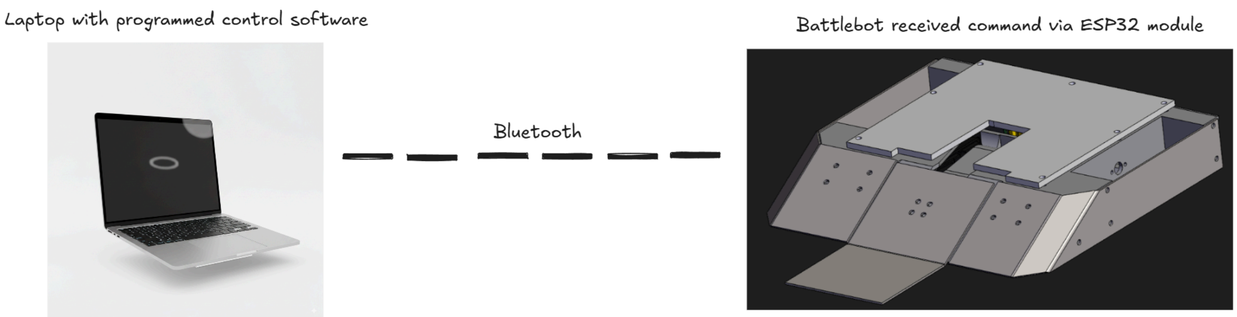

Figure 2:Bluetooth communication

1.4 High-level requirements

- **1. Performance requirement:** The lifting wedge must generate at least 1.8 Nm of torque and be able to lift a 2 lbs load to 30° within 0.5 seconds and return to the starting position within seconds.
- **2. Control requirement:** The control system must process commands and actuate movement/weapon within 300 ms of a PC command and maintain stable wireless communication over at least 10 meters without signal loss.
- **3. Mobility requirement:** The drivetrain must move the bot at a minimum forward speed of 1 m/s on a flat surface and produce at least 0.5 Nm torque per wheel, enough to push against an opposing 2 lbs bot without stalling.

2. Design

2.1 Physical Design

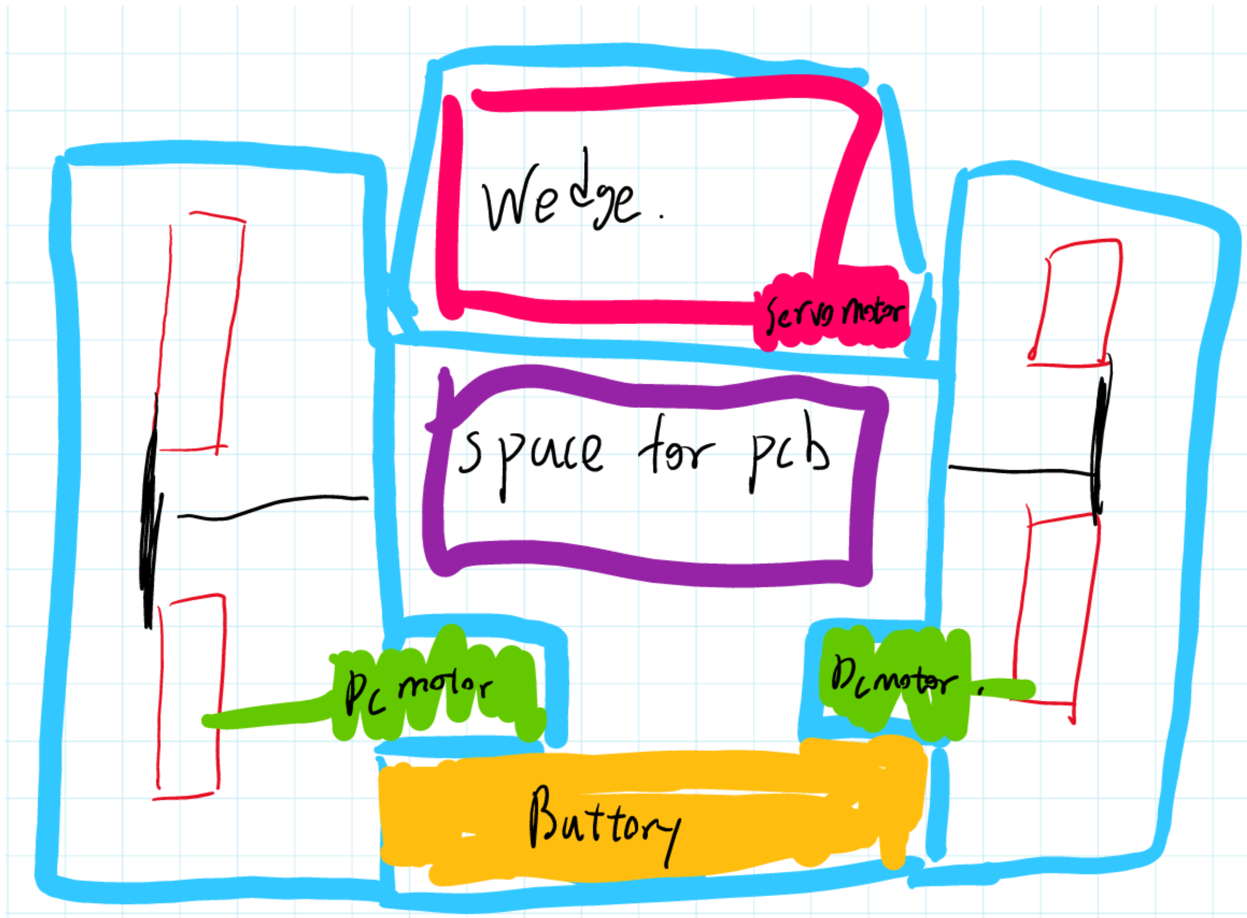

Figure 3: physical design

2.2 Block diagram

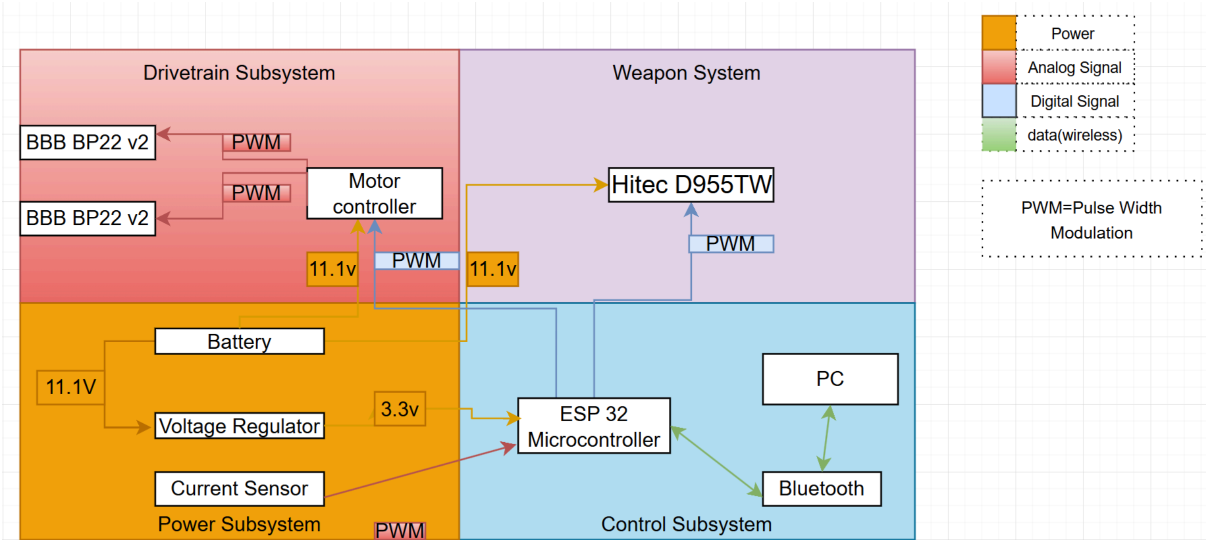

Figure 4: Block Diagram

2.3 Subsystem Overview

2.3.1Power subsystem

The Power subsystem is responsible for supplying the necessary voltage for the other subsystems. We plan on using Lithium-Polymer (LiPo) batteries: 3S, 11.1 V, 450 mAh with a continuous discharge rate of 70C(Turnigy Nano-Tech Plus). This amount of capacity will ensure that the battlebot can last for 2 minutes in the competition. We have three converters for them, One LM2596S-3.3 chip converts 11.1 V to 3.3 V for ESP32 power input, another two LM25965-ADJ chips converts 11.1 V to 6V and 10.8 V respectively for power input into servo motor and drivetrain subsystem with an H bridge chip DRV8833TRY that can take the maximum of 10.8V.

The buck converters chosen are all LM2596 as it is specified to allow for an input up to 40 V and provide up to 3A. Since our battery is 11.1V , it is within the allowed range and 3A current limit is suitable. It also has adjustable versions so we can convert not only into standard 3.3V, but also 6V for servomotor and 10.8V for H bridge drivetrain. The schematic is shown in figure 5.

Undervoltage Lockout (UVLO) in Figure 6 is a critical protective feature in buck converter designs that prevents operation when the input voltage drops below a safe operational threshold, ensuring reliable and predictable system behavior.

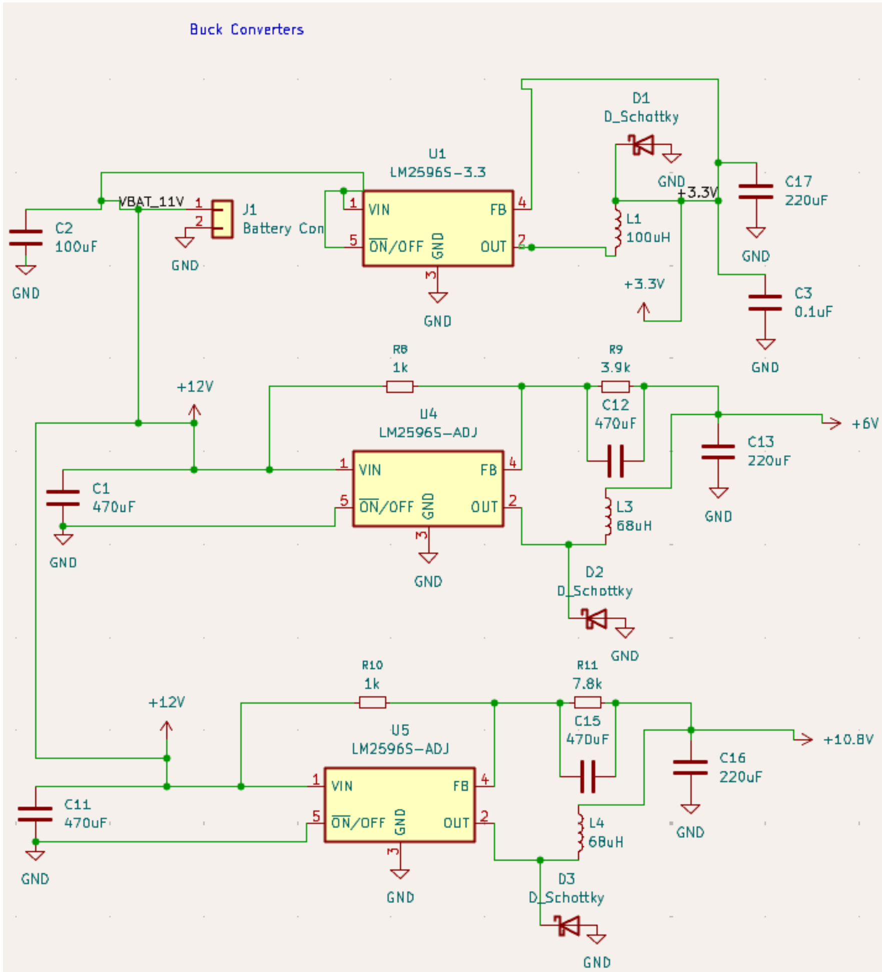

Figure 5: Buck Converters

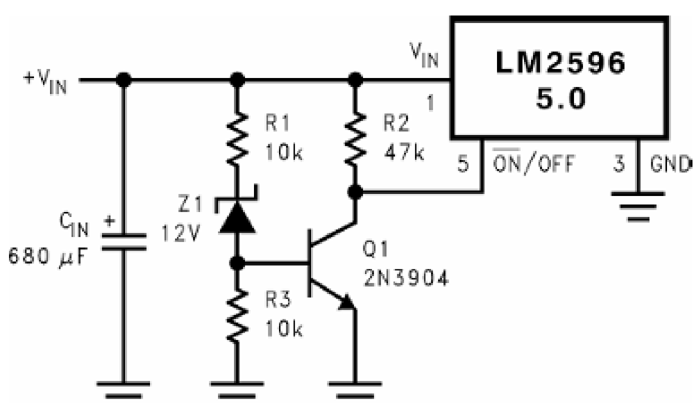

Figure 6: Undervoltage Lockout for Buck Regulator

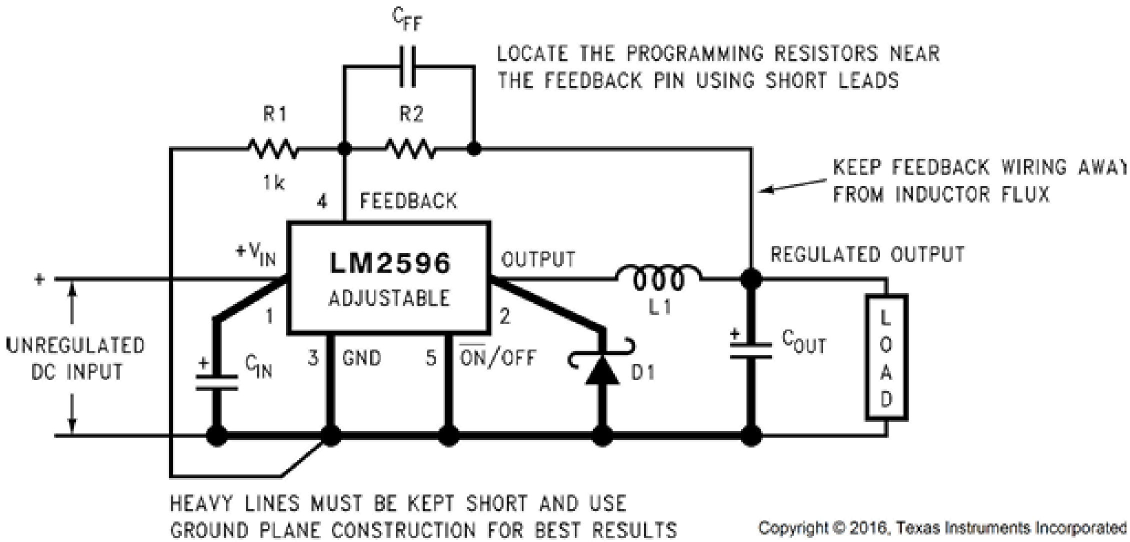

Figure 7: LM2596 Adjustable Output Voltage Version

For the adjustable version in figure 7, the final output voltage depends on the R1 and R2: Vout = Vref(1+R2/R1), Vref = 1.23V. For our own design in figure 5, we take R1 to be a standard 1K, and following the equation, we choose R2 to be 3.9K for 6V output and 7.8k for 10.8V output.

Requirements	Verification
11.1V 3S battery must provide a stable ● 3.3 V ± 0.3V to the ESP32 ● 6.0 V ± 0.3V to the servo motor ● 10.8V± 0.3V to the H-bridge through the buck converters	The buck converter output voltage can be confirmed and validated through oscilloscope measurements.
It must be able to supply power to finish 2 2-minute battlebot competition	To verify the battlebot meets the 2-minute match duration requirement, the continuous operation test will operate the drivetrain and weapon motor at combat-like duty cycles for the full match duration.

2.3.2Drivetrain subsystem

We will use four small wheels (2.25″), with the two rear wheels driven by high-torque 508 RPM, 12 V DC motors. The small wheels lower the bot’s ride height, reducing the center of gravity to improve stability and decrease the chance of being flipped, while still providing good traction. The selected motors strike a good balance between speed and torque, offering sufficient pushing power to maneuver our heavily armored bot effectively.

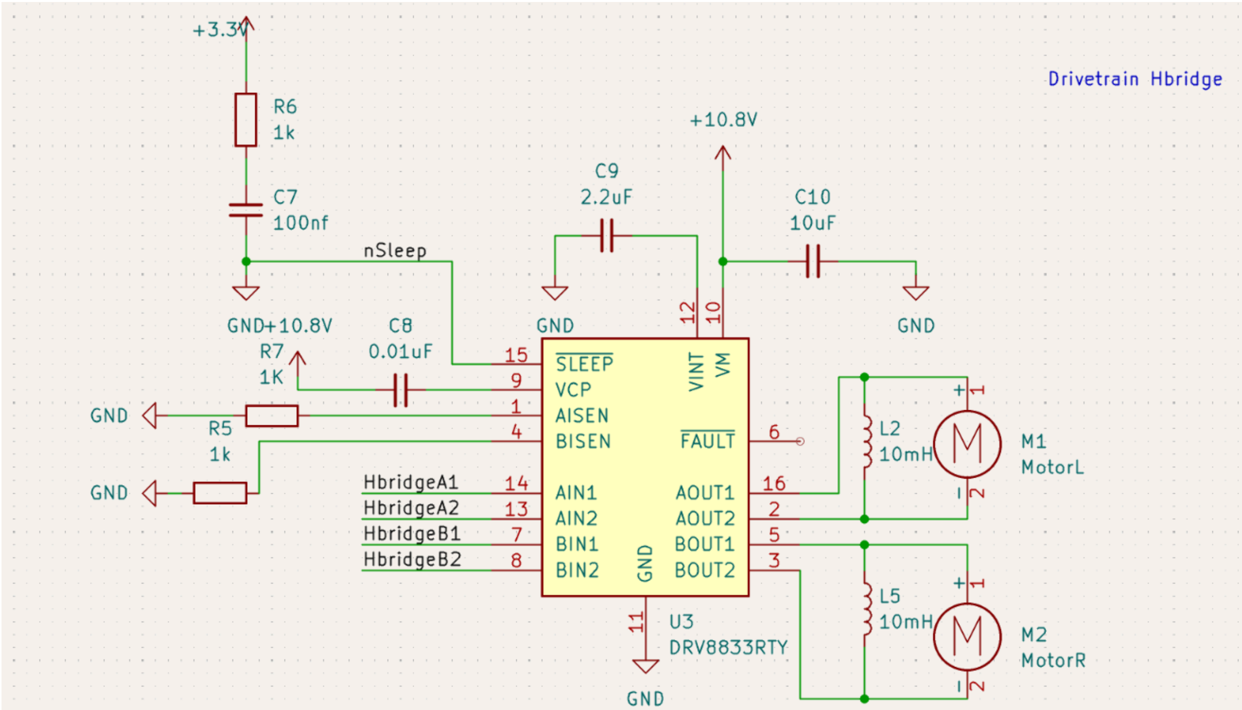

Figure 8: Drivetrain system

The drivetrain subsystem is responsible for all propulsion and maneuvering of the antweight BattleBot. It converts electrical energy from the 3-cell 10.8 V lithium-polymer battery into mechanical motion at the wheels, enabling the robot to accelerate, steer, and reverse during combat. Our drivetrain utilizes two 508 RPM Mini Econ Gear Motors (ServoCity), each driving one wheel through a differential control configuration. These 12V brushed DC motors provide enough stall torque and stall current to move the 2 lb robot quickly while still remaining efficient and lightweight. Operating them from a 10.8 V supply corresponds to an approximate wheel speed of 450 RPM and a top linear velocity of around 0.5 m/s for 2.25'' wheels. This speed range is ideal for antweight combat robots, providing quick directional changes without sacrificing traction or control.

Motor control is handled by the DRV8833RTY dual H-bridge driver. This chip is an efficient solution for controlling two DC motors independently. It supports up to 10.8 V motor supply voltage, 1.5 A continuous current, which aligns well with the current draw of the 508 RPM gearmotors, even during stall conditions. The DRV8833 is controlled by an ESP32 microcontroller, which supplies four PWM and logic signals, AIN1, AIN2, BIN1, and BIN2, to adjust the direction and speed of each motor. This design allows smooth steering adjustments through differential speed modulation. In addition, decoupling capacitors are placed across the supply lines (2.2 μF and 10 μF) to reduce voltage transients during direction changes, ensuring reliable operation under varying loads.

Overall, the combination of the 508 RPM Mini Econ Gear Motors and the DRV8833 H-bridge driver forms an efficient, lightweight, and robust drivetrain solution. The motor's torque-to-weight ratio is well-suited for a 2 lb robot.

Requirements	Verification
The BattleBot must be controllable both forward and backward.	Send directional control signals from the ESP32 through Bluetooth; verify forward and reverse motion by observing wheel rotation and robot displacement.
The drivetrain must achieve a torque of at least 0.63 N·m and handle short-term stall current.	Measure current draw during startup and turning; ensure the driver does not exceed 1.5 A continuous current and that the torque output meets the calculated requirements.
The drivetrain must provide at least 1.4 m/s design linear speed.	Measure wheel RPM at maximum PWM using a tachometer; verify that calculated linear velocity meets ≥ 1.4 m/s.
The drivetrain must have a command latency of less than 300 ms from PC input.	Use an oscilloscope to measure the delay between control signal transmission and motor response.

2.3.3Control subsystem

The control subsystem serves as the central intelligence of the battlebot. It generates PWM signals for motor control (High-Level Requirement 3: Mobility), commands the weapon servo for lifting opponents (High-Level Requirement 1: Performance), and processes wireless commands with low latency (High-Level Requirement 2: Control). The ESP32-S3's dual-core architecture dedicates one core to real-time motor control and another to Bluetooth communication, ensuring responsive operation. Specific performance targets are defined in the Requirements and Verification table.

The ESP32-S3-WROOM-1-N16 integrates Bluetooth, eliminating external modules and saving 15-20g versus Arduino solutions. The 240 MHz dual-core processor with 512 KB RAM handles simultaneous motor control, sensor processing, and communication. Sixteen hardware PWM channels support four motor signals plus servo control. At 6.5g weight, the ESP32 provides better integration than Arduino (lacks wireless), lighter weight than Raspberry Pi Zero (9g), and lower cost than STM32 while meeting all requirements. The LM2596S-3.3 buck converter provides 73% efficiency versus 30% for linear regulators. External components include C1 (100μF input filtering), C2/C3 (220μF/0.1μF output filtering), L1 (100μH energy storage), and D1 (1N5819 Schottky).

Bluetooth 5.0 LE provides wireless control with 122ms total latency: 5ms PC input, 7-15ms transmission, 1ms processing, and 50-100ms motor response. This gives 59% margin below the 300ms requirement.

Four GPIO pins (IO4-IO7) generate 20 kHz PWM signals for differential motor control through the H-bridge. The ServoCity 508 RPM motors operate at 12V with 1.4A stall current and 2.4 kg·cm stall torque per motor. Pin IO15 generates 50 Hz servo PWM with 500-2500μs pulse width for 180° control. The DFRobot SER0063 servo provides 2.0 Nm stall torque at 7.4V, meeting the 1.87 Nm requirement. The servo operates at 0.151s/60° speed, enabling rapid weapon actuation.

The INA226 connects via I2C on IO8/IO9 with 2.2kΩ pull-ups, monitoring system current through a 0.01Ω shunt resistor. Software polls the sensor at 100 Hz to detect abnormal current conditions and trigger protective shutdowns when necessary. Six connectors provide external interfaces: J1 (battery input), J2 (motor control signals), J3 (servo PWM and power), J4 (I2C sensor), J5 (UART programming), and J6 (motor power passthrough).

Supporting components include decoupling capacitors C4/C5 (22μF/0.1μF) placed within 5mm of the ESP32, EN circuit with R1/SW1/C6 for manual reset, and boot circuit with R2/SW2 for programming mode. The control subsystem draws approximately 800mA peak for control electronics. All requirements are verified per the R&V table procedures.

The DF15RSMG servo requires 4.8-6V operation, so it connects directly to the battery voltage (nominal 11.1V, which exceeds spec) or to a separate 5V/6V regulated supply. The control signal from IO15 remains at 3.3V logic level. Similarly, the 508 RPM motors operate at 6V nominal, requiring consideration of the higher battery voltage or a voltage regulator for the motor H-bridge supply. Current monitoring helps prevent damage during voltage mismatches or stalls.

Requirement	Verification
Voltage regulator provides 3.3V ± 0.15V for input 10-13V and load 100-800mA.	Apply variable input voltage and load. Measure output with DMM. Verify voltage within 3.15-3.45V across operating range.
System processes commands within 300ms from PC input to motor response.	Send command while triggering oscilloscope on motor output. Measure delay from command timestamp to signal change. Average 10 trials, verify <300ms.
Bluetooth maintains <5% packet loss at 10m distance.	Transmit continuous packets at 50Hz while increasing distance from 1m to 12m. Log packet loss over 30s intervals. Verify <5% loss at 10m.
Four GPIO pins output 20kHz ± 5kHz PWM	Program 50% duty cycle. Measure frequency,

with 0-100% duty cycle and 3.3V ± 0.3V logic high.	duty cycle, and voltage on oscilloscope. Verify specifications met on all four outputs.
GPIO generates 50Hz ± 2Hz PWM with 500-2500μs pulse width for positioning control.	Output 500μs, 1500μs, and 2500μs pulses. Measure frequency and pulse widths on oscilloscope. Verify servo positions at 0°, 90°, and 180°.
Subsystem operates ≥2 minutes on battery without failure.	Run typical operation scenario with fully charged battery. Monitor voltage and communication. Verify ≥2 minute runtime before shutdown.

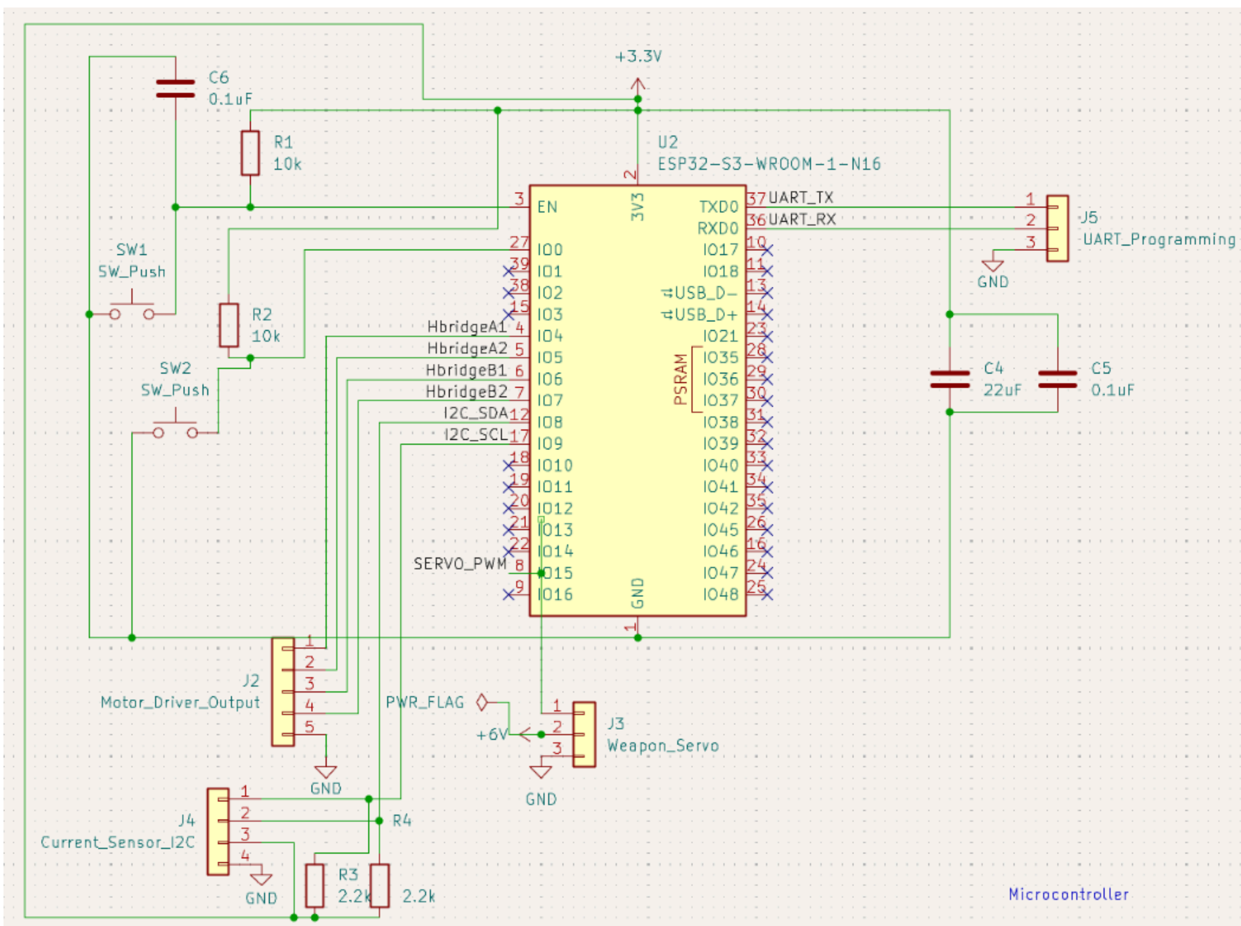

Figure9: Micro-controller system

2.3.4Weapon subsystem

To attack, destabilize, and flip opponent bots, we will use a front-hinged lifting wedge ("shovel") as our primary weapon. The wedge will be 3D-printed in PETG for impact resistance and will be reinforced at hinge and linkage points to withstand stress. It will span approximately 50–70% of the bot's width and feature a low, angled tip to slide effectively under opponents.

For the weapon's actuation, we will use a High Torque Waterproof Metal Gear Digital Servo (20KG, 180°, IP54) operating at 6V with a shovel arm length of around 70 mm. This servo provides robust torque output of approximately 20 kg·cm (1.96 N·m) at the specified voltage, t. The metal gear construction ensures durability under combat conditions, while the IP54 waterproofing rating protects against dust and moisture. The servo's 180° range of motion allows for a full lifting and flipping action.

At 6V operation, the servo delivers sufficient torque to lift the opponent battlebot through the critical 75-degree tipping point, after which gravity assists in completing the flip. The lever linkage amplifies the servo's torque through mechanical advantage, enabling the wedge to effectively destabilize and flip the 2-lb target. The digital control interface provides precise position control and rapid response to input commands, ensuring reliable weapon deployment during combat.

Requirements	Verification
The weapon must be able to lift 2lb of weight at least 10 mm from flat ground when the opponent is standing still.	Placing a 2-lb test weight on flat ground and measuring with a ruler to confirm the weapon lifts it to a minimum height of 10 mm.
The weapon must be able to return to its default position within 3 seconds after activation.	Timing the weapon's full cycle from maximum lift position back to its default resting position using a stopwatch to ensure the return time does not exceed 3 seconds.
The weapon motor must provide at least 1.869 Nm torque.	Measuring the lifting force at the weapon arm using a force gauge and calculating the torque by multiplying the measured force by the arm length to confirm it meets or exceeds 1.869 Nm.

2.5Tolerance analysis

We flagged energy consumption as a potential problem because of how the design stacks high-power elements onto a very small energy source. Our weapon strategy needs large, short bursts of torque, while the drivetrain must also deliver high currents for pushing and maneuvering, and both are serviced by a single 3S, 450 mAh LiPo battery. High-power bursts from the weapon and high-current drive pushes could stress the battery if it cannot supply enough current. Besides, we also need to calculate if the battery could last for a two-minute game.

Computation:

Inputs:

ESP32 peak current : 0.8 A
Rear drive motors: 2 × 4.3 A = 8.6 A
Weapon motor peak: 5.2 A
Battery: Turnigy Nano-Tech Plus 450 mAh 3S 70C (450 mAh, 11.1 V, 70C continuous, 150C burst)

Total peak current (sum):

$$I_{total}=0.8+8.6+5.2=14.6\ A$$

Battery continuous current capability:

$$I_{cont}=0.45\ Ah\times 70\ C=31.5\ A$$

Safety margin:

$$Margin=I_{cont}/I_{total}=31.5/14.6=2.16$$

Burst capability:

I burst = 0.45Ah * 150C = 67.5A(1-3s)

Theoretical runtime at continuous 14.6 A:

$$t=0.45\ Ah\times 3600\ s/h14.6\ A$$
1620/14.6 = 110.959s

The Turnigy Nano-Tech Plus 450 mAh 3S 70C battery is well-suited for our BattleBot design because it can comfortably handle both the continuous and burst current demands. The total system peak current is 14.6 A, while the battery's continuous rating is 31.5 A, providing a safety margin of over 2×. Its burst capability of 67.5 A for 1–3 seconds easily accommodates short, high-torque weapon strikes without risking voltage sag or damage. Additionally, the theoretical runtime at a continuous draw of 14.6 A is approximately 111 seconds, which is nearly sufficient to cover a full two-minute match, and in realistic conditions, average currents will be lower than the peak. Overall, both the burst capacity and the runtime of this battery are sufficient for the demands of the drivetrain and weapon system.

To ensure that the drivetrain and weapon subsystems can meet the mechanical demands of combat, torque and speed requirements were analyzed for both the weapon arm and the drive motors. The torque requirement determines whether the selected motors can generate enough rotational force to move or lift the robot effectively, while the linear velocity calculation confirms that the drivetrain can reach the necessary maneuvering speed during matches. For the weapon, the torque must overcome the robot's weight and moment arm to achieve a flipping action. For the drivetrain, torque is limited by traction and wheel friction, defining the maximum pushing force the robot can exert without wheel slip. The linear velocity analysis then links motor speed and wheel diameter to overall translational speed, ensuring the robot can accelerate, turn, and reposition quickly within the arena. Together, these calculations verify that the selected 508 RPM Mini Econ Gear Motors can provide sufficient torque and speed for both mobility and combat performance.

Weapon torque requirement:

- $F = mg = 0.907kg\ (2lb) * 9.81\ m/s^2 = 8.9\ N$
- $T = Fr = 8.9N\ (70mm) = 0.623\ Nm$

Drivetrain torque requirement:

- $F = 8.9\ N$
- $F_{rear,max} = \mu pF$ (μ = coefficient of friction, p = percentage of battlebot weight on the rear wheels), let's assume $\mu = 1$ for the competition, 65% of the weight on rear wheels, p = 0.65.
- $F_{rear,max} = 1(0.65)(8.9) = 5.79\ N$, $F_{rear,wheel} = F_{rear,max}/2 = 2.95\ N$
- $T_{,wheel} = F_{rear,wheel}\ r = 2.95N(2.25''/2) = 0.0844\ Nm$

Linear velocity calculation:

- $v = 2\pi r\ (RPM/60) = 2\pi * 0.0286(2.25'')\ (508/60) = 1.521\ m/s$

3. Cost and Schedule

3.1 Cost Analysis

Labor: $40/hour

- Software Development (20 hours)
- Schematic and PCB Design (30 hours)
- CAD Design (15 hours)
- 3D Printing (10 hours)
- Electrical Assembly (10 hours)
- Mechanical Assembly (5 hours)
- Testing and Iteration (10 hours)

Description	Manufacturer	Quantity	Price	Link
Microcontroller ESP-S3-WROOM-1-N-16	Espressif	1	$8	https://www.espressif.com/sites/default/files/documentation/esp32-s3-wroom-1_wroom-1u_datasheet_en.pdf
Drivetrain motor 508 RPM Mini Econ Gear Motor	Servocity	2	$15 * 2	https://www.servocity.com/508-rpm-mini-econ-gear-motor/
Weapon servo High Torque Waterproof Metal Gear Digital Servo	DFrobot	1	$18	https://www.dfrobot.com/product-2787.html?gad_source=1&gad_campaignid=22388643497&gbraid=0AAAAADucPIBO13eEFT5mFBdIe4KjyZL1i&gclid=CjwKCAjwxrLHBhA2EiwAu9EdM8SoqXEIzdtqb-giJFFY5KLSM6tpKhw9GrwZ1rVNWLbb8K0x8iGQPBoChGMQAvD_BwE
Battery Turnigy nano-tech plus 450 mAh 3S 70C	Turnigy Nano-Tech	1	$25	https://hobbyking.com/en_us/turnigy-nano-tech-plus-450mah-3s-70c-w-xt30.html?srsltid=AfmBOopTPSZrV4RrP0Gm7hB6syWrQ-oCFf9KxIWb6oyjgXbpFXTgL_km
H-bridge HiLetgo	DRV8833	3	$8 * 3	https://www.amazon.com/HiLetgo-Stepper-Controller-Tb6612fng-Replace/dp/B00U

				YIFYCW/ref=sr_1_1_sspa?dib=eyJ2IjoiMSJ9.avY188RKP6SpCmkgJgccYccdS3myffKGcScYhpItXpzRHlUg7I5GPrgaiF9Oa2EGQQ4gyXdtm007KmlDbtkBAOCy90OuWZMKZSkiLoSefQ63nOWMcZ5MjwCt3HEbb0bYvuPW1eZ1KjKKOsGLWW2rNgGhYMO44UMHjuVdOF_KJkzCX5GGmYz4nyhe4WEFf4Yv4jgc6ZA7bgPD5YcuAivzqfcSBfHGhL_bNPwr3eO-JSRA7j0BG5tChAoeMme5oaR_E3dzRsDT4o1-RbVoyKTZNp2j5hDo6WREYiIpFeW3rXI.mT2tUU5H4ITc-fY55IdqaGLbmtKdOjGRmVUYcxkkWL0&dib_tag=se&hvadid=777761376477&hvdev=c&hvexpln=67&hvlocphy=9022196&hvnetw=g&hvocijid=10022942037344053504--&hvqmt=e&hvrand=10022942037344053504&hvtargid=kwd-299636053329&hydadcr=26612_11867909&keywords=drv8833&mcid=206d682ba8d63e418c15b2e28907e6c1&qid=1760390435&sr

				=8-1-spons&sp_csd=d2lkZ2V0TmFtZT1zcF9hdGY&psc=1
Voltage Regulator LM2596S	Texas Instruments	3	$8.76 * 3	https://www.digikey.com/en/products/detail/texas-instruments/LM2596S-3-3/3701219
Motor driver MCF8316A1VRGFR	Texas instrument	2	$5 * 2	https://www.mouser.com/ProductDetail/Texas-Instruments/MCF8316A1VRGFR?qs=rSMjJ%252B1ewcSvC9rVuQgDWA%3D%3D&utm_id=22380207736&utm_source=google&utm_medium=cpc&utm_marketing_tactic=amercorp&gad_source=1&gad_campaignid=22376567996&gbraid=0AAAAADn_wf02ovBm4UaMFwfimQ8tHzk_7&gclid=CjwKCAjwxrLHBhA2EiwAu9EdMy3AkQxlJ9hXu1rhS9aWyq_VeeJ6M7IlCeU0LMgZhnQhC0h23elPjhoC0BEQAvD_BwE

Total cost: $10000 (labor) + $141.28 (parts) = $10,141.28

3.2 Schedule

Week of 9/29	• Finalize component selection and

	system architecture for control subsystem (All) ● Create initial KiCad schematic (ESP32, voltage regulator, motor drivers, weapon motor, sensors) (All)
Week of 10/6	● Test initial proof-of-concept on breadboard (basic motor control) (All) ● Finalize and submit PCB design for fabrication (All) ● Order all electronic components and mechanical parts (All)
Week of 10/13	● Build breadboard prototype with all subsystems connected (All) ● Develop core firmware (Bluetooth communication, PWM motor control, voltage regulator, weapon control) (All) ● Begin chassis design and 3D printing structural components (John)
Week of 10/20	● Complete mechanical chassis assembly and test fitment (John) ● Implement weapon servo control and emergency stop functionality (Jimmy) ● Test and tune motor control for required speed and torque specifications (Jimmy and John)
Week of 10/27	● Demonstrate functional breadboard prototype with wireless control (John) ● Verify all performance requirements (~1 m/s speed, <300ms latency, 10m range, 2min runtime) (Mig) ● Refine code for reliability (Jimmy and Mig)
Week of 11/3	● Receive and assemble custom PCB with all components (Mig) ● Test PCB functionality and debug any hardware issues (Jimmy) ● Begin integration of PCB with mechanical chassis (All)
Week of 11/10	● Complete full system integration (PCB, motors, battery, chassis, weapon) (Jimmy and Mig) ● Wire all subsystems and verify electrical connections (John)

	• Conduct comprehensive system testing (drivetrain, weapon actuation, sensors) (All)
Week of 11/17	• Run full combat simulations and stress tests (All) • Fix any identified issues and improve robustness (All) • Optimize control responsiveness and weapon performance (All)
Week of 11/24	• Final reliability testing and durability improvements (All) • Add strain relief, secure loose components, reinforce weak points (All) • Prepare backup components and document troubleshooting procedures (All)
Week of 12/1	• Complete final performance testing and data collection (All) • Prepare demonstration and document system performance (All)
Week of 12/8	• Complete documentation with final design, results, and analysis (All) • Deliver presentation and demonstrate complete battlebot (All)

4. Ethics and safety

4.1 Ethics

Our project follows the IEEE Code of Ethics (IEEE, 2025) and the ACM Code of Ethics (ACM, 2025) to ensure responsible engineering practice. Key ethical considerations for our BattleBot include safety of participants and bystanders, fair competition, respect, and team integrity. We will prioritize the health and safety of all team members, competition officials and bystanders. Risks such as LiPo batteries, high speed motors, and weapon systems will be addressed with proper handling procedures and kill-switch buttons. For fair competition, we will comply with all rules in BattleBot and make sure we don't exceed weight or use materials other than allowed ones. For Respect and Team Integrity, we will treat all participants fairly and with respect, avoiding harassment, discrimination, or misconduct in any form.

4.2 Safety

Safety is the most important aspect of combat robotics. Our team will comply with NFPA electrical safety standards (NFPA, 2025) and competition rules (NHRL, 2025) to minimize risks. Key measures include:

- Electrical Safety: The 11.1V LiPo battery will be housed in an insulated, impact-resistant enclosure and charged only with approved balance chargers. We will follow IEEE 1725-2011 battery management guidelines to prevent overheating, short-circuits, or fire hazards.

- Mechanical Safety: Moving parts such as wheels and weapons will not be activated outside of enclosed test zones. A kill switch will be implemented to immediately cut power in emergencies.

- Wireless Communication: Since the robot uses Bluetooth/Wi-Fi, we will configure secure authentication to prevent unauthorized access and ensure the robot enters a safe shutdown state if communication is lost.

- Lab and Shop Safety: We will wear PPE (goggles, gloves) while handling batteries, soldering, or machining parts, and follow UIUC lab safety rules. Lockout/tagout (LOTO) procedures will be followed during maintenance.

5. References

[1] IEEE, "IEEE Code of Ethics," IEEE Policies, Section 7 - Professional Activities. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8. [Accessed: Oct. 13, 2025].

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