ECE 445
Spring 2025
Senior Design Document

Project #1: Ant-weight, 3D Printed Battlebot

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1. Introduction

Problem

In the Ant-weight 3D Printed Battlebot Competition, designing a robot that is both strong and lightweight is a big challenge. The robot needs to have enough power to move quickly and use its weapon effectively, but at the same time, it cannot be too heavy. A heavier bot might be stronger, but it will use up the battery too fast. On the other hand, if the bot is too light, it might break easily during battle. Finding the right balance between battery life, weight, and material strength is important to make sure the bot lasts the full match while staying durable.

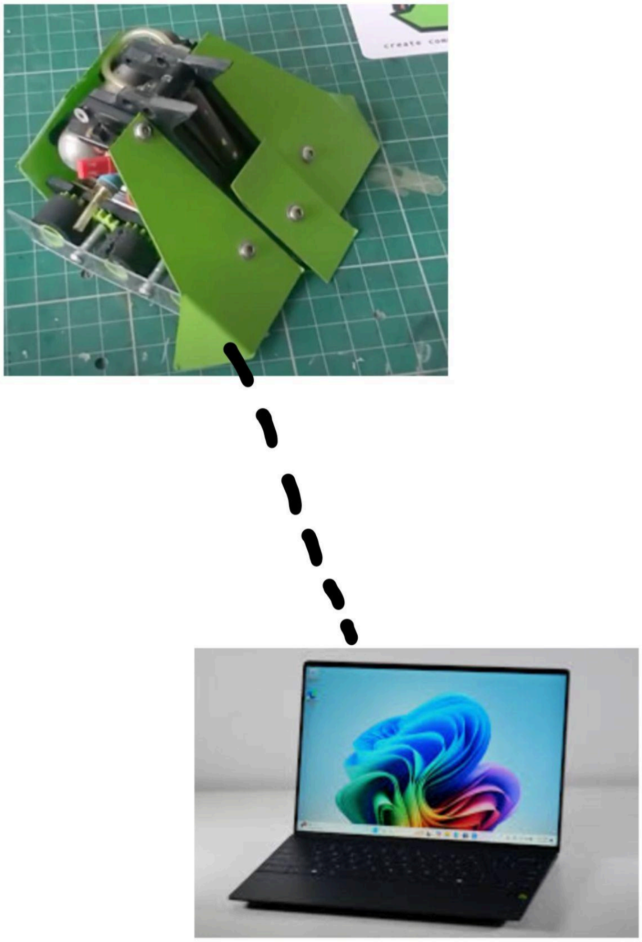
Another key problem is Bluetooth communication. The robot must receive real-time commands from the controller without any delays or connection problems. However, in a competition setting, many robots are using Bluetooth at the same time, which can cause signal interference and slow response times. If the bot does not react quickly to commands, it could be at a big disadvantage. To build a competitive Battlebot, we must make sure the Bluetooth connection is fast and stable, even in a crowded environment.

Solution:

To solve these challenges, we are designing a 3D-printed, Bluetooth-controlled Battlebot that balances strength, weight, and power efficiency. The chassis will be made from PLA+, which is stronger than regular PLA but still lightweight, helping the bot survive impacts without being too heavy. The battery is carefully chosen to provide enough power for the whole match while keeping the bot within the weight limit. The motors are controlled using PWM signals, allowing for smooth movement and quick direction changes while using power efficiently.

For better wireless control, we are using the ESP32-WROOM-32E module, which supports fast and stable Bluetooth communication even in environments with many signals. This will reduce delays when sending commands, making sure the bot reacts quickly. The weapon system uses a pneumatic flipping mechanism with a controlled air pressure system, allowing for powerful but efficient attacks. Together, these improvements ensure our Battlebot is durable, fast, and responsive, making it highly competitive in the Ant-weight class.

Visual aid:



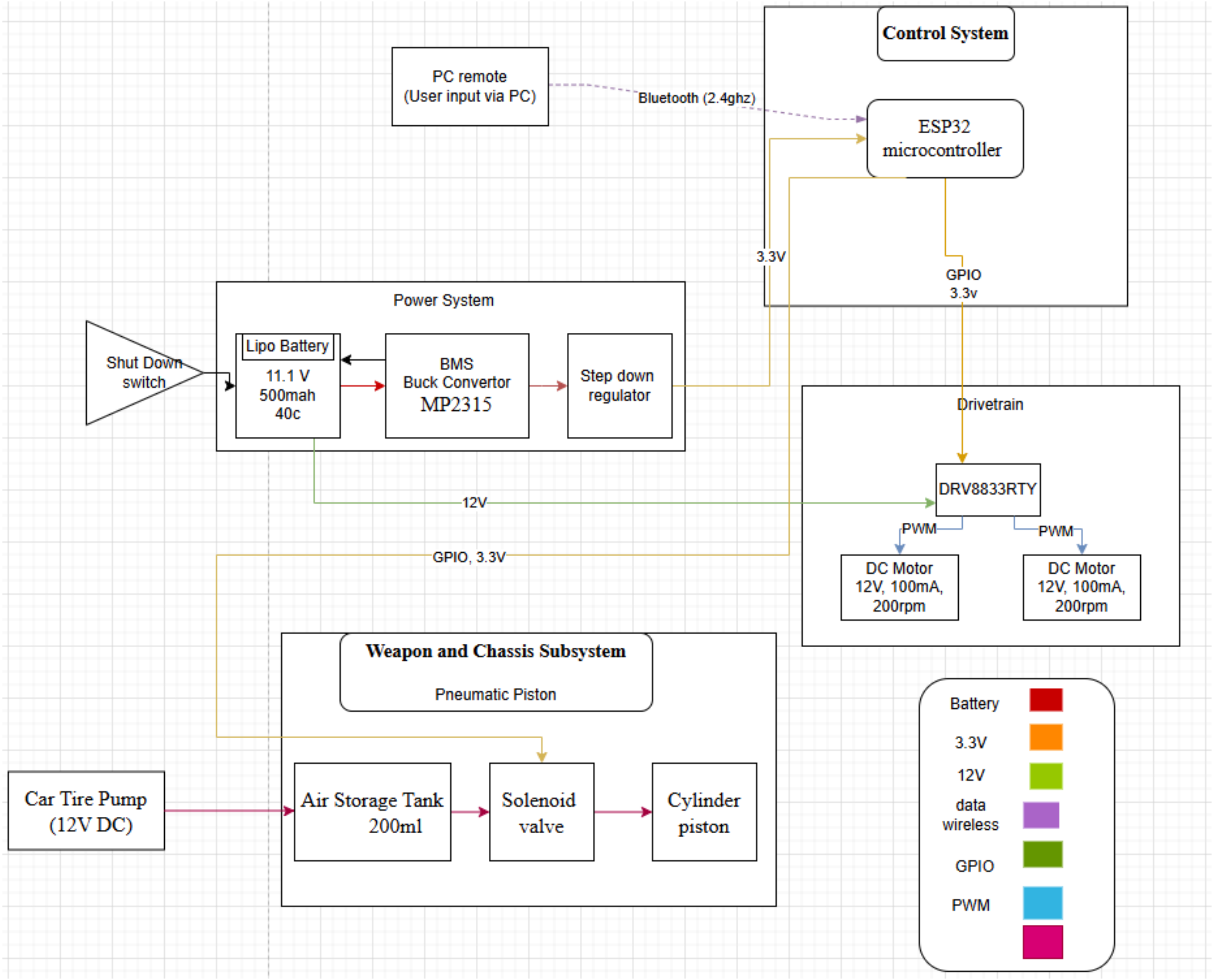
Our Bluetooth-connected Battlebot will be controlled using a computer-based interface, where movement commands are sent wirelessly through the ESP32-WROOM-32E module with minimal delay. The control scheme will be simple and intuitive: pressing "W" moves the bot forward, "S" moves it backward, "A" turns it left, and "D" turns it right, allowing for precise maneuverability. Additionally, pressing the spacebar will activate the ramp-flipping mechanism, enabling strategic attacks during battle. This setup ensures smooth and responsive control, giving the operator the ability to quickly adapt to the competition and make real-time decisions.

High level require list

1> The Battlebot must be wirelessly controlled via Bluetooth, ensuring smooth and real-time command execution without huge delay.
2> The chassis must be strong yet lightweight, using PLA+ 3D-printed material, capable of withstanding high-impact collisions.
3> The weapon system must function reliably, utilizing a pneumatic flipping mechanism with a controlled air pressure system that allows at least one successful flips per charge without performance degradation.

2. Design

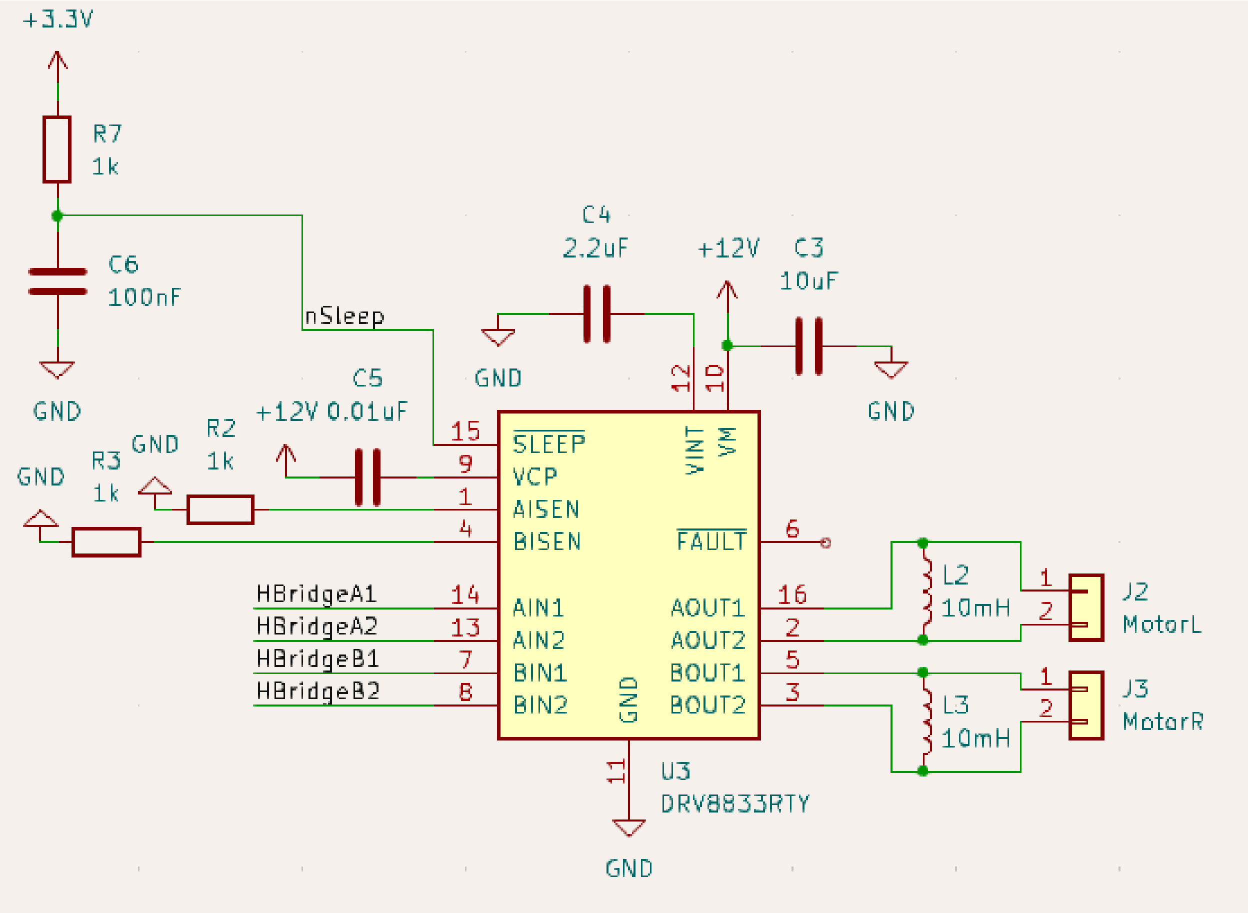
Block Diagram:



Subsystem Drivetrain

The drivetrain is responsible for the Battlebot's movement and maneuverability. It utilizes two high-torque DC motors from Greartisan, which each provide 2.2 kg · cm of torque and a no-load speed of 200 RPM. These motors drive the rear wheels, enabling precise movement with enhanced torque for pushing against opponents. The motors are controlled via an H-bridge from Texas Instruments (DRV8833RTY), allowing bidirectional movement and speed control with improved efficiency. The circuit ensures the motors can dynamically adjust speed and direction for quick and strategic maneuvers. The battlebot employs PWM (Pulse Width Modulation) signals from the ESP32 microcontroller, ensuring variable speed control with smooth acceleration and deceleration.

The rear wheels are equipped with high-friction tires to maximize traction, enabling the bot to push against opponents effectively. The front wheel is omni-directional, ensuring smooth directional changes and enabling pivoting maneuvers. This combination optimizes the bot's agility and defensive capabilities while maintaining stability during combat.



Subsystem Requirements and Verifications:

- Each motor can roughly produce the a maximum of 2.2kg * cm amount of torque under no load per the motor's specifications; this will be tested in practicality by it being able to push something of approximately 2.2kg for about 1cm
- Each motor can reach a maximum of 210 rpm with no load, the upper limit of the motor providing no burnout conditions; this can be "simple" tested by taping something to the shaft (light) and seeing if it spins. The less we can see the paper flying about, the faster it is. With accurate tool measurements, (if provided) we can use a tachometer or strobe light with calculations to calculate the actual speed. Otherwise, we can test the RPM when actually accelerating the robot with wheels and calculating based on time, distance, and wheel diameter

Subsystem Weapon and Chassis

The primary weapon is a Pneumatic Ramp Flipper, specifically designed to flip opponents with precision and efficiency. It features a low-profile, angled ramp that smoothly slides underneath for effective lifting. The system operates using a pneumatic actuator connected to a 200ml gas tank pressurized at 120 PSI, enabling controlled solenoid valve activation for each flip.

Pneumatic Control System

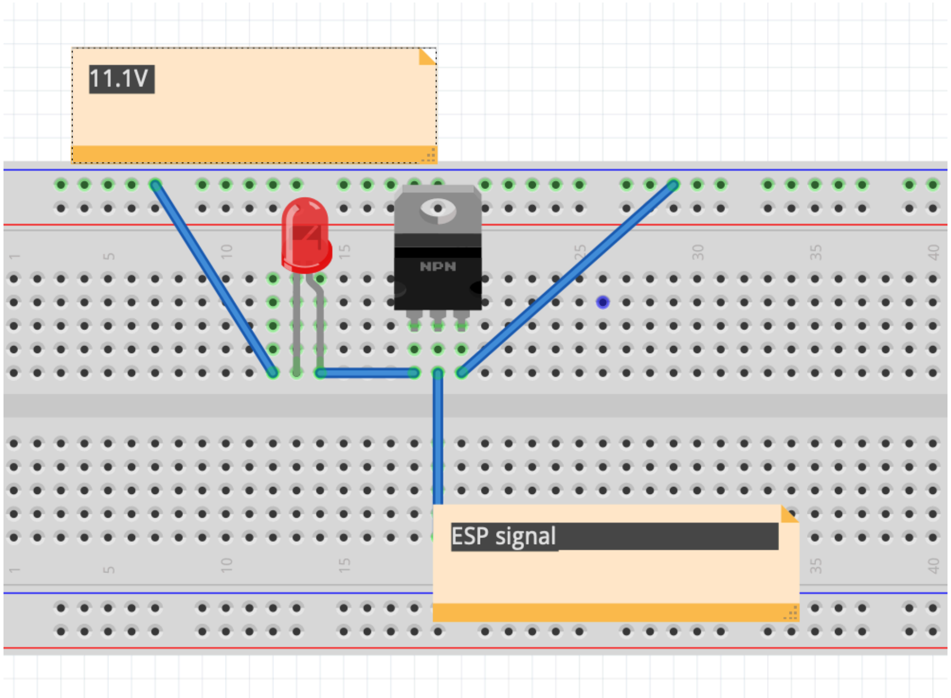
The solenoid valve is precisely controlled by an ESP32 microcontroller, ensuring exact timing for activation. The system utilizes a transistor-based switch to handle the 11.1V power supply required by the solenoid: A logic-level N-channel MOSFET is used to switch the solenoid valve on and off. NMOS is used to trigger low side, as the gate is powered, it will allow the current pass through to ground.

- Gate: Connected to the ESP32's GPIO pin (3.3V logic).
- Drain: Connected to the solenoid's negative terminal, which is powered by the 11.1V battery.
- Source: Connected to ground.

When the ESP32 outputs HIGH (3.3V), the MOSFET conducts, activating the solenoid and opening the valve to release air and flip the opponent. When the ESP32 outputs LOW (0V), the MOSFET turns off, closing the valve and stopping airflow. A pull-down resistor (1kΩ) ensures the MOSFET remains off when no signal is present, preventing unintended body leakage.

Pressure & Flow Regulation

To maintain consistent flipping power while conserving air, a pressure regulator ensures even pressure distribution to the pneumatic actuator. Additionally, manual flow control valves allow for safe pressure release when needed. The compact air tank is optimized to support up to 5 flips per charge before the pressure reduces, ensuring efficient battle performance.



The chassis is 3D-printed using PLA+ plastic, which offers a balance between durability and weight efficiency. PLA+ is selected over standard PLA due to its increased impact resistance and reduced brittleness. The chassis design features structural reinforcements in high-stress areas, ensuring it can withstand repeated impacts without compromising integrity.

The low center of gravity of the bot further improves stability, preventing easy flipping by opponents. Additionally, weight distribution is optimized to ensure consistent movement and controlled aggression during combat.

Subsystem Requirements and Verification:

- Have a solid building structure of PLA+ plastic that can withstand the force of ramming 2lbs; this can be tested by using something of roughly 2lbs to put in the way of the battlebot
- Have a gas tank that can withhold 120psi for the weapon; this will be shown and tested through the pressure gauge attached to the system to check for holding capabilities

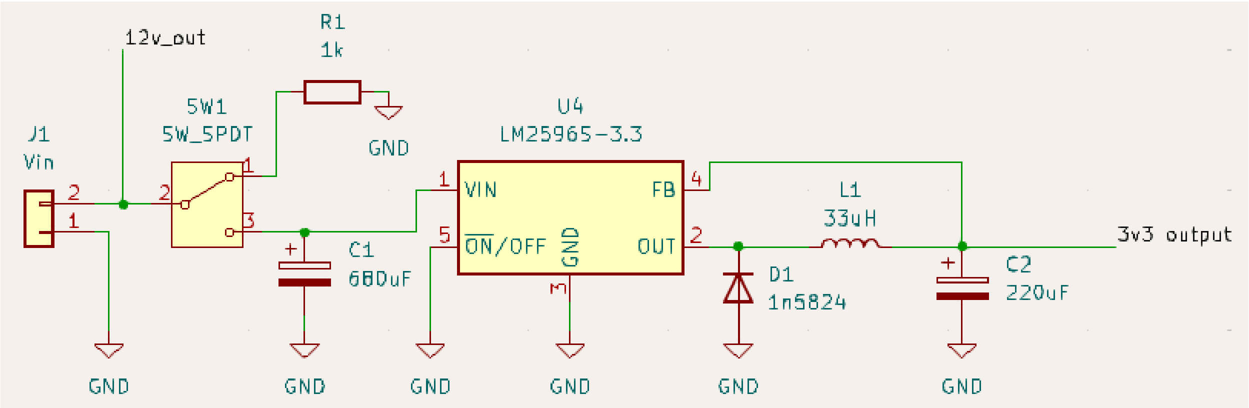
Subsystem Power System

The power system ensures consistent and reliable power delivery to all components. A 3S 11.1V 500mAh LiPo battery (Flex Innovations, 2025) provides power to the drivetrain, control, and weapon subsystems.

The Greartisan motors operate within a 6V-12V range, and since a fully charged 3S LiPo battery outputs 12.6V, the system can efficiently power the motors without additional voltage regulation. The battery voltage will naturally decrease during operation but will remain within the acceptable range.

A voltage monitoring circuit is integrated to track power levels and ensure the motors do not receive excessive voltage beyond their rated limits. The power system also includes overcurrent and short-circuit protection mechanisms, ensuring safety in case of electrical faults.

To supply lower voltage components such as the ESP32 microcontroller and sensors, a step-down (buck) voltage regulator is used to convert the 11.1V battery output to stable 5V and 3.3V power. This ensures efficient and heat-minimized operation, preventing excessive power dissipation that would occur with a linear regulator. The regulated voltage allows stable operation of logic-level electronics while maintaining overall energy efficiency.



Subsystem Requirements and Verification:

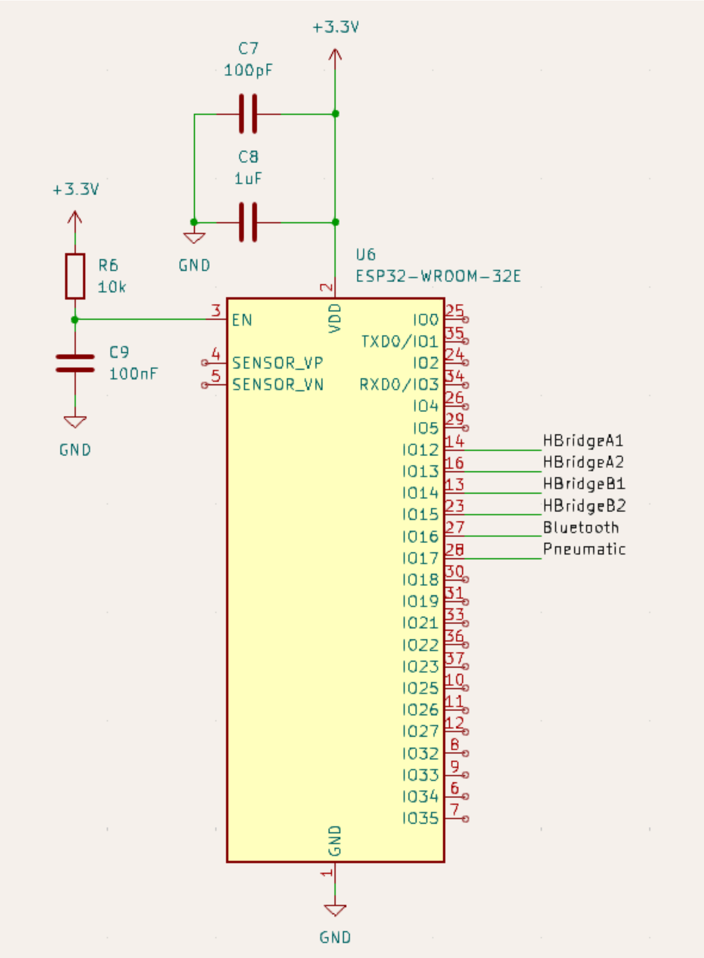
- Can supply a continuous 3A of current to all subsystems when under load (Check Tolerance Analysis). This can be formally measured through a multimeter on the current setting.
- Have enough capacity to last 2 minutes of continuous usage to last the battle (our current battery is 500mAh). The most accurate way to test this would be timing our system using a timer when the battlebot is turned on.

Subsystem Control System

The ESP32-WROOM-32E microcontroller serves as the central processing unit of the Battlebot, handling real-time control inputs, motor operation, and weapon activation. The microcontroller is programmed to interpret Bluetooth commands from a PC controller, ensuring precise movement and attack execution.

The control system leverages PWM for speed modulation, GPIO for directional control and communication for sensor data (if applicable). The microcontroller processes commands with a response time of under 100ms, ensuring low-latency execution during battles.

The Bluetooth module is optimized for high-speed, interference-free communication, ensuring real-time command execution without signal drops. Extensive testing is conducted to mitigate latency issues and improve responsiveness.



Subsystem Requirements and Verification:

- Be able to connect via bluetooth from the computer we intend to use as a remote to our ESP32 microcontroller and control/send signals to the different subsystems. This can be tested when our ESP32 is receiving and demonstrating inputs from our computer. Additionally, we will have an LED to display if connected via bluetooth.
- Be able to control the direction of the battlebot with given signals. To demonstrate this, we will show the motors being able to spin in different directions when the controls indicate a turning movement.

Tolerance Analysis

An aspect of our design that may pose a threat to the successful completion is if our battery depletes before the end of the 2 minute time limit with the assumption that it is an endurance fight. In order to counteract this, we have decided to find a battery that will supply enough voltage to the different components while also having enough amperage such that it can sustain throughout the whole fight with extra power to spare.

To calculate the amount of amperage required of our battery, we need to calculate the power usage of all the subsystems based on a given time.

The motor we selected (at 12V) has a max efficiency of 0.1A draw with a 2A stall current.

Average and Peak Current Draw of both motors:
$I_{motors} = N_{motors} * I_{motor} = 2 * 0.1A = 0.2A$
$I_{peakM} = N_{motors} * I_{motor\_peak} = 2 * 2A = 4A$

Our Pneumatic system has a rough average current draw of 3A with a peak current draw of 5A. Additionally, our ESP32 and related components have an average current draw of 0.15A and a peak current draw of 0.2A.

The calculation of how much our battery capacity need as well as tolerance can be calculated as follows:

Total and Peak Current Draws:
$I_{total} = I_{motors} + I_{pneumatic} + I_{IC} = 0.2A + 3A + 0.15A = 3.35A$
$I_{peak} = I_{motors\_peak} + I_{pneumatic\_peak} + I_{IC\_peak} = 4A + 5A + 0.2A = 9.2A$

Capacity of Battery Wanted = I_{total} * Total Time = 3.35A * 2min = 3.35 * 2/60 h = 0.1116 Ah
Peak current of battery = 9.2A

Because actual consumptions with batteries will vary, we need to make sure that the battery can handle 9.2A of peak load draw as well as have a total capacity of at least 0.1116Ah. This will ensure that the battery can handle the components we are using as well as last the total battlebot round of 2 minutes. The battery we have opted for has a capacity of 500mAh - which satisfies the capacity of battery wanted by a lot to ensure even with not optimal conditions it will work - as well as discharge rate of 35C and max discharge rate of 70C. To ensure that the peak current and current ratings are within this discharge rate, we take the amperage divided by the total capacity of the battery (3.35A/500mAh = 6.7C and 9.2A/500mAh = 18.4C), both of which are within limits: 6.7C < 35C and 18.4C < 70C.

3. Cost and Schedule

Cost Analysis:

The total cost of the project consists of labor costs and parts costs required for the development and assembly of the Battlebot. Our team consists of one Electrical Engineering student and two Computer Engineering students, each contributing 60 hours to the project. Based on recent salary estimates for ECE graduates from the University of Illinois, we assume an hourly rate of $40 for the EE student and $38 per hour for each CE student. The total labor cost is calculated as $40 × 60 = $2,400 for the EE student and $38 × 60 = $2,280 per CE student, resulting in a total labor cost of $6,960 for the team.

In addition to labor, the project requires various electronic components, mechanical parts, and structural materials, as listed in the budget document. This includes the ESP32-WROOM-32E Bluetooth module, high-torque DC motors, 3D printing materials (PLA+ filament), a LiPo battery, and pneumatic system components for the weapon mechanism. The total cost of these parts, calculated from the latest budget list, amounts to $7200
Combining labor and parts costs, the total estimated cost for the project is $7350, ensuring that all subsystems, including control, power, drivetrain, and weapon systems, are fully developed and tested within budget constraints

Schedule:

Include a time-table showing when each step in the expected sequence of design and construction work will be completed (general, by week), and how the tasks will be shared between the team members. (i.e. Select architecture, Design this, Design that, Buy parts, Assemble this, Assemble that, Prepare mock-up, Integrate prototype, Refine prototype, Test integrated system).

Week	Checklist
3/10	Pass audit check and order pcb
3/24	Soldering parts together, and check if bluetooth connect properly
3/31	Buy the pcb again if the first pcb does not work and use 3d printer to print out battle bot
4/7	Solve the pneumatic system and make sure it is work
4/14	Assemble all parts together
4/21	Final check

4. Discussion of Ethics and Safety:

Ethical Considerations
Our project adheres to the **IEEE Code of Ethics (IEEE, 2023) and the ACM Code of Ethics (ACM, 2023)** to ensure ethical responsibility in both design and development. Key ethical concerns include fair competition, safety of participants and bystanders, and transparency in development.

1> Fair Competition: We will ensure compliance with competition rules, avoiding unauthorized modifications that may provide an unfair advantage. All components used will comply with the competition's technical regulations, and no deceptive practices will be employed.

2> Safety of Participants and Bystanders: The Battlebot will be tested in a controlled environment, ensuring it does not pose accidental risks to participants or observers.
3> Transparency in Development: We will maintain proper documentation of hardware and software to ensure integrity and reproducibility. Design files and testing reports will be kept up to date for reporting purposes.

Safety Concerns and Strategies

To ensure the safety of developers, users, and bystanders, we will implement the following safety measures in accordance with **Occupational Safety and Health Administration (OSHA, 2023)** regulations.

Electrical Safety

Our project involves a 11.1V LiPo battery and high-torque motors, necessitating robust safety measures to prevent electrical hazards:

1> Battery Protection: The LiPo battery will be housed in an impact-resistant, ventilated enclosure to prevent overheating and mechanical damage.
2> Circuit Safety: Wires and power components will be properly insulated and undergo continuity and resistance testing to prevent short circuits or electrical failures (NFPA, 2023).
3> Emergency Shutoff: A physical kill switch will be integrated into the circuit, allowing for immediate power cutoff if an electrical failure occurs.

Mechanical Safety

The weapon system and chassis structure will be designed to minimize risk to operators and audience:

1> Finite Element Analysis (FEA): The chassis and weapon system will undergo stress and impact simulations to ensure they can withstand combat forces without unexpected failure.
2> Material Safety: The bot will be 3D-printed with PLA+ plastic, selected for impact resistance and durability.

Pneumatic Safety

Pressure Limits Compliance

- Do **not exceed 120 PSI** during normal operation.
- Safety buffer limit: **130 PSI maximum** before automatic pressure release is triggered.

Pre-Operation System Check

- Inspect all **air hoses, connections, and fittings** for leaks or damage before every use.
- Check **pressure gauge readings** to ensure the system is within the safe operating range.
- Ensure the **manual safety vent valve** is functional before charging the system.

Safe Charging & Pressure Release

- Always **charge the system in a well-ventilated area**.
- Use only **approved pressure sources** with a regulator to prevent over-pressurization.
- Before maintenance, fully **depressurize the system** using the **manual release valve**.

Lab Safety Compliance
Development and testing will follow **University of Illinois Lab Safety Guidelines**, including:

1> Personal Protective Equipment (PPE): Team members will wear safety goggles, gloves, and anti-static wristbands when handling batteries, electrical circuits, and pneumatics.
2> Safe Work Practices: All testing will occur in designated safety zones, with emergency response plans in place.

Required Documentation

Given the **high-risk factors** associated with **pneumatics, high voltage, and combat interactions**, we will develop a **comprehensive Safety Manual** that includes:

- **Emergency Procedures**: Clear steps to handle system failures, air leaks, electrical shorts, and unintended solenoid activation.
- **Risk Mitigation Strategies**: Guidelines for **safe handling of pressurized air systems**, **battery management**, and **ESD protection** for electronic components.
- **Safe Handling Guidelines**: Standard operating procedures (SOPs) for **system assembly, maintenance, and combat deployment**.

Demonstration of Safety Compliance

- **Adherence to Best Practices**: During the **final demo**, we will **showcase strict compliance** with our Safety Manual, demonstrating that all team members follow safety protocols.
- **Pneumatic System Integrity Test**: Before operation, we will **verify that all connections hold pressure without leaks**, ensuring the gas tank, solenoid, and actuator function correctly.
- **Electrical Safety Measures**: We will implement **proper insulation, fuse protection, and emergency cutoff switches** to prevent accidental system overloads.
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References

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