ANTWEIGHT BATTLEBOT

By

Praman Rai

Anthony Shen

Batu Yesilyurt

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TA: Sanjana Pingali

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Abstract

This project presents the design and implementation of an antweight battlebot for the spring 2025 ECE 445 final project and the associated competition. Our battlebot employs a lifting arm mechanism capable of raising opposing robots into the air, rendering them immobile while suspended. The 2-wheel tank drive configuration provides maneuverability while maintaining pushing power, reaching speeds of 5.32 ft/s. The system operates via WiFi control through an ESP32 microcontroller with automatic shutdown capabilities within 138 ms of connection loss for safety compliance. The lifter arm generates 4.48 ft-lbs of torque, exceeding the 1.333 ft-lbs requirement to lift the maximum 2-lb opponent weight. Despite challenges with motor gearbox durability and power management, all subsystems were successfully tested and verified. The battlebot demonstrated competitive performance in tournament conditions, defeating both pneumatic and spinner opponents through effective mobility and control strategy to win the competition.

Contents

1. Introduction
Six teams compete with their own battlebots in a bracket elimination tournament with the goal of dominating the opposing robot. Two battlebots are placed in a ten-by-ten foot walled-off arena for two minutes. A winner is deemed when a battlebot is disabled or through a judge's decision at the end of the time limit. In this version of battlebot, the robot must be less than 2 lbs, 3D printed from plastics, contain a custom Printed Circuit Board (PCB) that connects the microcontroller to a remote-control system, use a motor or pneumatic fighting tool, and have easy manual/automatic shutdown. Other rules and constraints are detailed in the National Robotics Challenge 2025 Contest Manual [1].

1.1 Solution
The most challenging part of this competition is the 2 lb weight restriction. For this reason, we designed a control battlebot with the capability of lifting and flipping over the opposing battlebot. Our goal is to win by a judge's decision at the end of the two-minute time limit. Our battlebot is equipped with a lifting mechanism to lift the opposing battlebot into the air. When suspended in the air, the opposing battlebot is unable to move or to attack our battlebot. To successfully achieve this mechanism, our lifting arm is designed to be strong enough to lift the other robots. Additionally, we employ defense measures to keep our battlebot safe when approaching and after lifting the opposing battlebot. Our battlebot contains a strong frame that encompasses our drivetrain motors, lifting motor, wheels, PCB, and battery. The controlling weapon system paired with a strong and durable design proves to be a tough challenge for any battlebots we come up against.

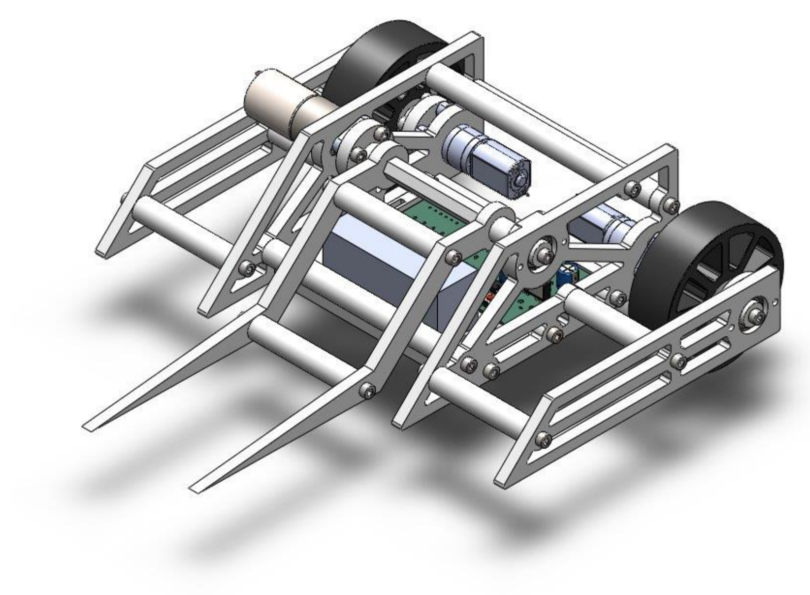

Figure 1. 3D model of battlebot.

1.2 Functionality

To deem our project successful, we have achieved the following high-level requirements.

1. Bluetooth remote control of the robot within at least a 15 ft range.

2. The robot should drive at a speed of at least 5 ft/s and operate a lifter weapon capable of lifting at least 2 lbs.

3. The robot should automatically disable within 500 ms of connection being lost

The motivation behind high-level requirements 1 and 2 is to put up a competitive robot during the competition. WiFi remote control range of 15 feet lets us control the battlebot for the span of the entire ten-by-ten foot battlebot arena. Driving at a speed of 5 ft/s gives the battlebot enough mobility to drive around opposing battlebots while also being at a controllable speed. The lifter weapon lifting 2 lbs allows us to lift all battlebots in this competition due to the 2 lb restriction on the battlebots.

The motivation behind high-level requirement 3 is to abide by the safety rules of the competition. In the case that our battlebot loses connection, the battlebot disables within 500 ms to prevent any random and unpredictable operation.

All of these high-level requirements were tested and verified successfully. The testing process and verification results are discussed later in this report.

1.3 Subsystem Overview

Our battlebot design is organized into four main subsystems. These subsystems are the power subsystem, control subsystem, drivetrain subsystem, and the weapon subsystem. The power system is to manage power delivery to all the different components of our battlebot. The motors, ESP32 Microcontroller, and L298N H-bridges demand 12 V, 3.3V, and 5V respectively [2-5]. For proper operation of these components, the power system is responsible for supplying 12 V, 3.3 V, and 5 V. Additionally, the ESP32 microcontroller demands a very stable power source. The control system will encompass the microcontroller and motor control. With these components, we will be able to remotely control our battlebot and operate the motors through an H-bridge. The drivetrain subsystem utilizes two high rpm brushed motors to be able to drive the battlebot. The weapon subsystem consists of one high torque brushed motor to be able to lift opposing battlebots. The subsystems will be discussed in more detail later in this paper. In Figure 2, the final top-level block diagram is shown.

However, this final top-level design differs from our initial design. Initially, we were planning on using the STM32 microcontroller, HC-05 Bluetooth Module, and the DRV8952 H [6-8]. The DRV8952 H-bridges demand 3.3V to operate properly [8]. The HC-05 Bluetooth Module and STM32 microcontroller demand 3.3V as well, so the 5 V line coming out of the block diagram was unnecessary [6, 7]. The initial top-level block diagram is shown in Figure 3.

The performance requirements to deem our battlebot successful in the proposal were broken up into each subsystem of the battlebot design. Later in this report, we will detail the requirements and the verification process of each subsystem.

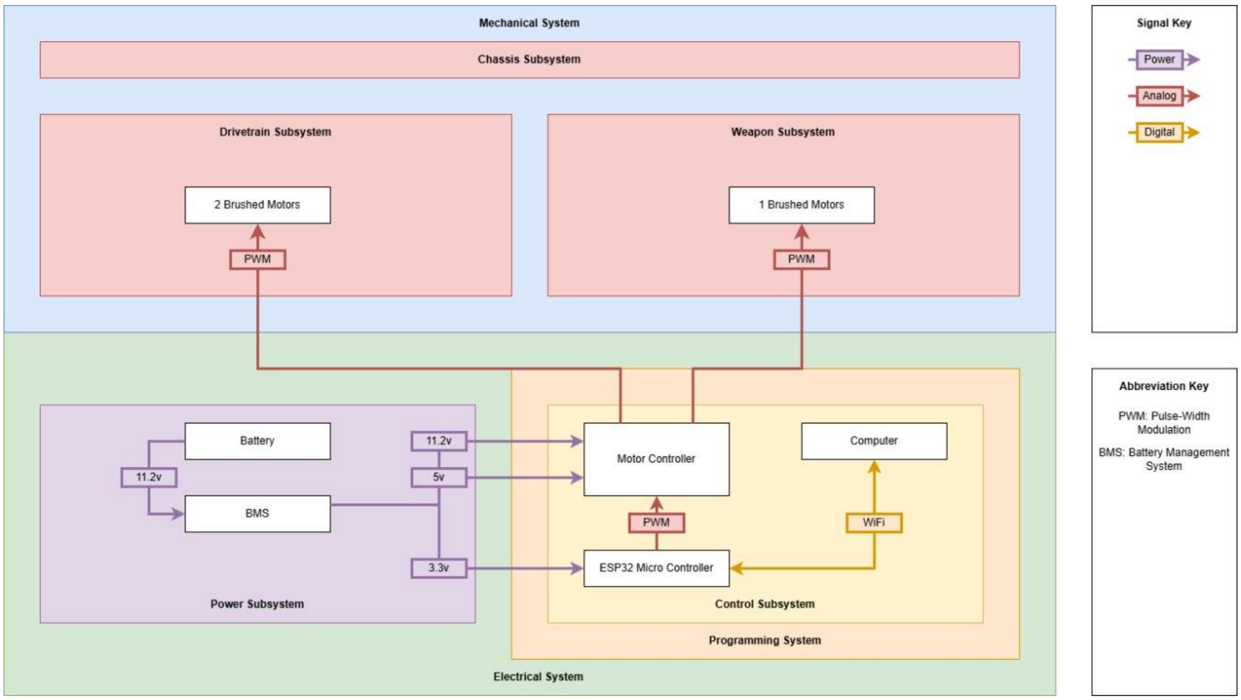

Figure 2. Final top-level block diagram.

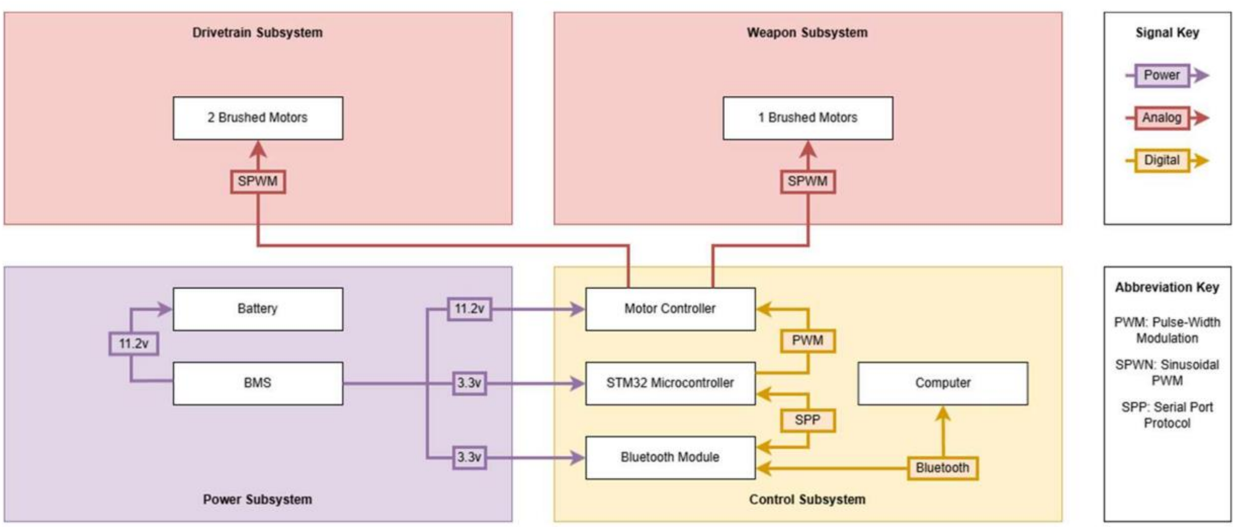

Figure 3. Initial top-level block diagram.

2 Design

2.1 Physical Design

The design of our battlebot is crucial to its success. By maximizing our weapon system and preventing damage to vital components, we have designed a battlebot that won the battlebot competition. The durability and defensive ability of our battlebot is crucial to its survival. We need to approach and lift the opposing battlebot without taking damage. Our battlebot employs protective safety measures to protect the vital components of our battlebot. It is important to keep the battery and PCB protected because our battlebot will not operate without them. Our battery and PCB are placed inside of the frame. Initially, we had designed the frame to entirely encapsulate the wheels with the frame to keep the driving system safe. Due to the weight restriction, we decided to add the frame only to the side of the wheels.

Within battlebots there are 2 types of weapons (Lifters, Kinetic Spinners) generally used. We chose a lifter weapon system for a few reasons. First, because of the weight class and restrictions on the use of metal for offensive and defensive purposes, we believe that kinetic spinners will be less effective. Second, we decided to use a lift motor rather than pneumatics because of the weight constraint. Weight constraints impact our ability to place an onboard compressor meaning that our robot would need to be pre-pressurized and have a limited number of lifts. Pneumatics also require an air tank and solenoid on top of a pneumatic cylinder. These component weights quickly add up and would require severe compromises in other systems. Our approach to the lifter system consists of two lifter prongs that will get under the enemy robot and lift them up. These prongs will also serve as a way to self-right our robot in the event it is flipped over.

We initially considered a few different drive trains like H-Drive (3 Motors Required), Mecanum (4 Motors Required), and Tank Drive (2 Motors Required). We quickly settled on Tank Drive because of its simplicity (weight and design) and resistance to being pushed around when compared to the other options at the cost of the mobility the other 2 options provide. We settled on a 2-wheel rather than 4-wheel Tank Drive because it allows the front of the robot to rest on the ground and to get underneath the enemy robot. A decision matrix for the drive train configuration can be seen in Table 1.

After performing an initial 3D model of the robot, we were able to design the PCB around the battery and motor placement, as well as determine the PCB size constraint. This allows us to place the battery connectors at the front of the PCB while the motor connectors in the back to reduce wire management problems.

Table 1. Drivetrain decision matrix.

Drivetrain	Mobility	Pushing Power
H Drive		
Mecanum		
Tank Drive		

2.2 Weight Considerations

The weight and size constraint of the event significantly influenced the design of the robot on top of the considerations previously discussed. First, we opted to utilize spur gear gearboxes that were built into the motors in order to save weight and area that would come with building an in-house solution. Second, the robot has pockets of material strategically removed around areas of low stress in order to save weight while still providing protection to fragile components. Initially, the entire robot including the gears were going to be built using ABS plastic because of its strength and lighter weight. Unfortunately, ABS plastic printing was not available to us so we chose to go with PLA plastics. Finally, we chose lighter motors (also weaker) for the drivetrain when compared to the lifter arm because the battlebot is designed to get underneath the opponent and lift them up rather than push them around.

2.2.1 3D Printing Considerations

One of the key rules of this competition is that both the offensive and defensive capabilities of the robot must be 3D printed. As a result, the choice of material is very important to the robot's success. We considered the 3 main options (ABS, PLA, PETG) available to us and initially chose to use ABS as previously mentioned. The first consideration was the impact resistance and strength of the material. In this area ABS and PETG are generally regarded as having better characteristics in this area when compared to PLA [9]. The next consideration, weight, as previously mentioned, favored ABS over PLA and PETG [10]. The decision matrix for different 3D printing materials is shown in Table 2. We had initially decided to use ABS due to the advantages that were just listed. Unfortunately, we were not able to 3D print with ABS because the provided lab only had PLA.

With PLA there were a few changes that had to be made. First because of the increase in density, the infill of the print had to be decreased to compensate. Another change was the switch to directly threading the plastic for M4 bolts instead of M3 bolts. Because PLA is softer than ABS, its ability to hold threads was also less than expected, so to compensate, we had to increase the thread size. However, the switch from M3 to M4 bolts also meant an increase in weight which led to the further reduction of infill. Overall, while the change to PLA did not impact our final performance, however a carefully trial and error approach was needed to maximize infill while not violating the weight constraint.

Another consideration is that we are using FDM printers which deposit material layer by layer. As a result, this results in a strong direction when the force is applied perpendicular to the layer, but weak when parallel. For this reason, we oriented our 3D printed components accordingly with the expected direction of force applied to it.

Table 2. Material decision matrix.

Material	Strength	Weight	Ease of Printing
PLA			
ABS			
PETG			

2.2.2 Motor Considerations

For our battlebot, we considered 2 types of motors (Brushed and Brushless), and ultimately chose brushed motors for an easier control scheme. We initially wanted to use Brushless motor because it is superior in weight, power, and size. However, further investigation led us to discover some drawbacks that ultimately pushed us to use Brushed motors. First is that the weight savings associated with a brushless motor is quickly negated by the need of bigger gearboxes to lower the RPM of the motor. Second, brushed motors have a higher starting torque that is desirable for our lifter weapon system [11]. Finally, the complexity of the control scheme which requires additional hardware to convert Pulse Width Modulation (PWM) to the 3 phases used by the brushless motors would add additional points of failure and potential blocks to our project [11]. The decision matrix for different motors is shown in Table 3.

Table 3. Motor decision matrix.

Motor	Power	Size	Instant Torque	Implementation Difficulty
Brushless				
Brushed				

2.3 Drivetrain Subsystem

The drivetrain shown in Figure (4) has a speed set at 5 ft/s for increased user drivability. Our initial idea was to set a drivetrain speed of 12 ft/s based on initial research of other combat robots in the similar class, however in the context of the arena size, it becomes apparent why that is too fast. An arena for this class is around 10 ft x 10 ft which means at 12 ft/s the robot will travel from end to end of the arena in 0.833 seconds. In our configuration our robot can travel across the arena in 2 seconds. Instead of prioritizing straight-line speed, we believe that prioritizing the turning speed of our robot to angle the front towards the enemy is more important. Calculations for these parameters are detailed in Equations (1), (2), and (3).

$$\text{Time to Travel from End to End of Arena 1} = \frac{\text{Arena Length}}{\text{Robot Speed}} = \frac{8\ \text{ft}}{12\ \frac{\text{ft}}{\text{s}}} = 0.667\ \text{s} \tag{1}$$

$$\text{Time to Travel from End to End of Arena 2} = \frac{\text{Arena Length}}{\text{Robot Speed}} = \frac{8\ \text{ft}}{5\ \frac{\text{ft}}{\text{s}}} = 1.6\ \text{s} \tag{2}$$

$$\text{Turning Speed} = \frac{\text{Left Wheel Velocity - Right Wheel Velocity}}{\text{Wheel Base Length}} = \frac{5\ \frac{\text{ft}}{\text{s}} - (-5\ \frac{\text{ft}}{\text{s}})}{0.458\ \text{ft}} * \frac{\text{Revolutions}}{2\pi\ \text{radians}} = 3.474\ \frac{\text{revolutions}}{\text{second}} \tag{3}$$

The drivetrain consists of 2 brushed motors that will be appropriately geared in conjunction with the wheels to give a top speed of at least 5 ft/s. The 508 RPM Mini Econ Gear Motor that we plan on using has 508 rpm and torque of 0.173 ft-lbs. [2]. With three-inch diameter wheels, 508 rpm corresponds to 6.649 ft/sec which satisfies part of the third task in our high-level requirements. Calculations for these parameters are detailed in Equations (4), (5), and (6).

$$\text{Motor Revolutions Per Second} = \frac{\text{508 revolutions per minute}}{\text{60 seconds per minute}} = 8.466\ \frac{\text{revolutions}}{\text{Second}} \tag{4}$$

$$\text{Wheel Circumference} = \pi * \text{Diameter of Wheel} = \pi * 3\ \text{in} = 9.425\ \text{in} \tag{5}$$

$$\text{Speed} = \text{Motor Revolutions Per Second} * \text{Wheel Circumference} = 8.466\ \frac{\text{revolutions}}{\text{second}} * 9.425\ \frac{\text{in}}{\text{revolution}} * \frac{1}{12}\frac{\text{ft}}{\text{in}} = 6.65\ \frac{\text{ft}}{\text{s}} \tag{6}$$

The .173 ft-lbs of torque at each wheel should be enough to push around the opposing robots as well. The motors weigh about 0.09 lbs each [2]. The weight of some additional gears, wheels, and axles will be negligible compared to the motor weight. The total weight of the drivetrain subsystem is going to be around 0.2 lbs. This is a reasonable weight for the subsystem. The motors draw 11 volts and are controlled by the motor control subsystem [2]. The power supply and motor control subsystem will be detailed further in the power subsystem and control subsystem sections. The initial requirements to deem our drivetrain subsystem successful and the verification process are shown in Table 4. These were the same requirements and verification process given in the proposal.

Table 4. Drivetrain subsystem requirements and verification process.

Requirements	Verification Process
Minimum Top Speed of 5 ft/s	This requirement can easily be verified with a tape measure and a timer. We can measure out a distance of 10 feet. Then with a timer, we can measure the amount of time it takes the battlebot to traverse the distance. If this time is less than or equal to 2 second, we have successfully fulfilled this requirement.
Minimum 0.1 ft-lbs torque per wheel	This requirement can be verified with a force gauge. The force gauge measures the force that is being pushed onto it. By fixing the force in a solid position, we will drive the battlebot into the gauge. Using the force gauge reading, we can calculate the torque at each wheel when considering that there are two wheels with a diameter of 3 inches. If the torque at each wheel is 0.1 ft-lbs, we have successfully fulfilled this requirement.

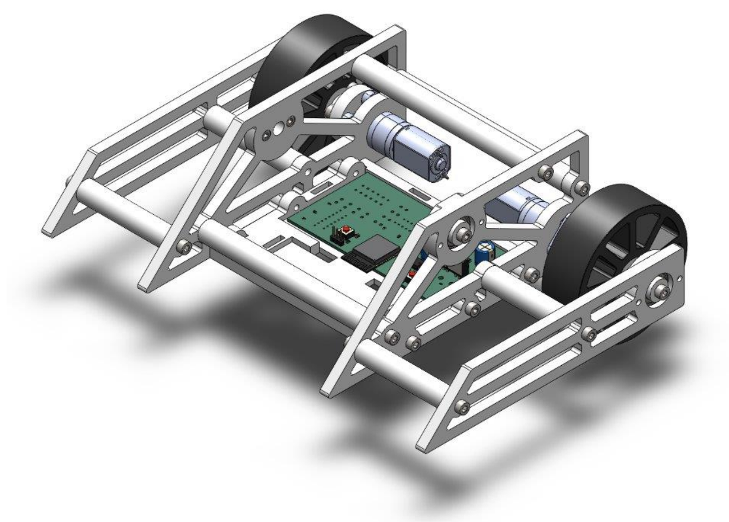

Figure 4. Drivetrain model.

2.4 Weapon Subsystem

The Lifter Prongs consists of 1 brushed motor that will be appropriately geared to provide at least 1.333 ft-lbs of torque. The 56 RPM Econ Gear Motor that we plan on using has 56 rpm and torque of 4.760 ft-lbs [3]. With a max theoretical torque of 1.33 ft-lbs and the motor supplying 4.760 ft-lbs this satisfies part of the third task in our high-level requirements. Calculations are detailed in Equations (7) and (8).

$$\text{Max Torque at Prong} = \text{Force*Arm Length} = 2 \text{ lbs} * 0.667 \text{ ft} = 1.333 \text{ ft-lbs} \tag{7}$$

$$\text{Total Time to Travel Full Prong Range} = \frac{\text{Arm Range (revolutions)}}{\frac{\text{Motor Revolutions}}{\text{Second}}} = \frac{0.5 \text{ revolutions}}{56 \frac{\text{revolutions}}{\text{minute}} * \frac{\text{minute}}{60 \text{ seconds}}} = 0.536 \text{ s} \tag{8}$$

The weapons system contains a lifting arm with the objective of lifting the opposing robot into the air. The lifting arms are made of two prongs. These prongs will lift the opposing battlebot. Additionally, they are used to flip our robot over in the event that we are flipped over. The 3D model of the weapon subsystem is provided in Figure 5. The maximum weight of the battlebots is two pounds so it is necessary to lift at least two pounds. We can approximately calculate the torque necessary by using the maximum weight of the opposing battlebot as well as our prong length, 8 inches. The lifting arms need to provide approximately 1.333 ft-lbs of torque. This higher demand for torque is the reason we use the 56 RPM Econ Gear Motor. This high torque brushed motor can provide up to 4.760 ft-lbs of torque [3]. Additionally, the prongs will be vulnerable to getting damage from lifting heavy weight and from the opposing battlebots weapon systems. For this reason, we 3D printed them with high infill. The motor weighs about 0.205 lbs each [3]. The total weight of the drivetrain subsystem with the lifting arms comes out to be around 0.3 lbs. The motors draw 11 volts and are controlled by the motor control subsystem [3]. The power supply and motor control subsystem will be detailed further in the power subsystem and control subsystem sections. The initial requirements to deem our weapon subsystem successful and the verification process are shown in table 5. These were the same requirements and verification process given in the proposal.

Table 5. Weapon subsystem requirements and verification process.

Requirements	Verification Process
	This requirement can be verified with a force

Minimum 1.333 ft-lbs torque at the lifting points	gauge. The force gauge measures the force that is being pushed onto it. By fixing the force gauge below the lifting arm, we will lower the lifting arm into the force gauge. Using the force gauge reading and the length of the lifting arm, we can calculate the torque. If the torque is 1.333 ft-lbs, we have successfully fulfilled this requirement.
Fully extended arm length and chassis length must be within 13” size limit	This can be verified using a ruler and measuring the dimensions of the battlebot with the arms fully extended.
Lifting mechanism must raise opponents a minimum 2 inches from ground	This requirement can be verified with a 2-pound load and a ruler. If the battlebot can lift the two pound two inches off of the ground, we have successfully fulfilled this requirement.
Must complete full deployment motion within 1 second	This requirement can be verified with a 2-pound load and a timer. If the battlebot can flip over the 2-pound load within a second, we have successfully fulfilled this requirement.
Self-righting capability must function when robot is flipped over	We will place the battlebot upside down. If we can get the battlebot to flip over using the lifting arms, we have successfully fulfilled this requirement.
Arms must withstand impact force of 20 N without structural failure	We can verify this requirement with a force gauge. We can press the force gauge against the lifting arm until the gauge reads 20 N. If the lifting arms can withstand the force without permanent deformation, we have successfully fulfilled this requirement.

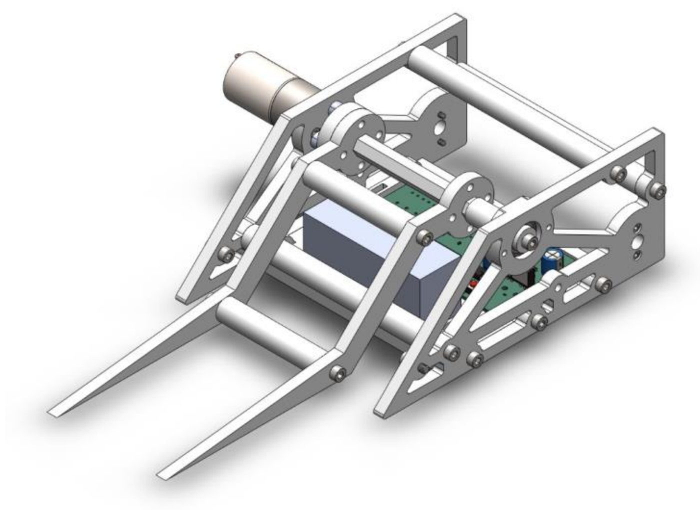

Figure 5. Weapon system model.

2.5 Power Subsystem

The power subsystem will distribute the 11V from the 3S LiPo battery to the motor controller and microcontroller. Initially, we only had to step down the voltage from 11 V to 3.3 V to be used in the STM32 microcontroller, HC-05 Bluetooth module, and DRV8952 H-bridges [6-8]. After making the switch to the ESP32 and L298N H-bridges, we now have to step down from 11 V to 3.3 V for the ESP32 and step down from 11 V to 5 V for the L298N H-bridge.

Additionally, we initially intended on using the LP2950CZ-3.3 voltage regulator to step down to 3.3 V [12]. During PCB testing, we realized that the ESP32 draws more current than the LP2950CZ-3.3 voltage regulator can provide [12]. The LP2950CZ-3.3 voltage regulator could output a max current of about 0.1 A and the ESP32, when connected to WiFi, draws around 0.5 A [12]. For this reason, we moved to the AZ1117CD-3.3TRG1 voltage regulator [13]. We use the BD50FC0FP-E2 voltage regulator to step down to 5 V [14]. With the 3.3 V regulator, we ran into heat dissipation issues. To help with the heat dissipation, we used a raspberry pi heat sink.

The power subsystem also contains a MOSFET and diodes to provide reverse polarity and over-current protection. A switch is utilized to turn on and manually shut off the system, which is one of the competition requirements. It is important that the microcontroller receives a steady power source, so it does not turn off randomly during the battlebot competition. Capacitors are used to provide smoother and more stable power to the microcontroller. A fuse is utilized to provide over-current protection. The final power subsystem PCB schematic is shown in Figure 6. The initial power subsystem PCB schematic is shown in Figure 7.

For the battery there were 2 choices, Lithium Ion (LiIon) and Lithium Powered (LiPo), that were considered, and we ultimately chose to go with the LiPo because of its higher discharge rate at the cost of lower power density. Under our expected power draw, Li-ion batteries that were capable of the discharge rate were also significantly heavier than a LiPo. The decision matrix for these batteries is shown in table 6.

Table 6. Battery decision matrix.

Battery Type	Power Density	Discharge Rate	Weight
LiIon			
LiPo			

The initial requirements to deem our power subsystem successful and the verification process are shown in table 7. These were the same requirements and verification process given in the proposal.

Table 7. Power subsystem requirements and verification process.

Requirements	Verification Process
Voltage regulation must maintain 3.3V ±5% for microcontroller under all load conditions	This requirement can be verified utilizing a multimeter. If the voltage at the voltage regulator output when operating the motors at different speeds is within 3.3V ±5%, we have successfully fulfilled this requirement.
Battery management system (BMS) must supply sufficient current to the robot for 2 mins	This requirement can be verified by running the robot and utilizing all subsystems. If the robot runs for the complete duration, we have successfully fulfilled this requirement.

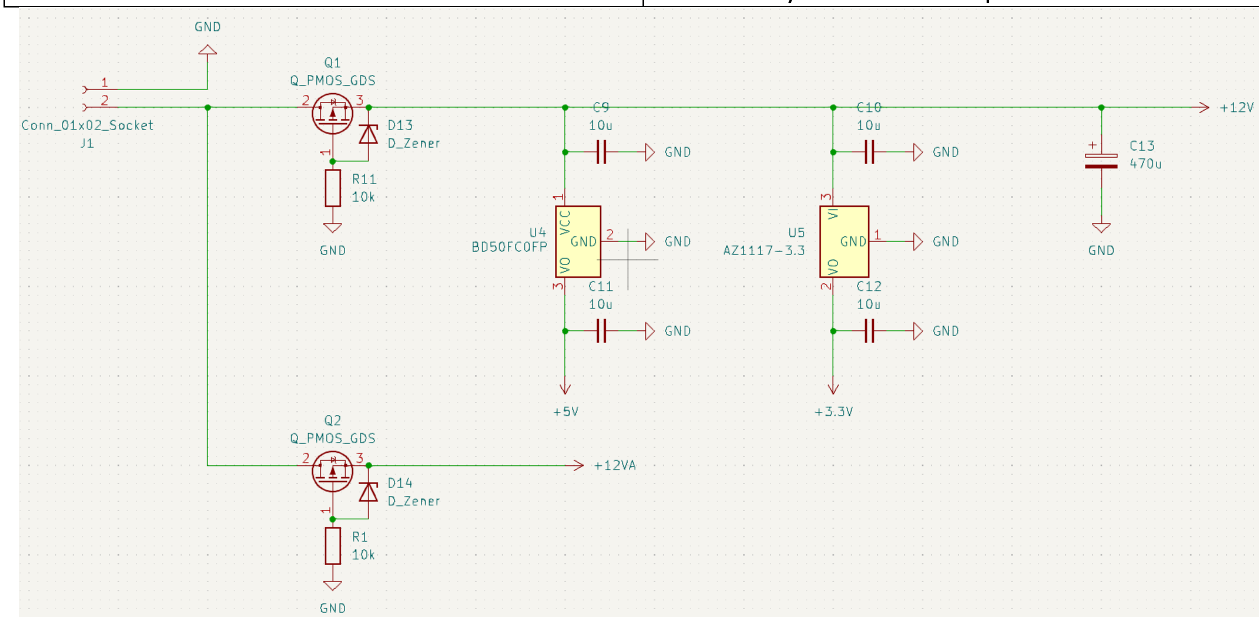

Figure 6. Final power subsystem PCB schematic.

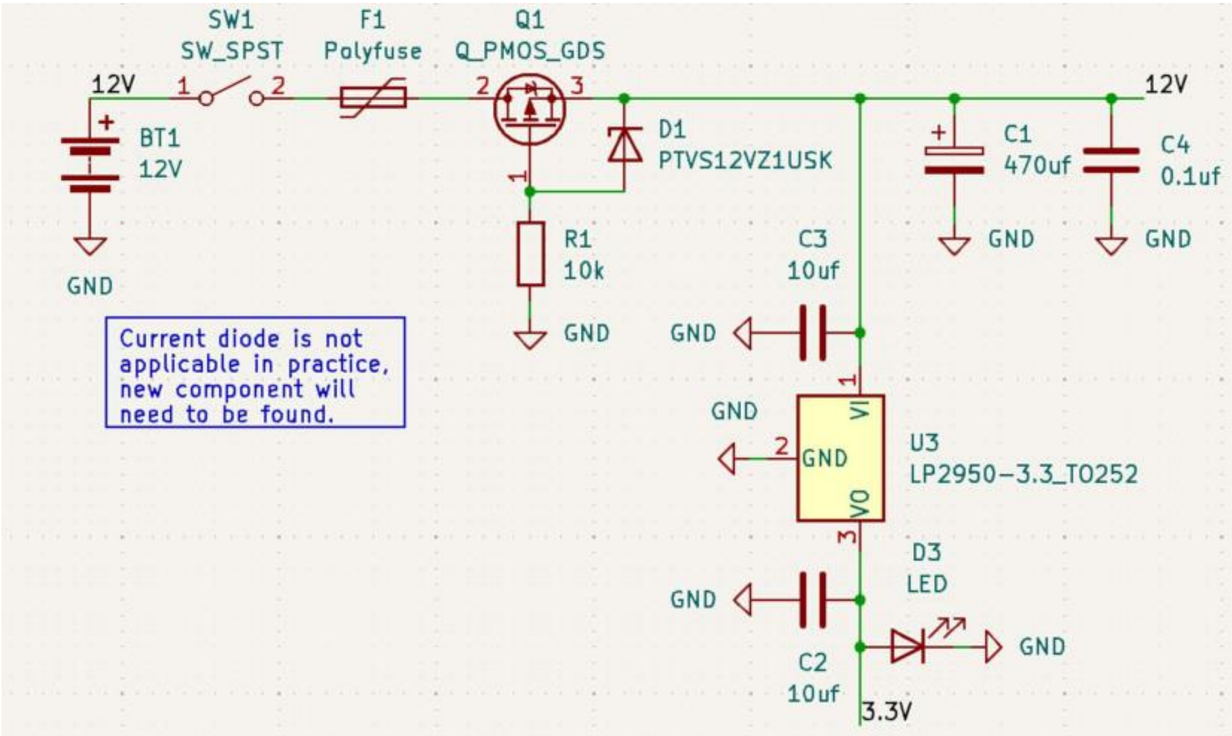

Figure 7. Initial power subsystem PCB schematic.

2.6 Control Subsystem

The control subsystem underwent many significant changes from our proposed design. Initially, we planned on using the STM32 microcontroller and the HC-05 Bluetooth Module. We were able to successfully program the STM32 microcontroller developer board and generate a PWM signal. We were also able to successfully control the STM32 via Bluetooth. However, we were not able to implement the 500ms automatic disconnect when the connection was lost. We were not able to generate a heartbeat signal through the bluetooth connection, which prevented the STM32 from knowing if there was any connection. For this reason, we were not able to detect when Bluetooth was connected or disconnected. This was the main contributor in switching from the STM32 to the ESP32. Another reason we decided to move away from the STM32 was due to the difficult of soldering the pins. The STM32 has very small pins making it difficult to solder, even through a baking process.

Additionally, we decide to use the L298N H-bridge instead of the DRV8952 H-bridge. We initially intended on using the DRV8952 H-bridge because it was rated to handle higher current output [8]. The lifter motors operate at a peak current draw of about 4 A [3]. The L298N H-bridge outputs maximum current of around 2 A but is much easier to use and implement [5]. Further into the project, we find that we can connect two L298N H-bridges in parallel to give a maximum output of 4 A which is enough for the lifter motors [5]. Due to the simplicity of the L298N H-bridge, we decide to use it over the DRV8952 H-bridge.

The interfacing of the microcontroller and H-bridges for the final design is shown in Figure 8. The interfacing of the microcontroller, H-bridges, and Bluetooth module for the initial design is shown in Figure 9.

The initial requirements to deem our control subsystem successful and the verification process are shown in Table 8. These were the same requirements and verification process given in the proposal.

Table 8. Control subsystem requirements and verification process.

Requirements	Verification Process
Bluetooth communication must maintain stable connection at 15-foot range	This can be verified with a measuring tape. When positioned 15 feet away from the motor, if the battlebot still operates properly, we have successfully fulfilled this requirement.
Emergency stop must trigger within 500ms of signal loss	This can be verified with a timer. After disconnecting the signal to the battlebot, if the battlebot shuts off within 500 ms, we have successfully fulfilled this requirement.
Motor controller can temporarily supply max stall current to the motors	This can be verified by stalling the motor on the robot for 2 seconds. Afterwards if the motor controller continues to power the motor after releasing the motor from the stall, we have successfully fulfilled this requirement.

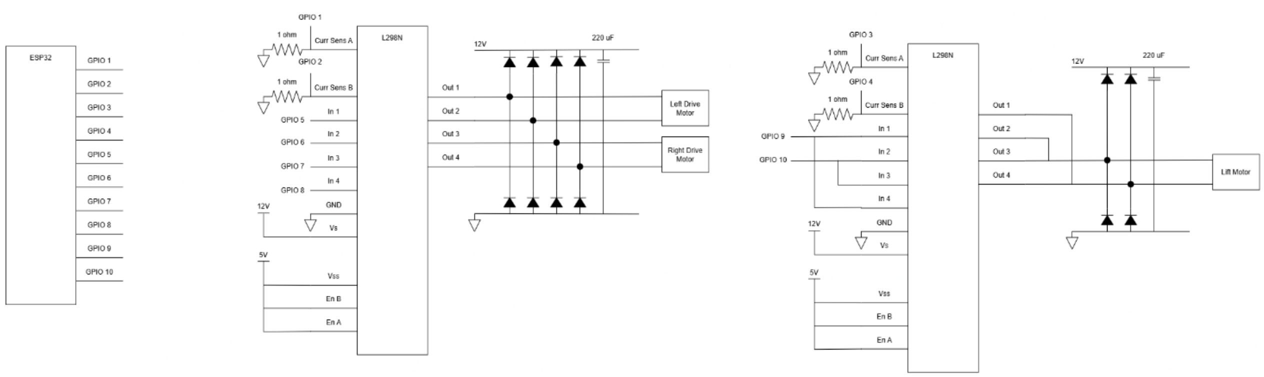

Figure 8. Final control subsystem PCB schematic.

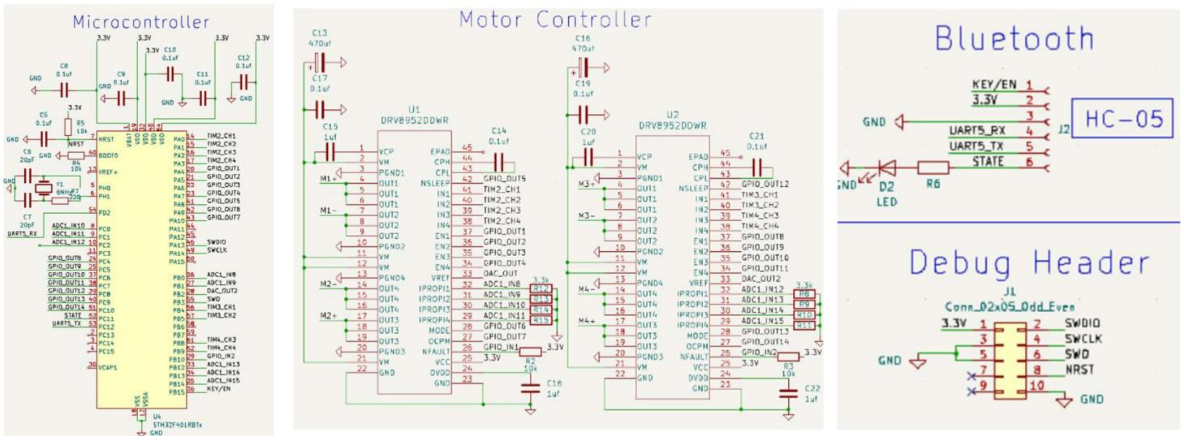

Figure 9. Initial control subsystem PCB schematic.

3. Design Verification

3.1 Power Subsystem Verification

The Power Subsystem was tested according to the requirements specified in Tables 7 and 12. The voltage regulation is tested using a multimeter connected to the 3.3V output while operating the motors at different speeds. The voltage remained stable at 3.3V±0.2%, well within our requirement of 3.3V±5%. The battery management system is tested by running the robot with all subsystems active for the full duration of a typical match (2 minutes). The 3S LiPo battery with 2200mAh capacity and 50C discharge rating provided sufficient power throughout operation without voltage sag.

A heat sink is added to the voltage regulator after initial testing revealed excessive heat generation during high-current operations. This modification improves the thermal performance and prevented potential damage to the PCB.

3.2 Control Subsystem Verification

The Control Subsystem is tested according to the requirements specified in Tables 8 and 12. The WiFi communication range is verified by operating the robot from various distances within the arena. We confirm stable operation at 15 feet, meeting our requirement.

The emergency stop functionality is tested by intentionally disconnecting the WiFi signal and measuring the time until the robot stopped all operations. The average emergency stop time is 138ms, well below our requirement of 500ms. This is achieved through a timer mechanism in the ESP32 code that continuously monitors the connection status.

The motor controller's ability to handle stall current is tested by deliberately stalling the motors and verifying that the controller continued to function afterward. All tests are successful, confirming the robustness of our design.

3.3 Drivetrain Subsystem Verification

The Drivetrain Subsystem is tested according to the requirements in Tables 4 and 12. We measure the top speed by timing the robot as it travels a measured distance of 10 feet. The average speed is calculated to be 5.32 ft/s, exceeding our minimum requirement of 5 ft/s.

The torque output is measured using a custom apparatus that allows us to press the motor output against a digital scale. The stall torque at each wheel is measured at 0.168 ft-lbs, which exceeds our minimum requirement of 0.1 ft-lbs.

3.4 Weapon Subsystem Verification

The Weapon Subsystem is tested according to the requirements specified in Tables 5, 6, and 12. The torque output at the lifting points is measured using a similar method as the drivetrain, resulting in a stall torque of 4.48 ft-lbs, significantly exceeding our minimum requirement of 1.333 ft-lbs.

The lifting mechanism is tested with a 2-pound weight to verify it could raise the load at least 2 inches from the ground. Various arm configurations are also tested, all successfully lifting the weight to the required height.

We also verify that the full deployment motion can be completed within 1 second, with an average deployment time of 0.86 seconds. The self-righting capability is confirmed by placing the robot upside down and activating the lifting mechanism to return it to an upright position.

Impact resistance is tested by applying a 20N force to the arms using a spring scale, with no structural failure observed.

4. Costs

The total cost of all the parts before shipping is $396.16, which can be seen in Table 9. Parts offered by the ECEB self-service shop are free. The total cost of labor for the entire team amounts to $27,250, which is calculated in the labor chapter later in this report. 3D printing was offered for free. We do not have any shop service costs. The total cost for the project is $27,646.16.

4.1 Parts

Table 9 Parts Costs

Part	Provider	Retail Cost ($)	Quantity	Total Cost ($)
MOSFET P-CH 60V 28A TO220F-3SG	Self-Service Shop	$0.00	4	$0.00
Resettable Fuse 16R400GU	Self-Service Shop	$0.00	8	$0.00
Ceramic Capacitors (2 pF, 0.1 uF, 1uF)	Self-Service Shop	$0.00	68	$0.00
Tantalum Capacitors (10 uF)	Self-Service Shop	$0.00	8	$0.00
Electrolytic Capacitor (470 uF)	Self-Service Shop	$0.00	12	$0.00

Resistors (220 Ohms, 10k Ohms)	Self-Service Shop	$0.00	28	$0.00
Diode	Self-Service Shop	$0.00	72	$0.00
L298N Motor Driver	Self-Service Shop	$0.00	8	$0.00
AZ1117CD-3.3TRG1	Amazon	$4.99	8	$39.92
BD50FC0FP-E2	Amazon	$4.99	8	$39.92
3S Lipo Battery 2200mAh 11.1V 50C	Zeee Battery	$38.99	1	$38.99
Lipo Charger	Amazon	$36.99	1	$36.99
508 RPM Mini Econ Gear Motor (638402)	ServoCity	$14.99	3	$44.97
56 RPM Econ Gear Motor (638348)	ServoCity	$14.99	2	$29.98
1314 Series Steel Set-Screw Hub (1314-0016-0004)	ServoCity	$5.99	3	$17.97
WD Bearing (WCP-0776)	West Coast Productions	$2.99	6	$17.94
M2 M3 M4 M5 Nuts and Bolts set	Amazon	$24.99	1	$24.99
Wheels (am-3946_blue)	AndyMark	$11.25	2	$22.50
ESP32	Amazon	$8.00	5	$40.00
Wago Connectors	Amazon	$4.00	7	$28.00
Screws	Amazon	$0.50	20	$10.00
Heat Sink	Amazon	$3.99	1	$3.99
Total				**$396.16**

4.2 Labor

We used Equation (9) to calculate labor costs for each team member. The calculated labor costs are given in Table 10. The weekly schedules of group members contributions to the project are given in Table 11.

$$\text{Deal Salary}\left(\text{Hourly Rate}\right) \times \text{Actual Hours Spent} \times 2.5 \qquad (9)$$

Table 10. Labor costs.

Team Member	Hours spent	Hourly Rate	Total Labor Cost ($)
Praman Rai	100	$35	$8,750
Batu Yesilyurt	100	$35	$8,750
Anthony Shen	100	$35	$8,750
Self-Service Shop	8	$50	$1,000
Total			**$27,250**

Table 11. Weekly team member schedules.

Week	Anthony Shen	Praman Rai	Batu Yesilyurt
2/3	Project Approval	Project Approval	Project Approval
2/10	Project Proposal	Project Proposal	Project Proposal
2/17	Initial 3D design	Initial PCB Research & Design	Test Breadboard Demo Components
2/24	Mechanical Component	Component Selection &	Design Doc

	Selection	Schematic Capture	
3/3	Revise 3D design	Full Schematic Design & PCB Layout	Breadboard Demo STM32 Programming
3/10	Determine weight and verify rule compliance	Breadboard Prototype & ESP32 Decision	Breadboard Demo STM32 Programming
3/17	SPRING BREAK	SPRING BREAK	SPRING BREAK
3/24	Revise 3D design for 1 motor	ESP32-based PCB Design (Rev 2)	Debugging Power Subsystem PCB
3/31	Create sample code to test dev board	PCB Testing & Rev 3 Planning	Debugging Power Subsystem PCB
4/7	3D Print V1	ESP32-based PCB Rev 3 Design	Soldering/Debugging first complete PCB
4/14	Soldering/Debugging first complete PCB	PCB Rev 3 Assembly & Testing	Soldering/Debugging first complete PCB
4/21	PCB Rev 4 Assembly & Final Testing	PCB Rev 4 Assembly & Final Testing	Soldering/Debugging final PCB
4/28	3D Print V2	Final Demo Preparation & Lift Motor Repair	Soldering/Debugging final PCB
5/5	Competition	Competition & Final Documentation	Presentation /Final Paper

5. Conclusion

5.1 Accomplishments

Our simple yet effective battlebot design proved to be competitive in the battlebot competition. Our battlebot ended up winning the competition, successfully defeating a pneumatic lifting battlebot in the first round and then defeating a spinning robot in the final round. The high mobility offered by our battlebot gave us an advantage over the pneumatic lifting battlebot. We were able to maneuver around the battlebot and flip it over. Against the spinner battlebot, we demonstrated the defensive capabilities of our design. The spinner battlebot was equipped with a shell that would spin at very high speeds. In the previous round, the spinner battlebot destroyed its opposing battlebot when they came into contact. When we were matched up against the spinner battlebot, we were able to use our speed to get the opposing battlebot quickly before it started spinning at a high speed. Our tough frame was able to come into contact with the opposing battlebot without being ripped apart and we succeeded in flipping the opposing battlebot over.

5.2 Uncertainties

Although our battlebot performed well during the competition, there are some features we were unable to implement into the battlebot. We were not able to 3D print with ABS, instead we printed our battlebot with PLA. ABS provides multiple advantages over PLA such as lighter weight and more durability. While our battlebot performed well during the competition, long-term durability testing would be beneficial to determine if material fatigue would become an issue in extended use. The lifting mechanism's axis point is particularly susceptible to wear and could benefit from reinforcement in future iterations.

Additionally, we were not able to implement analog inputs from a controller joystick. We control the battlebots' movement and lifter weapon through a keyboard. Using a controller joystick with analog inputs gives us more controllability over the battlebots speed. This would have allowed us even better maneuverability during the competition.

5.3 Ethical and Safety considerations

To make our battlebot, we had to use 3D printers and soldering equipment. To stay safe while soldering, we used proper soldering lab procedures. These safety precautions include PPE, safety glasses, maintaining a clean/organized environment, checking equipment before use, and working with a lab partner. We also followed proper procedure when 3D printing. Although 3D printers aren't necessarily dangerous, they can be fragile. By following standard operating procedure, we ensured safety for ourselves and the 3D printer. Our ability to maintain lab safety reflects the IEEE Code of Ethics [11]. (IEEE Code of Ethics I.1)

Safety is essential and a serious concern when it comes to battlebots. Battlebots are designed to damage each other. In most cases, these battlebots can just as easily hurt people. We equipped our battlebot with manual and automatic disable. This allows us to shut off the battlebot if we lose control of it or if we lose connection to it. We also safely operated the 11V 3s LiPo battery. If shorted or damaged, these batteries can catch on fire [13]. We followed the detailed safety precautions for LiPo batteries that can be found in reference 13 [13]. We thoroughly tested our battlebot in a controlled environment before the competition to make sure everything is operating properly. Our goals to maintain a safe environment reflect the IEEE Code of Ethics [12]. (IEEE Code of Ethics I.1)

In other battlebot competitions, there have been lots of cheating scandals. We followed all the rules for the competition. Multiple times throughout the design process, we checked the rulebook to ensure that our battlebot met all of the competition criteria. Our goals to honor integrity reflect the IEEE Code of Ethics [11]. (IEEE Code of Ethics I.1)

Beyond the IEEE Code of Ethics considerations already mentioned, our project also upholds the ethical principle of educational value. The battlebot design process promotes STEM education by providing hands-on experience with electrical and mechanical engineering concepts, encouraging innovation while maintaining safety standards. We carefully considered the balance between competitive performance and safe operation, ensuring our design would not pose hazards even if control systems failed.

5.4 Future work

Some possible future work to improve our battlebot design is to utilize sensors to automate some of the battlebots functionality. In some moments throughout the competition, we were able to get the lifting arm under the opposing robot but we did not react quickly enough to raise the lifting arm to flip the opposing battlebot over. With a sensor on the lifting arm, we could detect when the lifting arm is under a battlebot, and automatically flip the opposing battlebot over. This would eliminate the delay from the drivers reaction time. Additionally, we could use the current sensing from the H-bridge to prevent any damage to the lifting motor. During testing, we had sheared the gears inside of the lifting motor when we were operating the motors at stall current. To prevent this, we can use the current sense from the H-bridge to detect when the motors are at stall current. This would allow us to stop the lifting motors once they are at stall current to prevent any unwanted damage. Though the PCB and our program supports this functionality, we were unable to execute it as we were unable to acquire the 0.5 Ohm resistors needed for current sensing.

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Appendix A Requirement and Verification Table

Table 12. System Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
1. WiFi remote control of the robot within at least a 15 ft range	We tested the WiFi control range by operating the robot from various distances within the arena. We confirmed stable operation at 15 feet.	Y
2. The robot should drive at a speed of at least 5 ft/s	We measured the speed by timing our battlebot as it traveled a measured distance of 10 feet. The average speed was 5.32 ft/s.	Y
3. The lifter weapon should be capable of lifting at least 2 lbs	We verified this by successfully lifting a 2-pound weight with the lifter mechanism to a height of 2 inches from the ground	Y
4. The robot should automatically disable within 500 ms of connection being lost	We intentionally disconnected the WiFi signal and measured the time until the robot stopped all operations. The average emergency stop time was 138 ms.	Y
5. The robot should have self-righting capability	We placed our battlebot upside down and confirmed it could flip itself back over using the lifting arm mechanism.	Y
6. The lifting arm should withstand impact force of 20 N without structural failure	We tested by applying 20 N of force with a spring scale against the lifting arm, and observed no structural failure or permanent deformation.	Y