ECE 445

Fall 2024
Senior Design Project Proposal

Antweight Battlebot Combat Robot

Team 2
Jeevan Navudu, Keegan Teal, Avik Vaish

TA: Jason Zhang

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1. Introduction

1.1 Problem

In order to compete in Professor Gruev's robot competition, there are many constraints that need to be met, including:

- Maximum weight (2 lbs)
- Allowed materials (3D-printed thermoplastics)
- Locomotion system and fighting tool
- Wireless control via Bluetooth or Wifi

The main goal of this competition is to design a Battlebot that is capable of disrupting the functionality of the other Battlebots with our fighting tool while maintaining our own functionality.

1.2 Solution

To compete in the competition, we plan to build a 2lb robot that will have two main systems, drive and weapon. The drive will utilize 4 tank-style wheels, two on each side with a motor to power each set. The motor will either have a belt or tangential style (the motor shaft is touching the outside of the wheel and uses friction to spin the wheel) to drive the front wheel. There will then be another belt from the front wheel to the rear wheel that will ensure that each wheel on both sides are powered. This will help us in the case where one wheel gets disabled, we would still have three others that will work. The weapon will be a drum-style weapon that utilizes a hub motor that will be press-fit into the spinning weapon. Each of the motors will have its own individually-controllable ESC. We are currently expecting the weapon to have a max peak draw of 30A while the drive motors will have a max peak of 15A. These ESCs will be controlled by a central ESP32-S3 microcontroller. We will utilize the on-chip Bluetooth module to connect to our computer to send commands so that we can control our robot.

1.3 Visual Aids

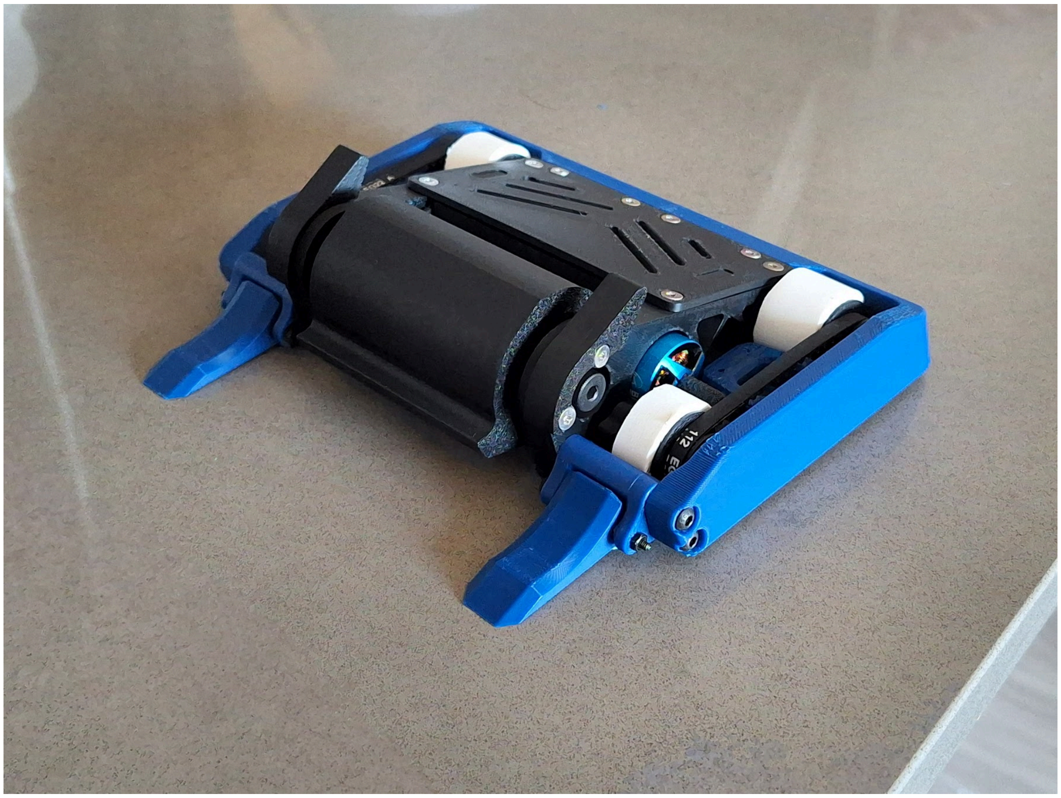

Figure 1: Sample Robot made for UIUC DPD Competition

Above is a picture of a robot made by Matthew Zhang, an UIUC Alumni, who competed in the DPD competition here at UIUC. Although his robot is a 1 lbs robot, we can utilize design ideas present in his robot and scale them up in size to our 2 lbs robot. Some specific ideas we plan to use are the way that he drives his wheels with a friction drive system, and the embedded motor in his weapon. These all allow the system to be simpler and lighter so we can invest more weight in the structure of the robot.

1.4 High-Level Requirements

1. The robot should have an acceleration of at least 1.5 m/s^2 so that we can move from any point in the arena to another in under 2 seconds, assuming a 3m arena.
2. The weapon should have a maximum tip speed of at least 150 mph and should be able to recover to that speed within 5 seconds after a collision.
3. The robot upon powering up should be able to pair with the computer in under 15 seconds and should be able to respond to a command within 100ms of a user input.

2. Design

2.1 Block Diagram

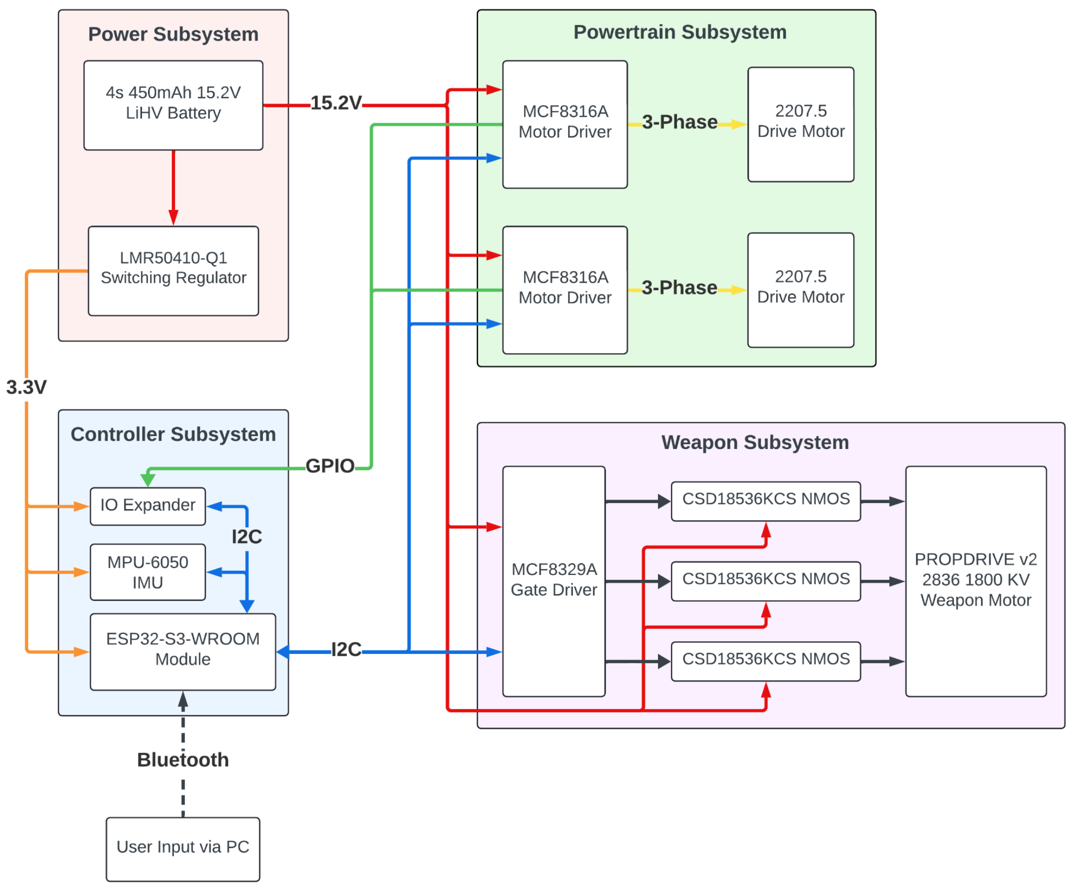

Figure 3: High-Level Block Diagram for Robot

2.2 Electronic Subsystems and Requirements

2.2.1 Power Subsystem

<u>Description and Purpose:</u>
The power subsystem is in charge of powering the robot for the duration of the match. The robot will utilize 3 different voltages: 16V, 5V, and 3.3V. 16V will provide power to the motors and the

ESCs. 5V and 3.3V will be used for all the low power electronics such as the microcontroller and other sensors and chips we have on the robot. We will use a switching regulator (buck converter) to reduce the battery voltage to 5V and 3.3V. We chose a switching regulator over a linear regulator because we do not want to dissipate too much power into heat on our PCB.

Buck vs Linear Regulator Power Dissipation:
$P_{linear} = (V_{in} - V_{out}) * I = (16V - 3.3V) * 350mA = 4.45\,W$ dissipated
$P_{buck} = P_{out}/E - P_{out} = 3.3V(350mA)/0.9 - 3.3V(350mA) = 0.128\,W$ dissipated

For the cells, we have looked into using a 4s 450mah LiPo made by Gaoneng from Amazon. The small form factor of a LiHV and high discharge rate make this the best type of battery for this use case. The battery claims to have a 80C/160C discharge rate which would mean it can continuously supply 36A with a peak of 72A. Based on our expectations from the motors, this should be sufficient to power our robot and not be the limiting factor for performance.

Interactions: This subsystem interacts with every other electrical subsystem by providing power to them, from the microcontroller to the motors.

Requirements:
1. Provide 10 A average/continuous current.
2. Provide 40 A peak current for the motors.
3. Provide stable 5V and 3V3 for the microcontroller.

2.2.2 Controller Subsystem

Description and Purpose:
The controller subsystem includes the MCU and the sensor package. The MCU will be an ESP32-S3 which has an internal Bluetooth module that can communicate with an external controller. This external controller will be able to control the robot but can also display live metrics of the car such as the robot acceleration, motor speeds, and battery supply. The sensor package will include an IMU (MPU-6050) to measure the lateral acceleration of the robot and a shunt resistor with an ADC to measure the current draw and battery capacity, as well as any IO expanders we might need to cover GPIO inputs the ESP32 doesn't provide.

The MCU will be communicating over I2C to all the external chips, such as the ESCs and IMU, and will also be communicating over Bluetooth. It will also be running our closed-loop control algorithm for the motors and BMS code to monitor the battery. This may require a simple operating system where we have a priority queue with tasks based on interrupts from the Bluetooth controller.

Interactions: The microcontroller is powered by the power subsystem and is used to control the drivetrain motors and the weapon motor. It will also communicate with the controller over Bluetooth

Requirements:
1. Provide stable and responsive Bluetooth connection
2. Read IMU sensor data to validate high level acceleration requirements.
3. Measure current drawn from the battery with 0.5A tolerance.

Expected Communication Protocols:
- Bluetooth (ESP32-S3 to Controller)
- I2C bus for ESCs
- I2C bus for IMU and IO Expanders

2.2.3 Powertrain Subsystem

The powertrain subsystem will consist of 2 ESC motor controllers and 2 Motors, but does not include the wheels or weapon. The motor controller will be TI's MCF8316A chip. This chip can receive either an I2C communication or PWM signal to control the speed of the motor. It is able to drive the motor with 3 phase AC current using a Field-Oriented Control (FOC) and current sensing, They are limited to 8A, which is why they are connected to the drive motors. The drive motors require a lot less amperage than the weapons motor, and while their peak current draw is higher than 8A, 8A continuous should suffice for our acceleration requirements. The ESCs are powered off the 16V power supply and draw as much current as necessary to supply the correct amount of 3-phase current to spin the motors at the desired speed.

Interactions: The powertrain communicates with the microcontroller to receive the speed commands, and it's powered by the power subsystem. It also interacts with the mechanical drivetrain subsystem.

Requirements:
1. Communicate over I2C to the MCU to provide proper current to the motors.
2. Be able to send speed data back to MCU for closed loop response.

Current Parts:
ESCs - MCF8316A (communicate to controller via I2C)
Drive Motors - Repeat Tangent Drive 2207.5 Motor (1800 KV)

2.2.4 Weapon Subsystem

Description and Purpose:
The weapon subsystem will consist of a single BLDC motor that is mounted to the weapon drum, as well as an ESC to control the speed of the weapon. Since we plan on having a powerful and high current-draw motor, we cannot use the same all-in-one BLDC motor driver as our drivetrain motors. To achieve a higher maximum current, we will be making a 3-phase motor driver using MOSFETs and a gate driver module. The gate driver module will be TI's MCF8329A chip, which also uses Field-Oriented Control (FOC) to drive the gates of 3 half-bridges, one for each phase of our motor. The half-bridges will be using CSD18536KCS NMOSs, which are rated for 200A, more than enough current for our weapon motor. The gate driver will be controlled by our MCU over I2C, similar to the drivetrain motor drivers. The motor itself will be powered off of our 16V LiHV battery via the NMOSs, with the gates driven by the gate driver.

Interactions: This subsystem is commanded by the MCU and is powered by the power subsystem. It also interacts with the mechanical weapon subsystem.

Requirements:
1. Communicate over I2C to the MCU to provide proper current to the motors.
2. Provide up to 40 A to the weapon motor in 3 phase current.

Parts:
Weapon Motor - PROPDRIVE v2 2836 (1800 KV)
Gate Driver - MCF8329A (communicate to controller via I2C)
NMOS Gates - CSD18536KCS (200A, 60V)

2.3 Mechanical Subsystems and Requirements

2.3.1 Chassis Subsystem

Description and Purpose:
For the chassis, we plan to 3D print a single piece for the main compartment which will house the custom ESCs along with the 4s battery. There will be mounting points on the left and right sides for the drive motors along with mounting points on the front that will support the weapon. To protect the wheels, we will have extra 3D printed parts on each side that will act as armor. We will also have little forks on the front whose job is to get under the opponents and help get a bigger bite with our weapon. We are currently planning on using Super PLA+ to print our chassis.

Interactions: This subsystem will be responsible for mating all the other subsystems together. The weapon subsystem will be mounted to the front, while the drive subsystems will be mounted on either side. This will also house all of the electronics, and fully enclose them while still allowing a few holes so that airflow can help keep the electronics cool.

Requirements:
1. The chassis must be able to house and properly mount all electronic components.
2. Have adequate rigidity and protection to survive impacts with other robots and the arena.

2.3.2 Weapon Subsystem

Description and Purpose:
The weapon will be a single tooth drum style weapon with an effective diameter of about 60mm. The benefit of a single tooth is we would be able to increase the amount of contact area on the weapon tooth to be able to transfer the most amount of energy to ultimately throw the opponents into the air. We plan for most of the damage to be done to the other robot from falling and hitting the ground compared to direct damage from our weapon.

Interactions: This subsystem will be attached to the front of the chassis and also will be providing airflow to the rest of the electronics which will be mounted right behind it.

Requirements:
1. Minimum bite surface distance of at least 2mm during impact
2. Be structurally strong enough to make impact multiple times without breaking but chips on the weapon tooth are expected.
3. The weapon should be able to reach a tip speed of 150 mph and maintain that speed for 2 minutes.

2.3.3 Drivetrain Subsystem

Description and Purpose:
The Drive will be a 4 wheel drive that operates on a tank style steering system. This is where one side will be faster than the other which allows the robot to turn. The drive will be powered in a unique way where the motor will have a custom knurled sleep on the shaft and will rub against the outside of the front wheel which will make the wheel spin. The front wheel will then be belted to the rear wheel using a HTD3 belt.

Interactions: This subsystem will be in charge of moving the robot, either evading the opponents attacks or driving towards them with our weapon to inflict damage. The drivetrain will have two pods that are attached to either side of the chassis.

Requirements:

1. The drive system should be able to drive the robot at a minimum of 1.5 m/s^2.
2. It should also be able to drive while the weapon is spinning and the robot is upside down.

2.4 Tolerance Analysis

2.4.1 - Drive System

For our drive system, we are planning on using tangential drive motors, which means that the motor output shaft will be tangential to the tire. This allows us to perform a gear reduction from the motor to the wheel. Our estimated motor shaft diameter is 7mm, and our estimated wheel diameter is 25mm. To meet our acceleration requirements, the drive motors must be able to drive the robot at 3 m/s. We found this by taking our minimum acceleration, which is 1.5 m/s^2 and multiplying by our estimated maximum drive time, which is 2 seconds.

For a 3 m/s robot speed, we need to find the minimum RPM of our motors:

$$\frac{3m}{0.025m \cdot \pi} = 38.2\, RPS \cdot 60\, s/min = 2291.82\, wheel\ RPM \cdot \frac{0.025m}{0.007m} = 8186\, motor\ RPM$$

Our motors have a 1800 KV rating, which means that for every 1V increase, their RPM will increase by 1800 RPM. Therefore, we need to drive our motors at 8186/1800 = 4.548V, which is lower than our battery supply voltage of 16V, and lower than our BLDC driver rating of 40V.

2.4.2 - Weapon System

For our weapon system, we have a requirement that our maximum tip speed is at least 150 mph (67.056 m/s). To achieve this, we need to calculate what KV rating we need on our motor. Our estimated weapon diameter is 60mm and our battery voltage is 16V.

$$\frac{67.056m}{0.060m \cdot \pi} = 355.74\, RPS \cdot 60\, s/min = 21344.59\, RPM \cdot \frac{1}{16V} = 1334\, KV$$

Our minimum motor spec is 1334 KV and our chosen motor exceeds that spec with 1800 KV, so we will be able to meet our minimum weapon speed requirement.

2.4.3 - Power System

For our robot, one of the main high level requirements as well as the competition requirements is the requirement that the robot drive continuously for 2 minutes while having peak acceleration of 1.5 m/s/s and a motor tip spinning at 150mph. All of this leads to massive current draws that will deplete our battery.

Drive Motors Power Consumption:
The motor we chose doesn't have a datasheet or many specs, but based off our ESCs we are using to control the motor, we can have some baseline power calculations:

Assuming highest power factor of 1, continuous current of 1.5A, and peak voltage of 16V:

$$P_{tot} = N_{motors} * \sqrt{3} * PF * V * I = 2(motors) * \sqrt{3} * 1 * 16V * 3A = 83.138\,W$$

Weapon Motor Power Consumption:
Assuming a continuous current draw of the motor at 10A running 25% of the time at 16V:

$$P_{tot} = 0.25 * \sqrt{3} * PF * V * I = 0.25 * \sqrt{3} * 1 * 16V * 10A = 69.282W$$

Controller Subsystem Power Consumption:
Given all the different components we may have on the PCB, one of the biggest current draws is the ESP32 MCU at 350mA. Other components such as the IMU and potentially the IO expander, we can assume a max current draw of 150mA.

$$P = V * I = 3.3V * 500mA = 1.65W$$

Given that buck converters operate at 90-95% efficiency and we want the power draw from the battery:

$$P_{out} = P_{in} * Efficiency \;{-}{>}\; 1.65W/0.9 = 1.833W$$

The battery cells have a maximum capacity of 450mAh at 4V:

$$E_{total} = V * C_{cell} = 16V * 450mAh = 7.2\,Wh$$

Total Power Draw:

$$1.833W + 83.138W + 69.282\,W = 154.253\,W$$

Given a Tolerance of 30 sec, we can calculate the max power draw:

$$T_{max} = \frac{E_{total}}{P_{total}} = \frac{7.2Wh}{154.253W} = 2.8\, minutes$$

Which gives us 48 seconds of tolerance.

C-rate Tolerance:
While the robot will most likely be running on continuous current ratings from the motors, there are times that the motors will be drawing peak current.
Drive Motor Peak Current: 8A
Weapon Motor Peak Current: 40A
Electronics Peak Current: 500mA

$$I_{peak} = 8A + 8A + 40A + 0.5A = 56.5A$$

$C_{rate} = \frac{56.5A}{450mAh} = 125.55\, C$ which is under the cell's maximum C-rate of 160. Running at peak current gives us a time constraint of around 30 seconds.

Overall, the cells have the capacity to last 2 minutes in the competition given our estimated continuous current draws, and the cells can handle peak current draws, as well, in the instances when they occur.

3. Ethics and Safety

3.1 Ethics

As outlined in Section I of the IEEE Code of Ethics [1], we will be disclosing any factors that could pose a risk to the public or the environment, as ensuring safety is of the utmost priority. One of the major risks our robot poses is having a lethal weapon that can harm humans. It's our responsibility to only turn on the robot during competition settings in the allowed zones or in contained testing environments.

In line with Sections II and III of the Code, we will value every team member's ideas and contributions to create a collaborative environment. That means having honest conversations about if people feel neglected and having weekly meetings to make sure we are all on the same page. This will create a positive and reinforced environment where everyone can learn and grow.

3.2 Safety

With such dangerous robots, safety is the utmost priority. We will follow safety procedures similar to that of other competitions. First we will never power the robot when it's not inside of a safe and approved test box. This ensures that no body part of ours is in the way of the spinning weapon. Second, we will follow the standard protocol for turning on the robot when entering the arena/test box.

1. Place robot inside of test box
2. Turn on the transmitter/computer
3. Turn on the robot
4. Ensure robot is connected to transmitter/controller and that robot does not have any motors that are actively trying to spin
5. Remove the mechanical weapon stop
6. Close arena doors
7. Move robot to check functionality

By following these procedures, we should be able to create a safe environment while also testing our robot. Our procedures are based on NHRL (combat robotics competition) procedures [2].

Our competition spec also contains some specific safety-related rules that we must implement:

1. If WiFi or Bluetooth connection is lost between the robot and PC, the robot will automatically go into shutdown mode: it will stop moving and the fighting tool will stop rotating.
2. All electrical power to fighting tools and drive systems must have a manual disconnect that can be activated within 15 seconds without endangering the person turning it off.
3. Robots must have a light easily visible from the outside of the robot that shows its main power is activated. You should also add a secondary light to indicate operational Bluetooth or WiFi connection.
4. Spinning blade must come to a full stop within 60 seconds of the power being removed using a self-contained braking system.

4. References

[1] IEEE. ”IEEE Code of Ethics.” (2024), [Online]. Available: https://www.ieee.org/

about/corporate/governance/p7-8.html (accessed Sep. 19, 2024).

[2] “Safety,” NHRL, https://wiki.nhrl.io/wiki/index.php/Safety (accessed Sep. 19, 2024).