ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

Antweight Battlebot

Team #9
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1. Introduction

1.1 Problem

The world of combat robots is almost always in a setting where you and your opponent compete within a restricted time limit and where the winner is whoever's robot remains standing in the arena or whoever has scored higher in the judges' eyes. Like in wrestling, these robots are categorized by their weight bracket. From 75 gram flea-weights all the way to the 250 pound heavy-weights seen on television, each bracket comes with their own considerations such as materials, costs, and electronics. Professor Gruev's robot competition lies within the 2 pound antweight bracket and our goal is to come up with a robot that is strong and reliable enough to defeat our opponents' robot within the professor's limitations. In this case, the robot must follow these restrictions:

1. Has to be less than 2lbs
2. Must be 3D printed using these materials: PET, PETG, ABS, or PLA, PLA+
3. Will have to be controlled from a PC via Bluetooth or Wi-Fi
4. Must have a fighting tool and be able to move
5. Easy manual shutdown (Power switch)

1.2 Solution

Our solution is to create a robot (under 2 lbs) that consists of four wheels (2 on either side) for drive and motion as well as a vertical spinning disk as our fighting tool. A 3d printed chassis will be used to house the electronics and safeguard against our opponents. The robot will be driven wirelessly using Bluetooth from a PC and will also have a power switch for manual shutdown.

1.3 Visual-Aid

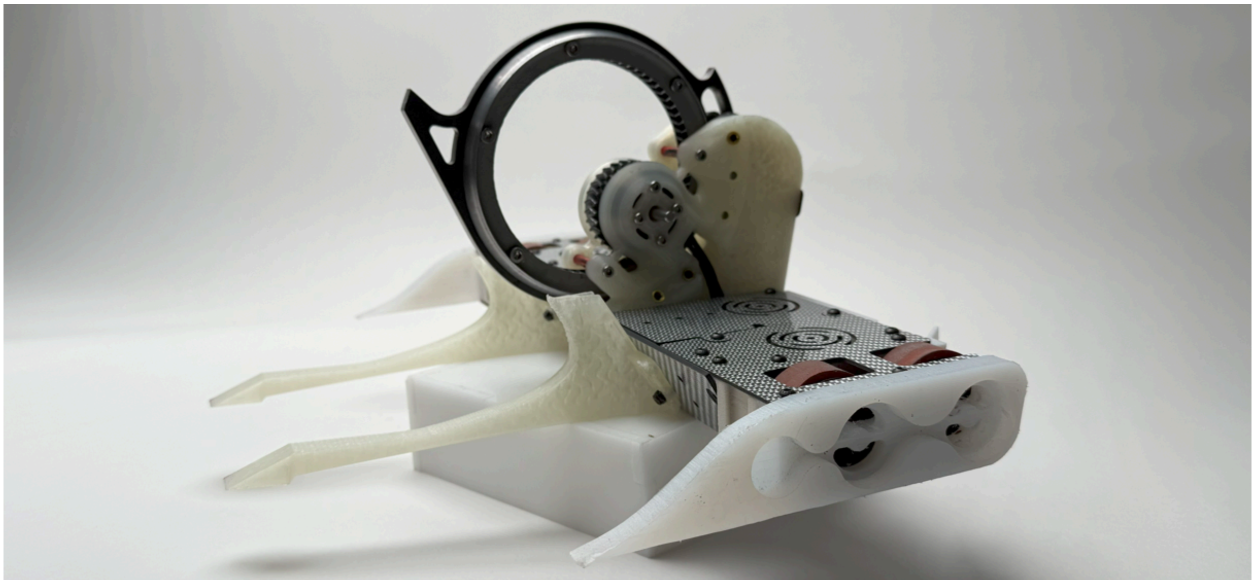

Figure 1: Example of a 4-wheel drive system with a vertical spinning fighting tool.

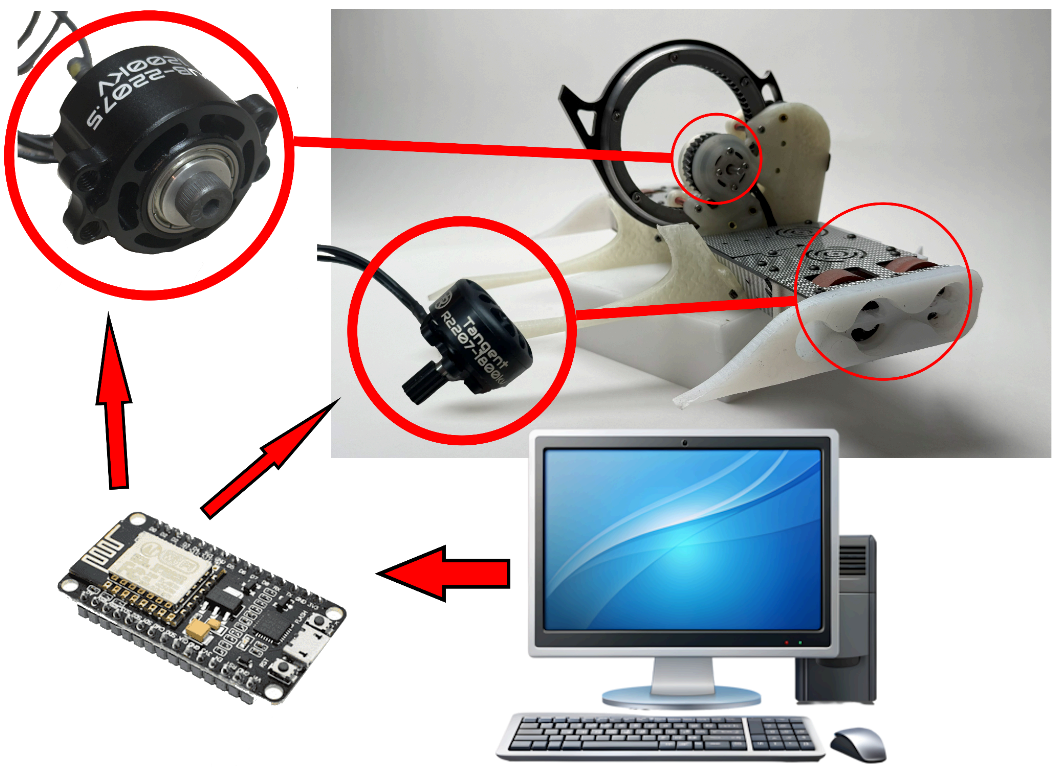

Figure 2: High-level overview: The computer sends controls (ex. go forward) to the ESP32 module via Bluetooth, which then sends the corresponding PWM (pulse width modulation) signals required to tell the motor drivers to rotate.

1.4 High-Level Requirements

1. **Top Speed:** Given a 10-foot by 10-foot arena and the fact that the robot will weigh no more than 2lbs, we will focus on maximum speed since acceleration is typically not an issue. We will aim for a speed of 20 miles per hour (mph)
2. **Weapon Tip Speed:** Typical combat robots of similar caliber (3 pounds) have tip speeds averaging 150-300 mph (The speed at which the weapon's outermost radius spins at). We will aim to reach a maximum speed of around 200 mph.
3. **Latency**: The robot in an ideal world should have as little latency as possible within our control. Trying to reduce latency between the PC and giving commands to the robot via Bluetooth is crucial for an effective combat robot. We will aim for an input delay from the PC to the robot of no more than 1000 milliseconds.

2. Design

2.1 Block Diagram

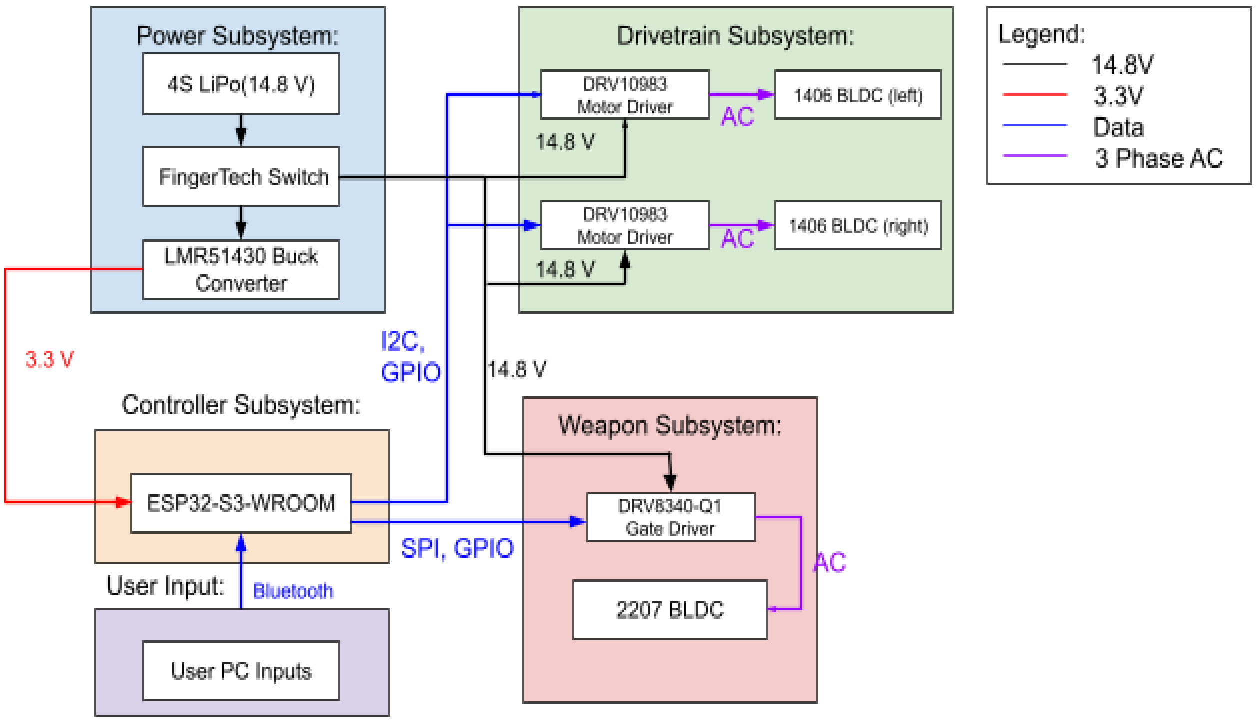

Figure 3: Block Diagram of Design.

2.2 Physical Design

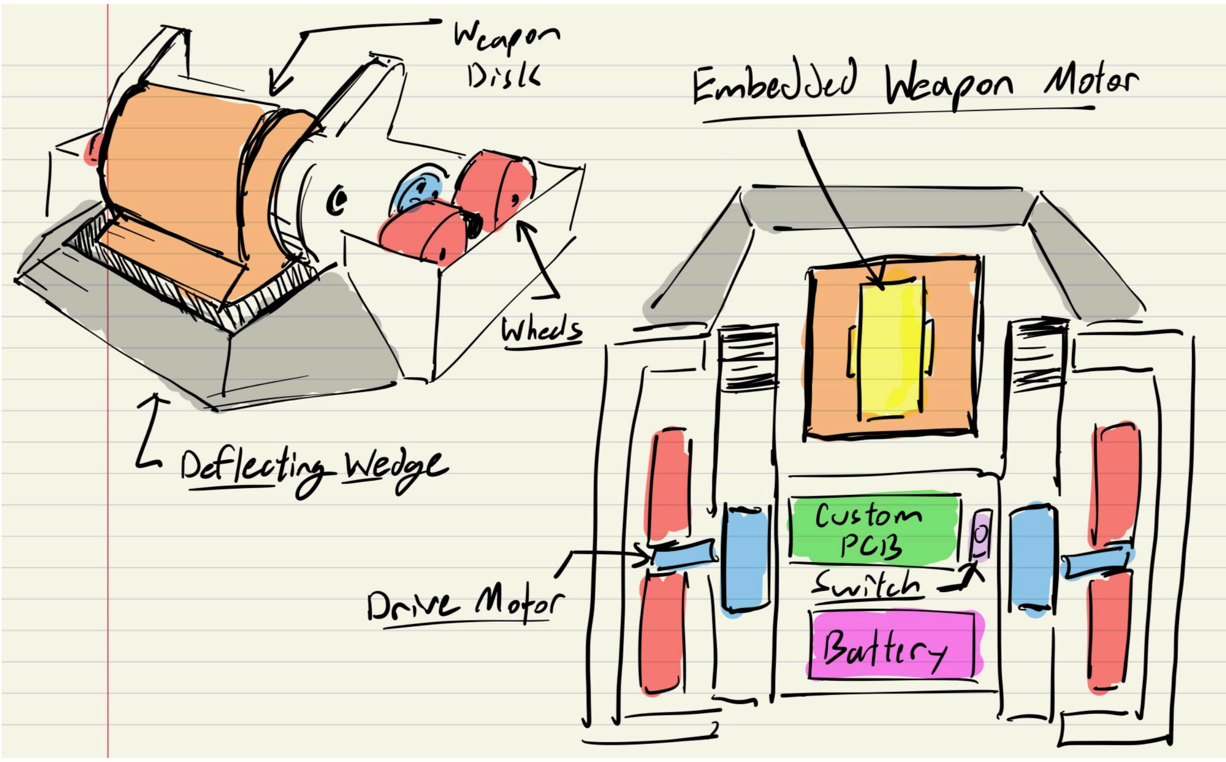

Figure 4: Physical layout of components.

A rough idea of the electrical setup. The physical design may be different in the final version, however, the core electronics will be the same. The custom PCB (green) will house the ESP32-C3 used for Bluetooth communication with the computer for control as well as the motor drivers for powering the pair of drive motors (blue) as well as the weapon motor (yellow). The weapon motor is embedded in a thick ring of 3D printed plastic to carry a substantial amount of energy for impacts against the opponent as well as protection for the motor itself. All the electronics will be powered from the 4S LiPo battery (pink) that can be manually disconnected via the power switch (purple). The drive mechanism has a central drive motor whose shaft rotates the outer wheels (red) via friction between the shaft and outer rims of the wheels. In addition, the white surrounding area will be 3D printed parts meant to protect the electronics and drivetrain with a wedge (grey) in front to help deflect opponent attacks.

2.3 PCB Design

The PCB has been split into two separate rectangular PCBs. This is due to the 100 mm by 100 mm area limit of a single PCB. Although the design can fit within these bounds, having a square shaped PCB is not ideal for fitting inside of a combat robot. There are extra debug connectors for testing and a safety linear regulator in case the buck converter doesn't work properly in the first round of PCB order design.

2.3.1 Controller PCB

The first PCB contains the ESP32-S3-WROOM and its programming circuit. The first round design of its schematic can be seen in Figure 5 and the PCB design can be seen in Figure 6.

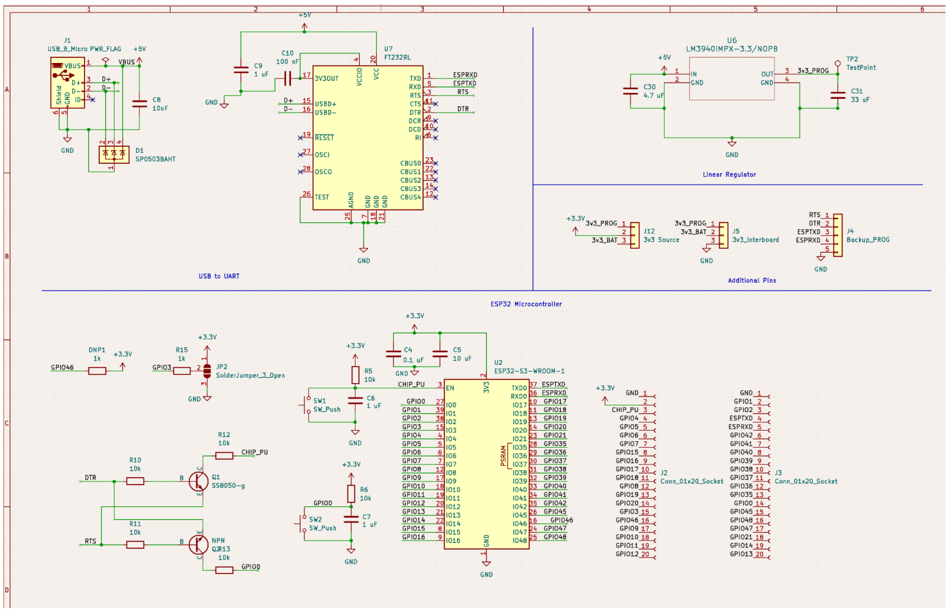

Figure 5: First round controller schematic.

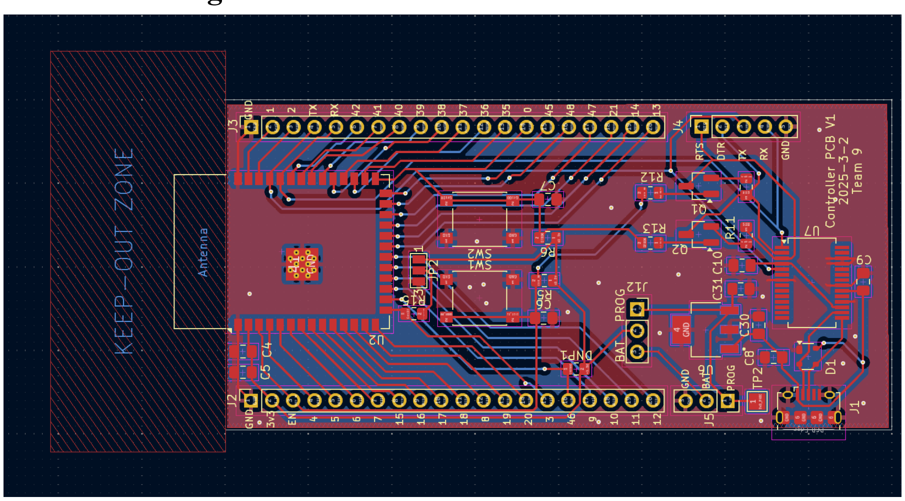

Figure 6: First round controller PCB layout.

2.3.1 Motor PCB

The motor PCB includes all 3 motor controllers as well as the buck converter for the battery step down. The schematic can be seen in Figure 7, and the PCB layout can be seen in Figure 8.

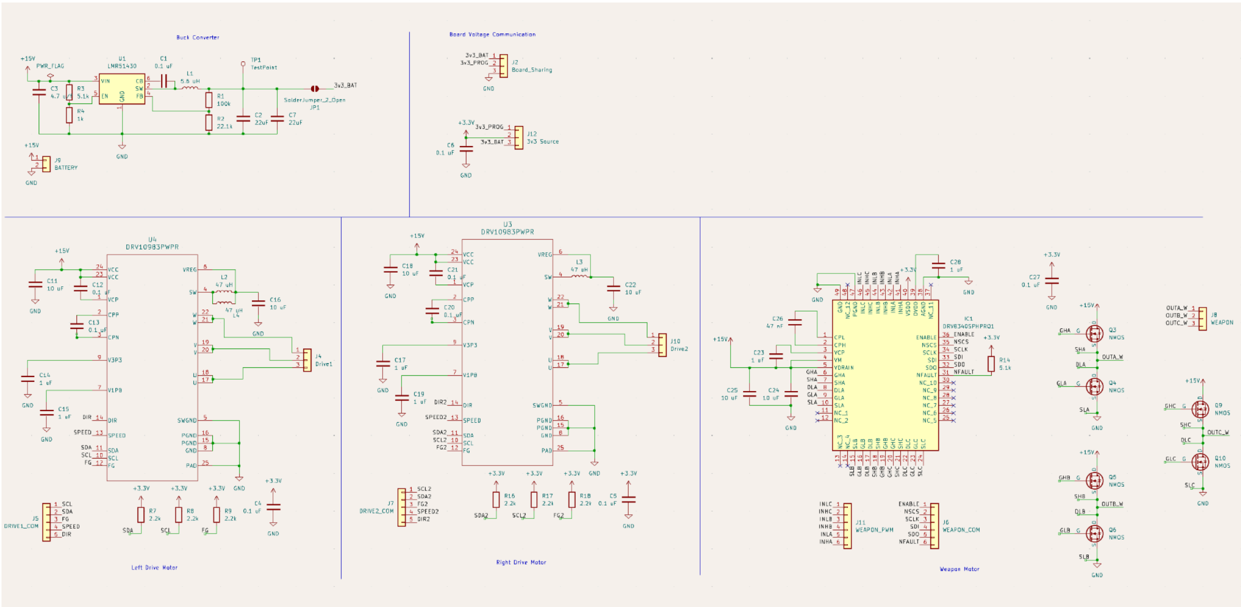

Figure 7: First round schematic of motor PCB.

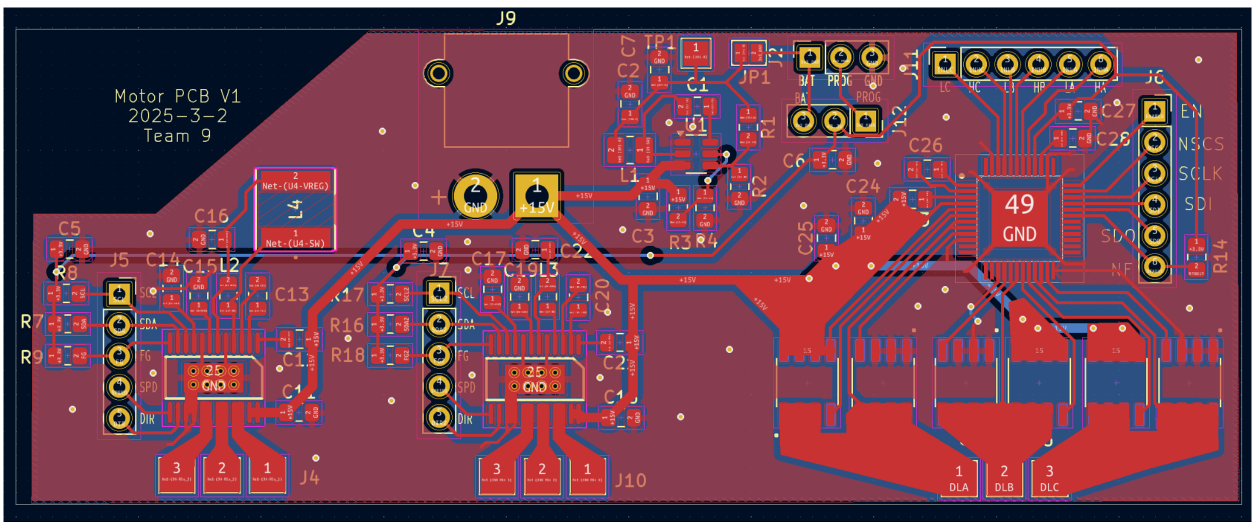

Figure 8: First round PCB layout of motor PCB.

2.4 Subsystem Overview

2.4.1 Power Subsystem

The power subsystem is responsible for supplying the necessary voltages for each of the other subsystems. There are two key components from the power subsystem: the raw 14.8 V that comes from the LiPo and is used to directly power the weapon and drive motors through the motor drives and the 3.3 V that is stepped down from the LiPo using a buck convertor to power control electronics like the ESP32 for Bluetooth communications.

The buck converter chosen is the LMR51430 as it is specified to allow for a 4.5 V to 36 V input and provide up to 3 A of output current. Since our battery is 14.8 V, it is within the allowed range and the 3 A current limit is suitable for the ESP32-S3-WROOM. The schematic used for the buck converter is shown in Figure 9, which follows the typical application schematic shown in its datasheet [1].

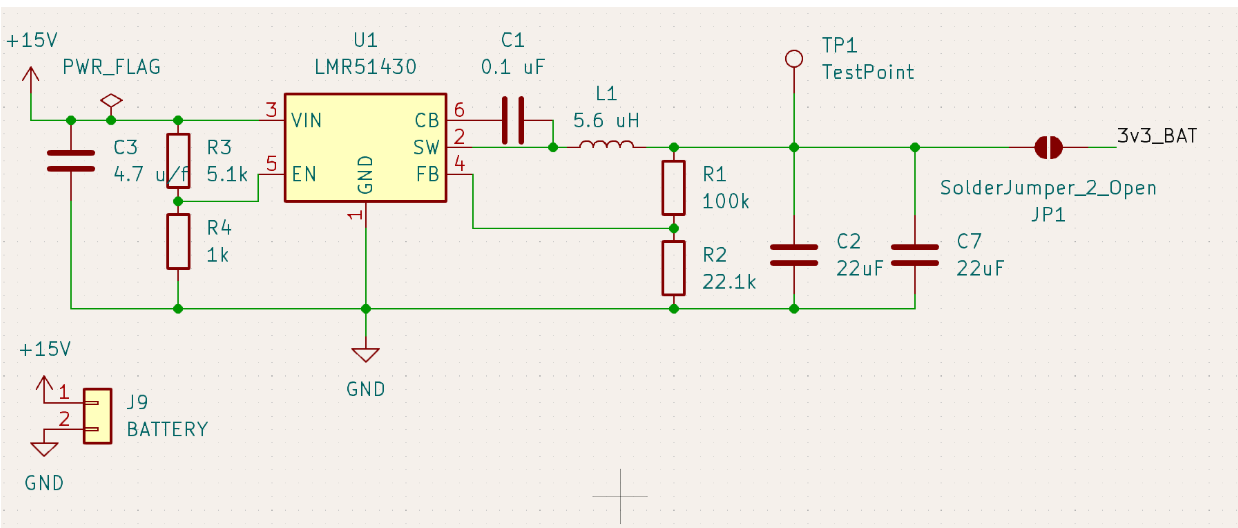

Figure 9: Buck converter schematic.

Requirements	Verification
• 14.8V 4S battery must provide a stable 3.3 V ± 0.3V to the ESP32 through the buck converter	• The voltage range can be measured and verified using an oscilloscope, measuring the output of the buck converter
• 14.8V 4S battery must be capable of providing power for all systems over the 2 minute match duration	• We have allotted a total constant current of 16.25 Amps over 2 minutes • Measure the current and voltage of the LiPo battery to see that the current can be sustained and the voltage drops no

	more than down to 3.2V per cell (4S has 4 cells so no further than 12.8V)

2.4.2 Controller Subsystem

The controller subsystem consists of an ESP32-S3-WROOM that has built-in Bluetooth and Wi-Fi modules. This allows it to wirelessly communicate with a PC via Bluetooth to receive commands. The ESP32 also has plenty of GPIO pins to communicate with the motor drivers with SPI or I2C depending on what motor controller we decide to use. It will be powered with 3.3 V from the power subsystem.

Requirements	Verification
• The ESP32 must be able to connect to the PC via Bluetooth with delays of no more than 1000 milliseconds from a PC input to the resultant output of a motor	• Measure the time it takes from giving a Bluetooth PC input to the ESP32 and the moment that a voltage changes across the motor driver or gate driver. The change can be detected via an oscilloscope.
• Must be able to receive instructions from the PC and send out the corresponding signals to the motor drivers to control motor speeds within ± 10% accuracy.	• Have the PC send an instruction for the motor to drive at a specific speed. Measure the generated PWM signal using an oscilloscope and verify that the wave duty cycle is within ± 10% of the expected duty cycle.
• Weapon must stop all movement within 10 seconds of losing Bluetooth connection	• Disable Bluetooth on the PC while the robot is driving a motor. Utilize a timer and make sure the motor comes to a complete halt within 10 seconds.

2.4.3 Weapon Subsystem

The weapon subsystem consists of a motor driver and a 2207 hubmotor from Repeat Robotics. The motor driver will convert command signals from the microcontroller to 3-phase AC signals to control the rotation speed of the motor connected to a fighting tool. The motor will use 14.8 V from the LiPo battery.

The motor driver is TI's DRV8340S gate driver. This chip was chosen because it has an input voltage range of 5.6 V to 60 V, which is suitable for our battery, and is a gate driver rather than being an integrated IC [2]. This means that the NMOS H-bridge system generating the 3-phase AC is separate from the chip, allowing us to drive a higher current for the weapon motor. The NMOS chosen is the FDS6680A NMOS chip. This MOSFET allows for a maximum voltage of

30 V and a maximum current of 12.5 A, making it suitable for our weapon motor [3]. The chip can be programmed via SPI from the ESP32 microcontroller, and then the speed of the motor can be controlled via PWM signals from the ESP32.

Requirements	Verification
● Weapon speed must be able to reach 200 mph to damage opposing robots	● Send the maximum speed PWM signal. With a tachometer or a slow motion camera, measure the angular velocity of the weapon at its outermost diameter to calculate if the top speed meets 200mph
● It must stop within 10 seconds of losing Bluetooth connection	● Have the weapon spinning and then disconnect Bluetooth on the PC. Use a timer to measure how long it takes for the weapon to stop to verify if it is within 10 seconds.

2.4.4 Drivetrain Subsystem

Similarly, the drivetrain subsystem takes the signals from the control subsystem to maintain a desired speed at any given moment. It will consist of 2 motor drivers and 2 tangent drive motors from Repeat Robotics. We plan on using a tank drive to control each motor, and each motor is attached to two wheels, therefore enabling 4-wheel drive. Control signals from the ESP32 will be converted to 3-phase AC signals to the two motors to control the speed and rotation of the robot. The motor choice for both the weapons and drivetrain is a result of motors' known reliability within combat robotics.

The motor driver for the drivetrain was chosen to be the DRV10983. This chip has an input voltage range of 8 V to 28 V, making it suitable for our battery, and has integrated H-bridges to directly provide the 3-phase AC signal for the motor. The chip can provide a 3 A peak current to the motors, which is sufficient for the drivetrain. We can program the chip via I2C and control the speed and direction of the motor it controls via PWM and GPIO signals from the ESP32 [4].

Requirements	Verification
● Must allow the robot to reach 20 mph	● Send max speed PWM signals to the drive motors. Use a tachometer or slow-motion camera to calculate the rotational speed and verify that it would allow the robot to reach 20 mph.

• Drivetrain must stop all movement within 3 seconds if Bluetooth connection is lost	• Start with the robot moving forward at a constant speed and then turn off PC Bluetooth. Measure the time it takes for the robot to come to a stop.

2.4.5 Mechanical Subsystem

The chassis of the robot will be made out of 3D printed PLA+ as the material is durable and more reliable when 3d printing. This will hold all of the electronic components including the PCB, motors, and battery. It is the main body of the robot and will be used to protect the electrical components. The weapon will also be 3D printed with the same material and will be attached to the weapon motor.

Requirements	Verification
• Chassis must be able to have electronics protected and be capable of handling external impacts from opponents to a reasonable degree. There should be no cracks exceeding 1 in. on the chassis and no solder connections lost on the PCB.	• Battery and electronics should not be exposed • There should be no wires hanging out from the robot • Enclose an unneeded PCB within the chassis and drop the chassis from a height of 5 ft. Inspect the chassis and enclosed PCB for significant damage that may cause issues with functionality.
• The weapon must be capable of handling internal stresses of its own mass without pulling itself apart. There should be no cracks exceeding a length of 1 inch.	• The weapon motor, along with the weapon disk, will be spun up in a safe enclosure at its maximum speed for 10 seconds and inspected for cracks or faults afterward.
• Total weight of entire robot must be under 2 pounds	• After final assembly, weigh everything on a scale and ensure that it is under 2 pounds.

2.5 Tolerance Analysis

Motor speed and battery life are crucial factors in determining the success of a battlebot. We must ensure that our motors can operate at adequate speeds for mobility and offense. Our battery must also be able to supply enough power throughout a 2-minute match.

2.5.1 Motor Speed

Looking at motor speed first, the 1406 repeat tangent drive motors are rated for 2500 kv and the weapon's 2207 hubmotor is rated for 1800kv. To determine motor speed in RPM we can use the following equation:

$$\omega_{rpm} = kv * Voltage$$

Since we are running at 14.8v nominally, our drivetrain motors, the 1406 repeat tangent drive motors rated at 2500kv, will have an RPM of 37,000 revolutions per minute. The weapon motor, the 2207 hubmotor rated at 1800kv, will have an RPM of 26,640 revolutions per minute. To determine our robot's velocity, we need to take the wheel's diameter into account. Solving for the circumference will allow us to convert from angular velocity to linear velocity of miles per hour. We can use the following equation:

$$Velocity\ [mph] = \omega_{rpm} * \pi D\ [in] * \frac{60[min]}{1[hr]} * \frac{1\ [mile]}{63360[in]}$$

With a wheel diameter of approximately 1 inch and an RPM of 37,000, our ideal linear velocity is around 110 miles per hour. Given our initial high-level requirement in section 1.4, this should be sufficient to account for external factors such as load, friction, and air resistance.

Similarly, with a weapon diameter of approximately 4 inches and an RPM of 26,640, our ideal weapon tip speed is around 317 miles per hour, which meets our requirement of at least 150 mph.

2.5.2 Battery Life

The main current drawing elements of the design are the motors. There aren't any datasheets for the Repeat Robotics motors that we found so the calculations are based on similar motors. The drive motors would have a current draw of about 0.5 A and the weapon motor would have an idle current of 1.2 A with a max burst current of 35 A. It would only reach the max burst current likely on startup, so we will use its current draw under constant load, which would be around 15 A. The total current from the motors would be:

$$I_{totalmotor} = 2 * I_{drive} + I_{weapon} = 2 * 0.5\,A + 15\,A = 16\,A$$

The ESP32 will also draw a small amount of current of about 0.25 A. Thus the total current draw is:

$$I_{total} = I_{totalmotor} + 0.25A = 16\,A + 0.5\,A = 16.25\,A$$

Thus, the total battery capacity for a 2 minute match would be:

$$I_{total} * time = 16.25\,A * 2\,minutes * (1\,hour\,/\,60\,minutes) = 0.55167\,Ah = 551.67\,mAh$$

As such, using a 650 mAh 4S LiPo battery will be sufficient to power the robot for the duration of the match. It would also have the capacity to handle the occasional burst current from the weapon motor.

3. Cost and Schedule

3.1 Cost Analysis

1. Labor:
    a. $30 per hour (Per person)
    b. Hours to Complete: 60 hours
    c. TOTAL = ($30/hour) x 3 x 60= $5400
2. Parts:

Description	Manufacturer	Quantity	Cost	Link
Repeat Tangent Drive Motors (1406)	Repeat Robotics	2	$20	https://repeat-robotics.com/buy/repeat-tangent-drive-motors/?attribute_motor-size=1406
FingerTech Mini Power Switch	FingerTech Robotics	1	$8.43	https://www.fingertechrobotics.com/proddetail.php?prod=ft-mini-switch
2207 Antweight Battle Ready Hubmotor (1800KV)	Repeat Robotics	1	$50	https://repeat-robotics.com/buy/2207-battle-ready-hubmotor/
0.25 x 1.5" Shoulder Bolt With Locknut	Repeat Robotics	1	$5	https://repeat-robotics.com/buy/2207-battle-ready-hubmotor/
XT30 Connectors	Amazon	1	$9.59	https://www.amazon.com
4S 660mAH LiPo Battery	Amazon	1	$41.63	https://www.amazon.com
Duramic PLA+	Amazon	1	$16.99	https://www.amazon.com
Assorted M3 Screws	Amazon	1	$24.68	https://www.amazon.com
4.7 µF (0805)	ECE Shop	2	$0.77	http://courses.grainger.illinois.edu/ece445/lab/eshop_smd_request.pdf

1k Ω (0805)	ECE Shop	3	\$0.18	http://courses.grainger.illinois.edu/ece445/lab/eshop_smd_request.pdf
5.1k Ω (0805)	ECE Shop	2	\$0.10	http://courses.grainger.illinois.edu/ece445/lab/eshop_smd_request.pdf
.1 µF (0805)	ECE Shop	10	\$0.671	http://courses.grainger.illinois.edu/ece445/lab/eshop_smd_request.pdf
100k Ω (0805)	ECE Shop	1	\$0.24	http://courses.grainger.illinois.edu/ece445/lab/eshop_smd_request.pdf
10 µF (0805)	ECE Shop	7	\$0.45	http://courses.grainger.illinois.edu/ece445/lab/eshop_smd_request.pdf
1 µF (0805)	ECE Shop	7	\$0.671	http://courses.grainger.illinois.edu/ece445/lab/eshop_smd_request.pdf
2.2k Ω (0805)	ECE Shop	6	\$0.11	http://courses.grainger.illinois.edu/ece445/lab/eshop_smd_request.pdf
FDS6680A	ECE Shop	6	\$0.92	http://courses.grainger.illinois.edu/ece445/lab/eshop_smd_request.pdf
ESP32-S3-WROOM	ECE Shop	1	\$5.49	http://courses.grainger.illinois.edu/ece445/lab/eshop_smd_request.pdf
SS8050-G	ECE Shop	2	\$0.24	http://courses.grainger.illinois.edu/ece445/lab/eshop_smd_request.pdf
SP0503BAHTG	ECE Shop	1	\$0.70	http://courses.grainger.illinois.edu/ece445/lab/eshop_smd_request.pdf
Micro USB-B Connector	ECE Shop	1	\$0.56	http://courses.grainger.illinois.edu/ece445/lab/eshop_smd_request.pdf

33 µF (0805)	ECE Shop	1	$0.91	http://courses.grainger.illinois.edu/ece445/lab/eshop_smd_request.pdf
10k Ω (0805)	ECE Shop	6	$0.25	http://courses.grainger.illinois.edu/ece445/lab/eshop_smd_request.pdf
Switch Tactile	ECE Shop	2	$1.96	http://courses.grainger.illinois.edu/ece445/lab/eshop_smd_request.pdf
LMR51430XDDCR	Texas Instruments	1	$1.29	https://www.digikey.com/en/products/detail/texas-instruments/LMR51430XDDCR/17878357
DRV8340SPHPRQ1	Texas Instruments	2	$5.50	https://www.digikey.com/en/products/detail/texas-instruments/DRV8340SPHPRQ1/10273195
CB2012T470K	Taiyo Yuden	2	$0.15	https://www.digikey.com/en/products/detail/taiyo-yuden/CB2012T470K/2230241
CBC2012T470M	Taiyo Yuden	2	$0.15	https://www.digikey.com/en/products/detail/taiyo-yuden/CBC2012T470M/957985
BRL2012T470M	Taiyo Yuden	2	$0.15	https://www.digikey.com/en/products/detail/taiyo-yuden/BRL2012T470M/1788957
DRV10983PWPR	Texas Instruments	1	$3.61	https://www.digikey.com/en/products/detail/texas-instruments/DRV10983PWPR/4946333
RMCF0805FT22K1	Stackpole Electronics	2	$0.10	https://www.digikey.com/en/products/detail/stackpole-electronics-inc/RMCF0805FT22K1/1760211
FT232RNL	FTDI	1	$4.80	https://www.digikey.com/en/products/detail/ftdi-future-technology-devices-international-ltd/FT232RNL-REEL/16836162

C0805C473K5RACTU	Kemet	2	$0.11	https://www.digikey.com/en/products/detail/kemet/C0805C473K5RACTU/411165
LM3940IMPX-3.3/NOPB	Texas Instruments	2	$1.63	https://www.digikey.com/en/products/detail/texas-instruments/LM3940IMPX-3-3-NOPB/367097
CL21A226MQQNNNE	Samsung Electro-Mechanics	4	$0.10	https://www.digikey.com/en/products/detail/samsung-electro-mechanics/CL21A226MQQNNNE/3886758
0805CS-562EJFS	Delta Electronics / Components	2	$0.28	https://www.digikey.com/en/products/detail/delta-electronics-components/0805CS-562EJFS/9764087
1008LS-562XJRC	Coilcraft	4	$1.19	https://www.digikey.com/en/products/detail/coilcraft/1008LS-562XJRC/15794069
NR6045T470M	Taiyo Yuden	1	$0.29	https://www.digikey.com/en/products/detail/taiyo-yuden/NR6045T470M/1788972

3. Total Cost: ($5664.43)
    a. Labor: **$5400**
    b. Components: **$264.43**

3.2 Schedule

Week	Description
3/3	● Design and place orders for first round of PCB parts (Evan) ● Order all electrical surface mount components (Evan) ● Order all motors (Allan) ● Prepare for first breadboard demo ○ ESP32 Bluetooth should work (James) ○ ESP32 should be able to generate PWM waves (James)
3/10	● Breadboard demo (All) ● Start work and design of the chassis for the robot (Allan) ● Second wave of PCB orders (Evan)

	● First wave of PCB parts arrive ○ Solder all components to PCB and begin tests (All)
3/17	SPRING BREAK
3/24	● Test PCB (All) ● Program ESP32 for drive motors controller (James) ● Program ESP32 for weapon motor controller (Evan)
3/31	● Complete individual progress reports (All) ● Finish programming (All)
4/7	● Final and fourth round of PCB order (Any last revisions must be made here to the PCB design) (Evan) ● Order any last components needed (All) ● Robot should be fully assembled (Allan) ○ Electronics soldered ○ Fully programmed and functions as intended ● Mechanical design changes, program bugs, or any final electrical changes must be completed by this week
4/14	● Complete team contract assessment (All) ● Robot completed and fully functional (All)
4/21	● Complete mock demo (All)
4/28	● Complete final demo (All) ● Complete mock presentation (All)
5/5	● Complete final presentation (All) ● Complete final papers (All)

4. Ethics and Safety

4.1 Ethics

The IEEE Code of Ethics Section I [5] states that we disclose any factors that may endanger the public or the environment. One such factor is the use of an active weapon or fighting tool. If carelessly handled, the fighting tools of these robots could cause harm that could be lethal. Therefore, proper safety measures on our part will be taken with the utmost importance, guaranteeing the safety of the public and its members, such as designated work zones and safety procedures when handling combat robots.

4.2 Safety

In combat robotics, safety is the most important aspect. There are some variations in rules for safety from competition to competition but here are some of the most important based on NHRL rules [6]:

1. The robot should not be tested (with an active weapon) unless placed inside an enclosed test arena. This is to keep you and everyone else safe from coming into contact with the fighting tool.

2. Since the requirements of this project call for wireless Bluetooth or Wi-Fi connections to the robot, it should be expected that the robot automatically shuts down to a safe state if the connection between the PC and the robot is lost.

3. Batteries should never be left charging unattended.

5. References

[1] Texas Instruments, “LMR51430 SIMPLE SWITCHER Power Converter 4.5-V to 36-V, 3-A, Synchronous Buck Converter in a SOT-23 Package”, [Online]. Available: https://www.ti.com/lit/ds/symlink/lmr51430.pdf?ts=1741253461782&ref_url=https%253A%252F%252Fwww.mouser.cn%252F (accessed Feb 24, 2025).

[2] Texas Instruments, “DRV8340-Q1 12-V / 24-V Automotive Gate Driver Unit (GDU) with Independent Half Bridge Control datasheet”, [Online]. Available: https://www.ti.com/lit/ds/symlink/drv8340-q1.pdf?ts=1741285208941&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FDRV8340-Q1 (accessed Feb 24, 2025).

[3] ON Semiconductor, “FDS6680A Single N-Channel, Logic Level, PowerTrench MOSFET”, [Online]. Available: https://www.onsemi.com/pdf/datasheet/fds6680a-d.pdf (accessed Feb 24, 2025).

[4] Texas Instruments, “DRV10983 12- to 24-V, Three-Phase, Sensorless BLDC Motor Driver datasheet”, [Online]. Available: https://www.ti.com/lit/ds/symlink/drv10983.pdf?ts=1741316777505&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FDRV10983%252Fpart-details%252FDRV10983PWPR (accessed Feb 24, 2025).

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[6] NHRL, Available: https://wiki.nhrl.io/wiki/index.php?title=NHRL_Open_Rules_-_2025 (accessed Feb. 13, 2025).