Combat Robotics @Cornell

Final Report

Sportsman Subteam
Lance

Spring 2022
Cornell University

Contents

1 Introduction

1.1 Subteam Purpose

The Sportsman subteam's mission is to creatively experiment in the realm of autonomous combat robots with low-kinetic-energy weapons. Sportsman focuses on creativity and innovation to compete and win not by destruction, but by domination. For this first full design cycle, the main goal was to build and compete with a fully operational combat robot.

1.2 Subteam Members

Michelle Zhou	Mechanical and Aerospace Engineering '23	Subteam Lead
Marcus Esposito	Mechanical and Aerospace Engineering '24	Vice Subteam Lead
Bruno Tassari	Mechanical and Aerospace Engineering '23	Vice Team Lead
Charles Liu	Mechanical and Aerospace Engineering '24	
Kevin Liu	Mechanical and Aerospace Engineering '22	
Molly Drumm	Mechanical and Aerospace Engineering '23	
Sana Gaya	Computer Science '24	
Shubham Mathur	Mechanical and Aerospace Engineering '22	

1.3 Subsystems

In the fall, Sportsman was organized into subsystems with the following responsibilities:
Chassis Subsystem (Charles Liu, Richard Jin, Shubham Mathur)

- To design the frame that holds the whole robot together, the outer shell, and the armor of the robot.

Powertrain (Bruno Tassari, Michelle Zhou, Molly Drumm)

- To design all components related to translating/rotating the robot, including motors, motor assembly, wheels, skids/castors, and flipping mechanism.

Weapon (Claire Chen, Kevin Liu, Marcus Esposito)

- To design a tool to dominate other robots and to show off our design creativity to judges.

In the spring, manufacturing and assembly work was spread out across the subteam, with subsystem members acting more as points of contact.

2 Fall 2021 Process

Below is a short synopsis of the Fall 2021 accomplishments. Please refer to the Fall 2021 Sportsman Report for more details.

2.1 Manny Project

Goal: To finish mechanically assembling Manny to allow the Firmware subteam to implement autonomous features led by Anna Boese.

- Robustly attached cams to servos and mounted servos in the walls
- Created 3D-printed holders for electronic parts
- Planned spacing of electronics inside Manny
- Created a rotating mount for a Time of Flight (ToF) sensor

2.2 Lance Design

Goal: To design and manufacture a functioning 12 lb. Sportsman robot with an active weapon capable of performing well at competition. The robot should allow for the Firmware subteam to implement autonomous features in the future.

2.2.1 Major Design Decisions

- **Indirect 4-wheel Tank Drive**
  - Indirect drive protects the motor from collisions and dangerous levels of torque by connecting the drive wheels to the motor with an elastic belt. With tank drive, the robot achieves high turning speed and maneuverability. With 4-wheel drive, all of the robot's weight is on a powered wheel, providing optimized pushing power that is limited only by the friction of the wheels on the ground.
- **HDPE Chassis**
  - HPDE is light, impact resistant, and elastic. This makes it perfect for a light-weight 12 lb. combat robot. HDPE was chosen for its high level of protection against low-kinetic-energy weapons in the Sportsman class as well as its low weight to alleviate our weight concerns.
- **Reversibility**
  - Many combat robots in the 12 lb. Sportsman Class are disabled or have diminished functionality when overturned. Lance was designed to be both reversible and to utilize a 360^o flipper as a self-righting mechanism to remain 100% functional when overturned.
- **Automation**
  - The current design cycle for Sportsman is to automate each robot after its competition. To make Lance open to automation, Sportsman 1) chose an active rather than passive weapon to challenge Firmware and 2) designed for a large and easily accessible chassis. Lance's chassis consisted of a large, rectangular space accessed by one large top plate to allow its internals to be accessed as easily as possible.

3 Spring 2022 Process

3.1 Logistics

Hard Deadlines
Deadlines set for the entire team.

Mar 14	Robots Driving at G-body
Mar 21	Robots Driving at G-body (make-up)
Mar 29	CRC Public Testing Event
Apr 22	NHRL Competition Weekend
May 6	CRC Showcase

Schedule
A record of the actual dates of accomplishments of the subteam.

Week of Jan 9	CADing Lance and planning manufacturing
Week of Jan 17	Manufacturing and design process documentation
Week of Jan 26	Creating timelines for the semester
Week of Feb 2	Fixing machining issues and electronics assembly
Week of Feb 12	Assembling chassis and drawing up circuit diagrams
Week of Feb 20	Machining plates and building circuit
Week of March 8	Connecting and testing ESCs
Week of March 12	Machining plates and building circuit
Week of March 19	Assembling weapon and circuits
Week of March 26	Weapon motor testing and programming
Week of April 15	Ordering new plates and testing new ESCs
Week of April 20	Fitting electronics into chassis and driving
Week of April 30	Reflecting on competition
Week of April 30	Fixing Lance and preparing for showcase

3.2 Machining Record

The subteam filled out weekly availability on a Google Sheet. Michelle Zhou coordinated with Kinetic Subteam Lead Ricky Wang to request machining slots for CRC at a daily 9:15pm machining Zoom meeting (Sun - Thurs) with other project teams.

Internal Machining

Jan 19	Top	Kevin Liu
Jan 22	Inner Right	Molly Drumm
Jan 24	Front and Back	Michelle Zhou
Jan 24	Inner Left	Molly Drumm
Jan 26	Inner Left cont.	Molly Drumm
Jan 27	Outer Left	Marcus Esposito
Feb 1	Outer Right	Bruno Tassari
Feb 5	Bottom	Molly Drumm
Feb 8	Outer Right	Bruno Tassari
Feb 12	Bottom	Molly Drumm
Feb 14	Outer Left	Marcus Esposito
Feb 15	Outer Right cont.	Bruno Tassari
Feb 17	Top	Claire Chen
Feb 19	Front	Michelle Zhou
Mar 5	Inner Right	Marcus Esposito
Mar 7	Inner Right cont.	Marcus Esposito
Mar 16	Inner Left	Charles Liu

Total Plate Machining Hours

- Molly Drumm: 15 hours
- Marcus Esposito: 12 hours
- Bruno Tassari: 9 hours
- Michelle Zhou: 6 hours
- Charles Liu: 3 hours
- Kevin Liu: 3 hours
- Claire Chen: 3 hours
- **Subteam total: 51 hours, 17 shifts**

Major Modifications

Pulleys (3 to 4mm ID x4)	Ricky Wang and Michelle Zhou
Top (facing) and pulleys (bolting holes x4)	Marcus Esposito
Weapon shaft key slot	Molly Drumm
Bottom motor mount holes	Marcus Esposito and Michelle Zhou
Bottom motor mount holes redo	Molly Drumm
Weapon shaft shortening	Bruno Tassari

External Machining

Flipper	3	Clark Machine Shop
Front ($48.35 each)	2	Empire Plastics
Outer Right ($47.79 each)	2	Empire Plastics
Bottom ($60.93 each)	2	Empire Plastics
Top	1	Clark Machine Shop
Inner Left	1	Clark Machine Shop
Inner Right	1	Clark Machine Shop

- Empire Plastics contact: Dave Cina (dave@empireplasticsinc.com)
- Clark Machine Shop contact: Robert Thomas Page (rtp43@cornell.edu)

4 Reflection of Manufacturing Process

4.1 CAD Improvements

Sportsman struggled with keeping the CAD up to date for several reasons. The CAD is complex with multiple files imported into one, containing multiple links. Sportsman also struggled to insert parts with no available CADs. This led to ”home-made” CADs of some parts that did not match the actual dimensions. Finally, the CAD was not consistently updated when issues arose and the real-life design was changed.

How can we design with dependencies between subsytems?

- For example, the belt length and chassis length were interdepedent. We just had to start with an educated guess.
- In the future we should have one separate assembly file to import everything else into, rather than importing everything into the chassis file. We should robustly parameterize each measurement in CAD, starting with an educated guess. Then, in the full assembly file, we will constrain each interdependent part so that changes in one part will affect dependent parts.

How can we specify tolerances in the CAD?

- We should keep “perfect” fits in CAD and manually shorten lengths by .005” in part drawings.

How can we ensure our CAD is constantly up to date? Should we designate a person to do this?

- We should keep track of CAD changes to make throughout the week and who will change this.
- (CRD) CAD Repair Day: Everyone would block out these one to two hours, but only the people who designed the part relevant to the change need to come. This would be announced one day in advance.

4.2 Fit / Tolerance Issues

Why were our weapon motor mount holes not aligned?

- There was no accurate CAD provided by the manufacturer.
- To avoid inaccurate CADs, we need to finalize any parts without CADs early on so that we can buy them and measure accurately to put into the CAD.
- Even afterward, when we measured the real motor, we did not update projection links in a timely manner.
- We later learned that the picture of the motor given that the inaccurate CAD was based on did not include the gearbox. In the future we would need to look up the motor and gearbox separately. Finding this gearbox and adding it to the CAD could have remedied the problem.

What should our allowable tolerances be in the machine shop? If someone is more than .005" off should they start over?

- In the future we should use tolerances of 0.005" as this is the standard from MAE 2250 Mechanical Synthesis.

Should we pick HDPE in the future?

- Designing with puzzle fits along with a soft material was extremely difficult to assemble. However, the soft material was so that we could have thicker plates without the robot being too heavy.
- The issues with assembly arose from the fact that the parts were not accurately machined and had to be filed down and forced together, so an emphasis on more accurate machining and tolerances, or possibly getting parts CNCed could fix this.

How should we decide who machines?

- Establish the expectation that every member needs to machine a certain amount of times in the semester.
- Make it clear that saying you are available for a slot means you are ready to go with a day's notice.
- Make a machining scheduling channel with all of the mechanical engineering subteams.
- Have "on call" weeks, in which each member would be assigned a week several weeks out that they must be available to machine if slots are given.

D **How can we make machining less stressful and more successful?**

- An older member will accompany a new member in the machine shop.
- The person machining is the person who will make the part drawing.
- The subteam lead will thoroughly check the drawings with each member.
- Have one person machine similar/symmetric parts.

Should we designate early on which pieces should be externally machined and allot a budget for external machining after we review Lance's total costs?

- We will look into remaining budget allowances after we learn Lance's budget.
- We are working on having a member get CNC trained. This member could then teach other members how to prepare parts to be CNCed.

5 Reflection of Assembly Process

5.1 Recurring Issues

5.1.1 Set Screws

- **Problem Description:** Components rotated with respect to each other (slipped), meaning we could not drive. There were set screws on the pulley to the axle, shaft collar to axle, weapon hub to weapon shaft, and wheel hub to axle (only set screw with good hold).
- **Reason:** Set screws came loose when attached to small shafts. It was difficult to tighten small set screws against round shafts because the Allen keys were so thin.
- **Solution 1:** We used 7 total clamping shaft collars on the 3mm drive axles. They clamped around the axle rather than just on one point where the set screw was.
- **Solution 2:** We took out the application of set screws in the wheel-hub connection entirely by bolting the large pulleys to the wheel, making power transmission as direct as possible.

Figure 1: The wheels and pulleys for the bolting solution after Marcus's modifications in the machine shop.

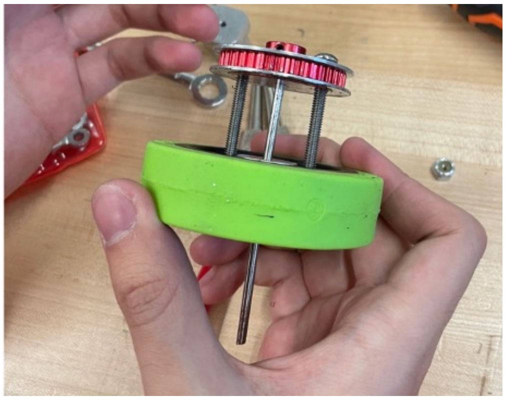

Figure 2: Our bolting solution before tightening.

- **Solution 3:** We created a D-profile with a file in order to give the perpendicular set screw more space to grab the shaft.
- **Potential Solution 1:** Use larger set screws and shafts.

Conclusion: Avoid using perpendicular set screw against circular shafts, especially in high torque regions.

5.1.2 Lateral Motion of Axles

- **Problem 1 Description:** The drive axles slid side to side after the axle bearings fell out.
- **Reason:** Our original shaft collars fell out often due to bad set screws and not enough clamping force.
- **Solution:** We used clamping screw collars, which we hadn't chosen earlier due to a tighter budget.

- **Problem 2 Description:** Objects on the axle (pulley and wheel) moved laterally along the axis, causing Lance to be unable to translate despite rotating motors.
- **Reason:** Set screws for the pulley were weak compared to the amount of resistance torque from the wheels.
- **Potential Solution:** Use spacers along the axles to prevent lateral motion.

- **Problem 3 Description:** The weapon shaft slid out of large black coupling after minimal weapon operation (flipping light objects for a short amount of time).
- **Reason:** The set screw on the key was unable to hold the weapon shaft in place.
- **Potential Solution 1:** Drill a small hole in the shaft and in the coupling. Thread the hole in the coupling and insert a set screw to prevent the shaft from coming out.
- **Potential Solution 2:** Use thread lock on the set screws. However, this should be a last-ditch solution as it makes reassembly messy.

Conclusion: No blanket solution, but perhaps prioritize using spacers and flanged bearings next year while brainstorming multiple hardware solutions.

5.1.3 Axles Stuck in Hubs

- **Problem Description:** Even without the snap rings and set screws on the hub, we were unable to remove the axles and reposition them such that the wheels were aligned well in the drivetrain.
- **Reason:** Tight tolerancing: the wheel hub hole was undersized.
- **Solution 1:** We borrowed metal scraps from Rocketry to make a mount: 1 tall cylinder metal scrap and 1 with a hole to let the axle slide out. We used CMR's push press and very easily pushed out the axle until we could manually pull it out from the other side.
- **Solution 2:** We used the same procedure, but used the scraps and push press in the machine shop.

Conclusion: We should collect metal scraps from the machine shop!

5.1.4 Electronics Could Not Fit

- **Problem 1 Description:** We could not fit the battery flat inside the chassis.
- **Reasons:** Didn't accurately model the battery and didn't include collars in CAD.
- **Solution 1:** We ordered a new top plate with 0.25" faced off of the middle 6" .
- **Solution 2:** CAD electronics to be a little larger than provided dimensions (we didn't notice the nub on the top of the battery where the wires came out of).
- **Solution 3:** Explore different wheel assembly configurations to reposition problem parts.

- **Problem 2 Description:** We could not fit the wires.
- **Reason:** We did not leave vertical space above the motors.
- **Solution 1:** The faced-off top plate allowed us to place wires over the motors.
- **Solution 2:** We also shortened some wires by re-soldering the connections
- **Potential Solution 1:** Leave space between motors and plates, based on wire gauge.
- **Potential Solution 2:** Dedicate time during the design process in the Fall to placing electronics in the chassis and draw all wires by hand on an isometric view of CAD.

Conclusion: Wires have volume and can only bend so much!! Leave space for them.

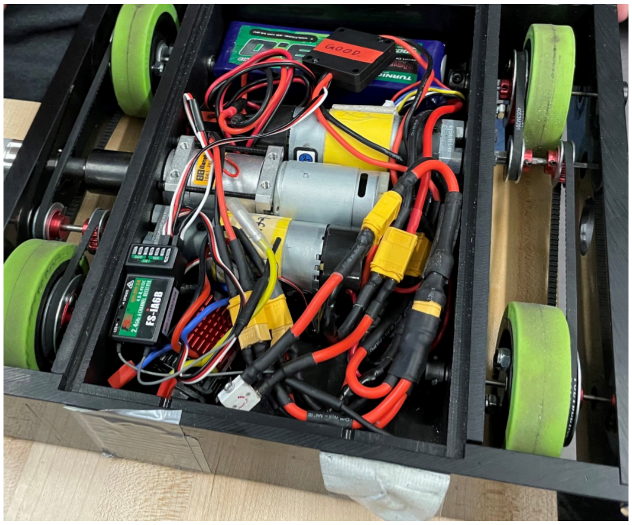

Figure 3: Lance's electronics.

5.1.5 Could Not Thread Axles

- **Problem Description:** Thin drive axles could not be threaded.
- **Reason:** We could not thread the small axle because it was made of steel and our dies (even in the machine shop) were not harder. The axles were also very thin (3 mm), making them more difficult to manually thread.
- **Solution 1:** Buy pre-threaded rods such as rod extensions or screws.
- **Solution 2:** Use thicker rods.

Conclusion: Ensure parts bought can be used with our toolkit.

5.2 One-Time Issues

5.2.1 Belt Lengths

- **Problem Description: Belts were improperly sized**
- **Reason 1: Length** We did not ensure the online calculator from FingerTech incorporated slack.
- **Reason 2: Width** We ordered belts that were 6mm width instead of 3mm width.
- **Solution 1:** Verify online calculations with back-of-the-envelope calculations for length, width, belt type, pitch, etc. **Solution extension:** Use belt tensioners to account for small errors when ordering the parts and warping of belts over time.

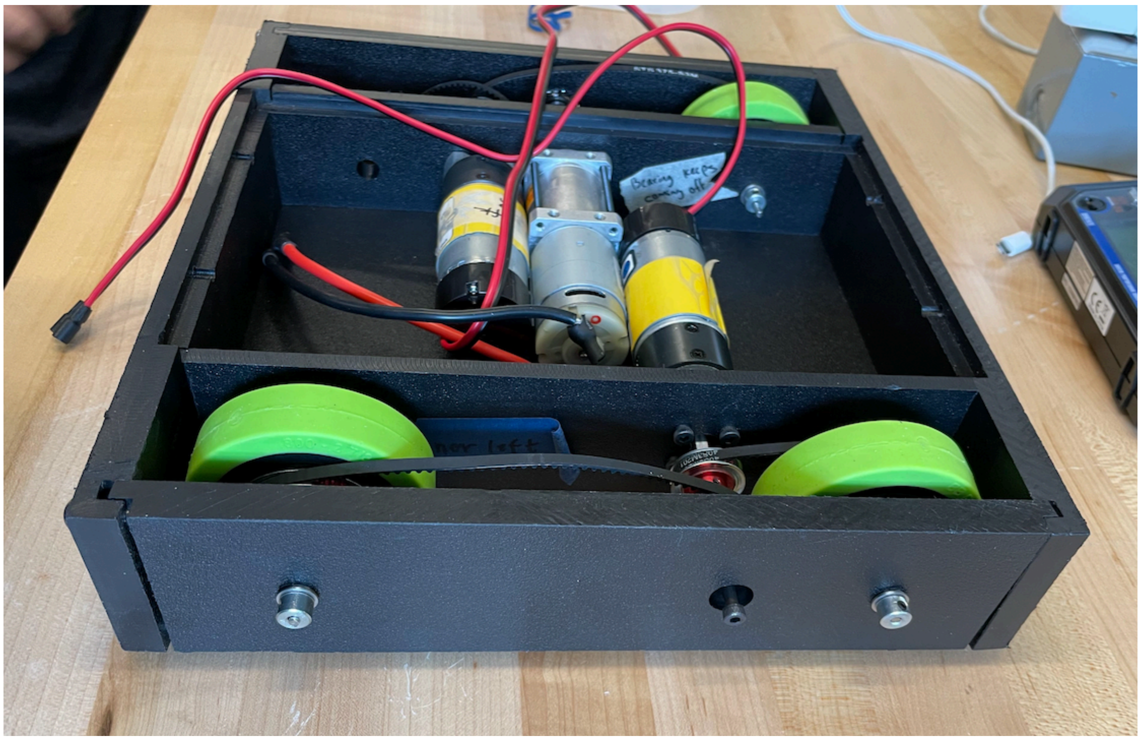

Figure 4: The small belt fit well, but the longer belt was very loose, initially.

5.3 Miscellaneous Comments

5.3.1 LiPo Battery Charging

- We were not always sure what settings to set the battery charger to.

Conclusion: By asking other teammates, we learned that we should set the current on the battery charger to ten percent of the battery's rated C value. However, if we are in a rush, or at competition, it is fine to set the current up to one third of the C value.

5.3.2 Unclear Part Drawings (orientation)

- When machining, sometimes cuts were made on the wrong side of the plate due to a misreading of the part drawing. Here is a folder of all our part drawings for Spring 2022.

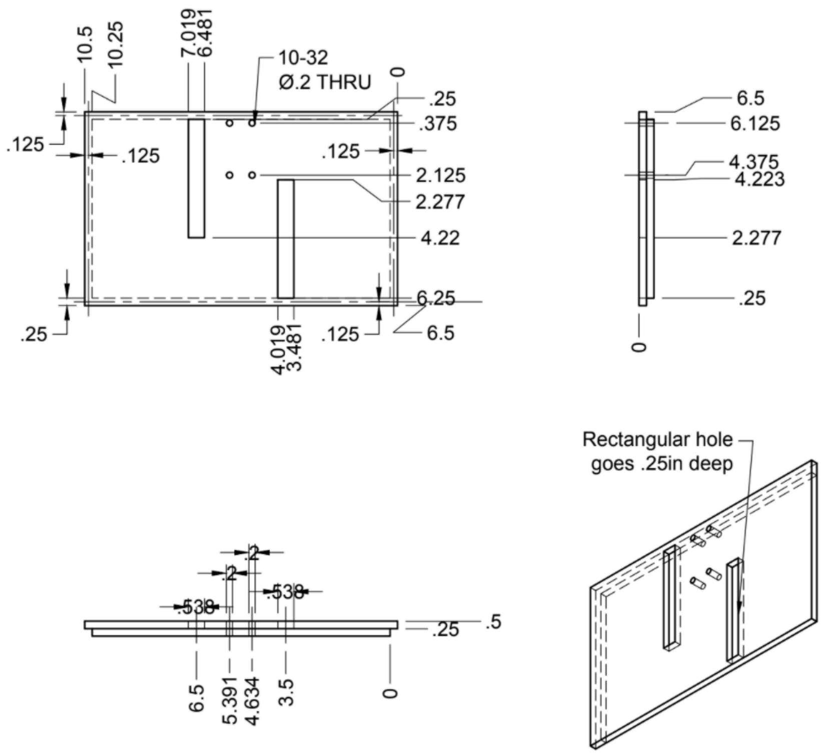

Figure 5: This is an example of a part drawing that lead to confusion as to which side the channels on the face were supposed to be cut in relation to the channels at the sides. While the side channels were supposed to be cut on the opposite side of the face channels, the person machining mistakenly cut them both on the same side.

Conclusion: To prevent future mistakes, the orientation of a part should be very clearly labeled in the part drawing. In addition, if the orientation is not clear then it should be verified in the CAD before going in to machine.

5.3.3 Soldering

- Soldering so many connections takes a lot of time (upwards of 15 hours total) but is impossible to avoid after the amount of connections have been mitigated.
- Be careful with every connection! Make sure they are fully and securely connected and properly shrink wrapped.

Conclusion: Be prepared to spend quite a bit of time soldering. Take your time on this; small mistakes can be costly when they burn out expensive electronics.

5.3.4 Weapon Motor Disassembly

- In order to attach anything to the weapon motor, it required us to take it apart and connect the internal snap ring to the axle. This was uncomfortable because we had to mess with the gears of the motor.
  - The first weapon motor burnt out after the axle was attached improperly. The gearbox was attached without noting the misalignment of the internal components.

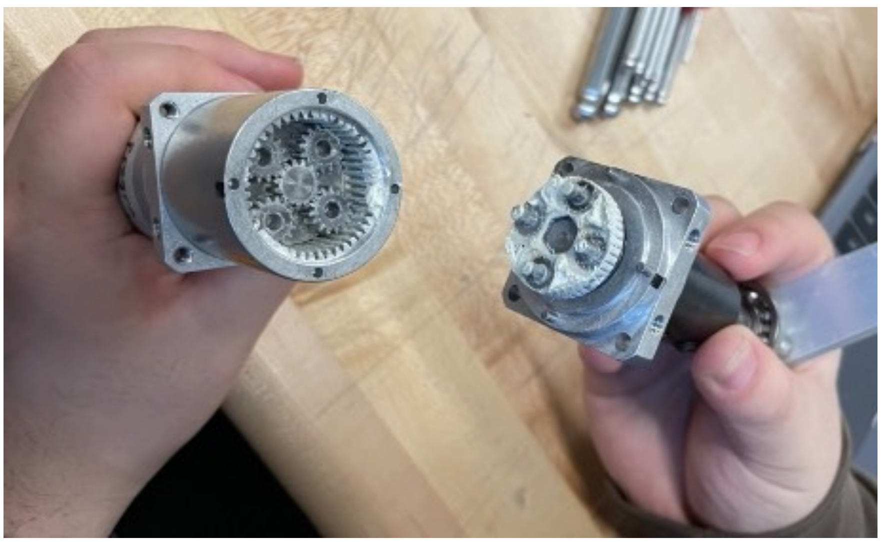

Figure 6: The disassembled weapon motor, showing the gears we messed up the first time around.

Conclusion: Be slow and careful when taking a motor apart or ensure that we do not need to open a motor to use it.

6 Reflection of Electronics Implementation

6.1 Overview of Remote Control (RC) System

The RC system consists of a transmitter, a receiver, a BEC (Battery Elimination Circuit, if necessary), and an ESC (Electronic Speed Controller) for each motor.

The transmitter sends the user's signals to the transmitters to power the motors at different speeds. The receiver dispenses the transmitters signals to each of the motor's ESCs. The ESCs control the voltage sent to the motors to determine their speed.

BEC's are used to restrict the voltage to a receiver. Receivers operate at low voltages (4-6V) compared to normal batteries (Lance's battery was 14.8 V). A BEC goes between the circuit and the receiver to lower the voltage going to the receiver. Most brushed ESC's have built-in BEC's, but brushless motors need an external BEC.

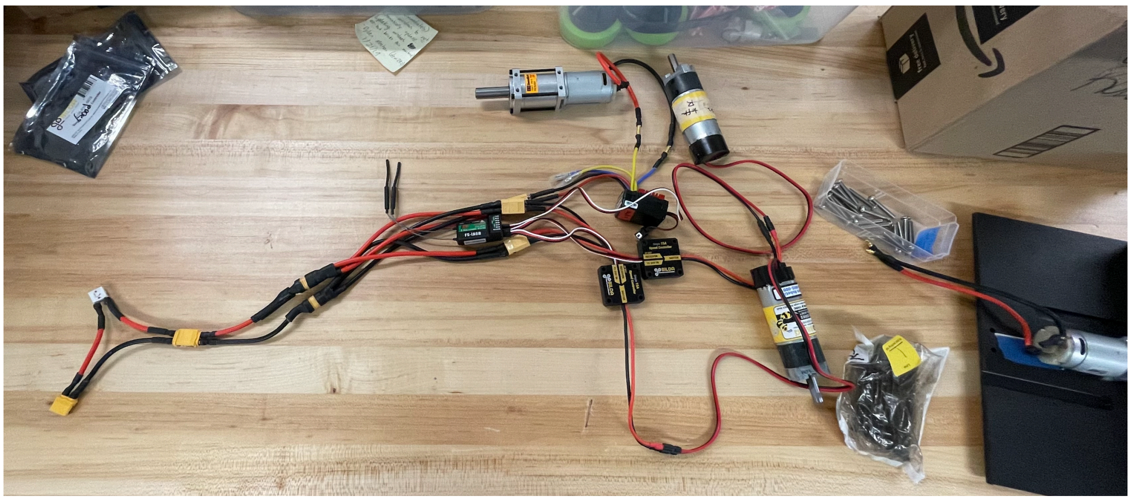

Figure 7: Final circuit configuration, diagram in Section 12.1. The battery was able to lay flat after we took off an internal shaft collar and Dremel-ed off the shaft sticking out.

6.2 Powering the Receiver

Receivers are powered by only one positive wire. Cut all but one positive wire going from the ESC's to the receiver. If a BEC is required, the only positive wire to the receiver should be through the BEC.

6.3 Channels

Each receiver has a certain number of control wire ports to control ESC's. The number of these ports correlates to the number of unique transmitter signals the receiver can handle (channels).

On a transmitter, each unique motion of the joysticks or switches correlates to a channel. Determine the channels and their respective motion through testing. To change the transmitter motion required to power a motor, simply change the receiver channel the ESC is plugged in to.

6.4 Channel Mixing

Channels sometimes need to be mixed to provide the desired joystick controls. For example, if the full right and left joystick extension correspond to their respective motors' full power, then the joystick forward will only push both motors to 75%. In this case, the transmitter channels will need to be mixed (i.e. proportion of signals changed) for the robot to go 100% forward.

Channel mixing is dependent on the transmitter. It involves accessing the transmitter settings with the screen located below the joysticks. Refer to online resources and the user's manual to change these settings.

6.5 Bind the Receiver to the Transmitter

Bind a receiver to a transmitter to allow the transmitter to control the receiver.

To bind a transmitter, plug the binding key (included with transmitter) into the binding radio control port of the receiver. Then, hold the "Bind" button (located next to the transmitter's screen) down until the receiver blinks and beeps.

7 Brands and Product Analysis

Since this is our first full design cycle, we would like to comment on our experiences with the brands we ordered from.

Brand	Product	Analysis
FingerTech Robotics	• 125T belt • 67T belt • 22T pulley • 42T pulley • Power Switch	• High quality parts • Commonly used in combat robotics • No contacts available for return/replacements • Located in Canada so shipping takes a while • CAD's available
ServoCity	• Drive Motor ESC	• Large company, so plenty of contacts and product information easily available • High quality products
GoBilda	• 4mm Flange ID Bearings	• Motors extensively used in combat robotics, lots of information available online • Pricey
McMaster	• 75mm socket head screw • Clamping Collars • Chassis flathead M5 Screws • Shaft Collars • ½" weapon shaft	• Expensive • Incredibly quick shipping • Huge inventory • Good return/replacement • Some things need to be purchased in bulk, so beware when trying to purchase small quantities of parts

Amazon	• Phillips 10-32 screws for weapon motor • Uxcell 3mm axles • Foam • RF (brand) HDPE • Wirefy heatshrink • BDHI parallel connectors	• Fast, but costly, shipping • Good return policies (refund without asking to return small items) • Very broad selection, but not engineering focused and generally low-quality brands • Specifications dependent on seller, can be quite poor • Beware of shipping from China
HobbyWing	• Weapon ESC	• High quality parts, but geared more towards RC cars, boats, and planes • Double check specifications to confirm that their parts work for our situation • Popular brand so lots of information available online
BaneBots	• Wheel Hub • Wheels	• High quality parts • Expensive • Ubiquitous in combat robotics so lots of combat robotics specific knowledge available online • Can be purchased from many different sources
Robot Shop	• Weapon Hub	• Large selection • No CADs and little specifications available • Hard to contact, use to find products then purchase from other sources to find CADs.

Bolt Depot	• Stainless steel 18-8, 6-32 x 1/2”	None
Lowes	• Ratchet Strap	None
Polybelt	• 354mm long, 3mm wide, 118 tooth belt • 357mm long, 3mm wide, 119 tooth belt	• Fast shipping (2 days)
Flysky	• Transmitter	• High quality and large variety of transmitters • Popular brand, lots of information available online
BNTECHGO	• 12 Gauge Wire	None

8 Design Critiques for Improvement

8.1 Chassis

8.1.1 Puzzle Fits

- As mentioned before, Lance's puzzle-fit chassis was extremely difficult to assemble and disassemble because most puzzle fits were too large and required significant force to put together.

Conclusion: While manually machining, enforce tighter tolerances (reject parts over .005" from design). Utilize more external or computerized machining.

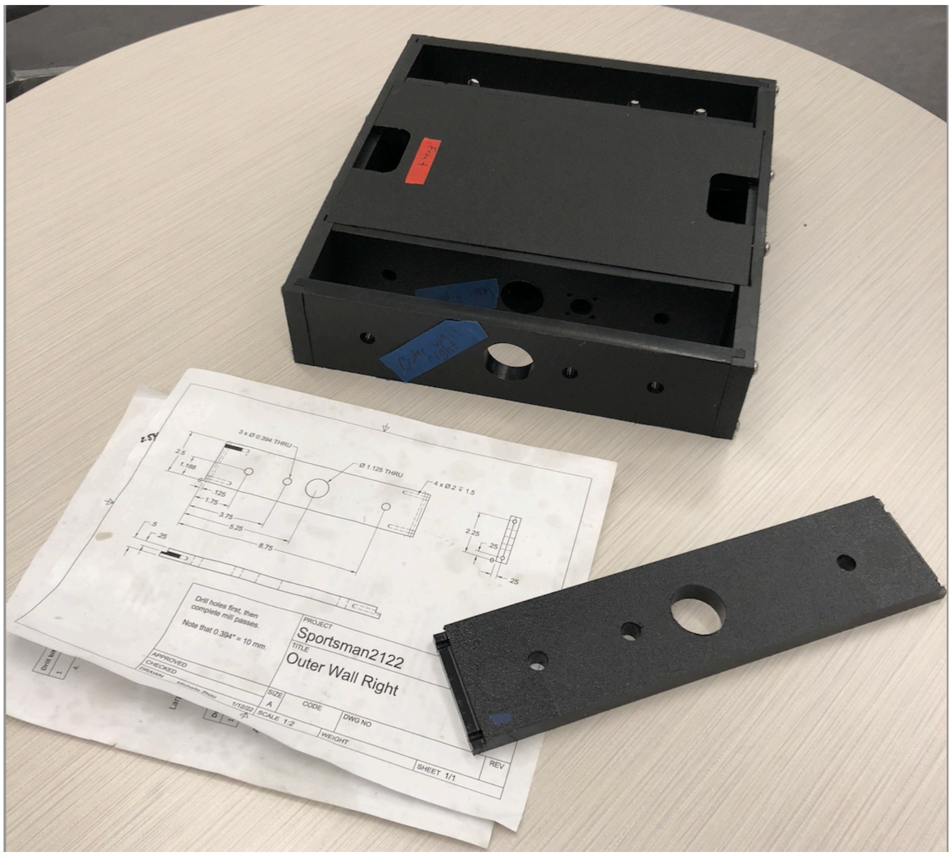

Figure 8: Lance's puzzle fit chassis.

8.1.2 Internals Access

- Lance's chassis struggled to fit its electronics inside the chassis. While originally designed to be large and easily accessible, due to improper electronics planning, overly thick material, and unaccounted internal shaft collars, the electronics did not fit.

Conclusion: Design with the electronics in mind. Plan where and how they will fit inside the chassis. Make sure to provide more internal space than expected.

8.2 Powertrain

8.2.1 Drive Axles

- Our drive axles were 3mm and 4mm in diameter (because of the pulley inner diameter problem explained in the next Section 8.2.2). Though they were steel, they bent severely during assembly and competition because they were so small and fragile. Lance's driving ability was not affected.

Conclusion: Use thicker drive axles (minimum 3/8" diameter), knowing that we can easily machine the pulleys.

8.2.2 Machining the Pulleys

- All of the inner diameters of the pulleys of FingerTech Robotics were 3mm (which is why we got 3mm axles). We later realized that their pulleys are meant to be modified.

Conclusion: As long as the diameter of the stickout section of the pulley is reasonably larger than the axle diameter, we can drill out the inner hole to match the axle diameter. Be sure to properly secure it on the mill with a v-block for 3 points of contact.

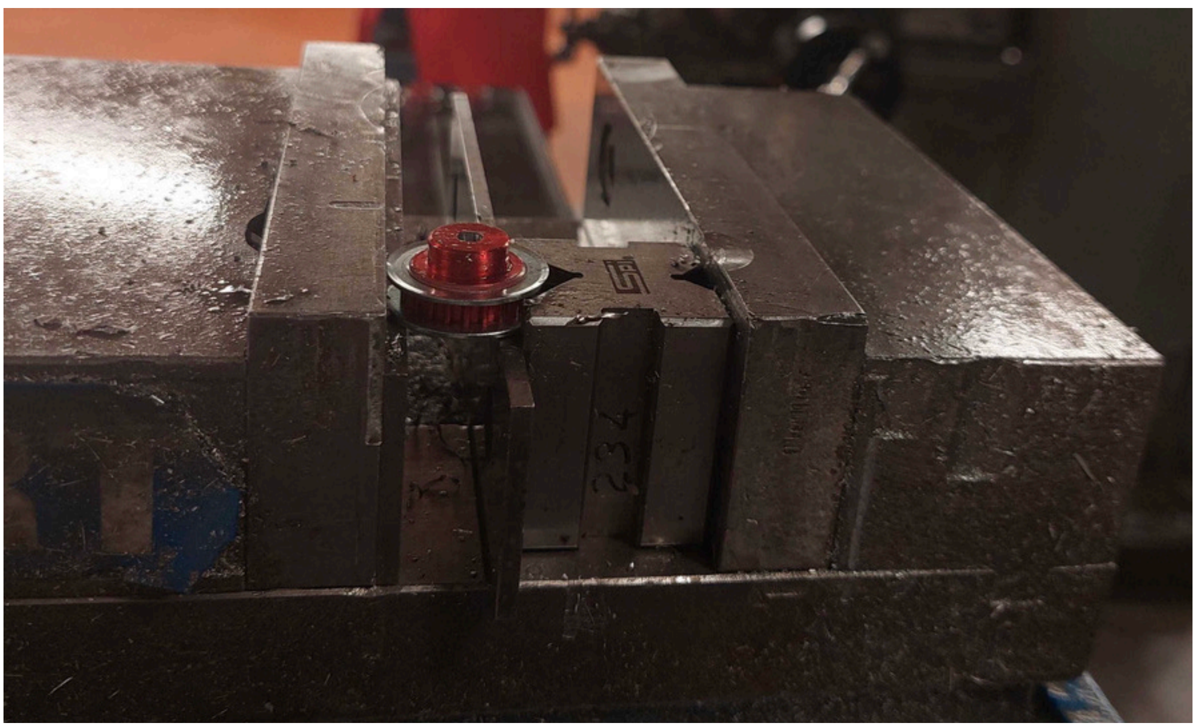

Figure 9: V-block fixture set up used to machine the pulleys. Use the wiggler to find the edges of the circle, matching with nominal dimensions. Use the mill's digital display buttons to then find the center. Repeat on both x and y-axes.

8.3 Weapon

8.3.1 Flipper Shape

- Our flipper was a long, slightly triangular aluminum bar. While this is a very simple design, it does not provide much leverage to lift opponents. Opponents slide off of the flat flipper edge.

Conclusion: To gain more leverage, flippers should have some sort of ”hook” on their end to gain more leverage while lifting. This usually looks like an angled ”forklift” at the end of the flipper.

8.3.2 Wedges

- Lance struggled to lift heavier opponents because its chassis was too short. Lance tended to flip itself over instead of the opponent.

Conclusion: Wedges would not only protect Lance against flipping and add a passive weapon, but lengthen its chassis to provide more leverage when flipping opponents.

8.3.3 Extra Weight

- Lance was significantly underweight (less than 10.5 lbs.)

Conclusion: As good practice, every combat robot should be as close to the weight limit as possible to provide the best performance. Heavier robots also have more momentum when colliding with other robots, stay on the ground better when lifted or flung, and carry more and advanced features.

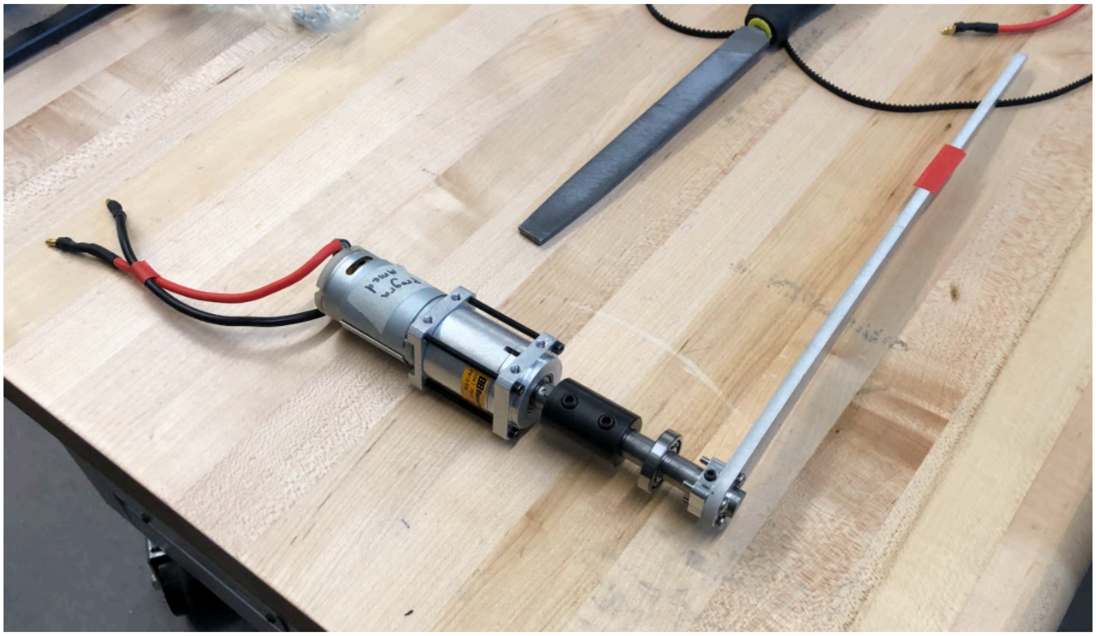

Figure 10: Lance’s weapon.

8.4 Hardware

Lance had a mixture of multiple types of metric and imperial screws rather than one standard screw type.

Screw type and part:

Chassis	M5
Drive Motors	M4
Weapon Motor	10-32
Securing Pulleys to Wheels	8-32
Weapon Hub	6-32

Set up for cutting screws:
We used a Wilton 11105 General Purpose Bench Vise whose base had not been bolted down. At first, we simply placed the screws vertically between grooved steel jaws inserts to get a cutting groove into the screws using a saw. Then, we placed these screws horizontally to cut them all the way through. To secure the base of the vise and help keep it sturdy, we asked our team mates for help. This included them holding the base to the table which was definitely not ideal. The next time around we used the same free vise. However, this time we secured it on a table using 4 clamps. This was much more sturdy and safe. In the future, it would be advisable to have the vise pre-secured to a table to make for a safe cutting environment.

Conclusion:
The team will discuss which path will become the team standard over the summer because we now have many metric screws, taps, and dies, but the machine shop has mostly imperial tools. If we do decide we absolutely need to cut screws, it is best to get a screw $>$ 1cm longer than needed so that it can be safely cut.

9 Reflection of Work Flow

This section describes several logistical/non-technical lessons that we made to our work flow as the semester progressed.

1. **Host mid-week work sessions for whoever can come.**
   Instead of trying to find a time in the middle of the week that works for *everyone*, send a weekly when2meet and choose a time that works for at least 3 people.

2. **Make and print out a reference document of which tool sizes are used.**
   Our Allen Keys reference document is attached in Section 12.2. Each Allen key was labelled with colored tape to be identified with the reference document.

3. **Collect all the Sportsman-specific hardware we may need in 1 box.**
   We did this the day before competition, but it would have been much more organized to do so earlier, rather than keep items in bags in our large Sportsman boxes on the shelves.

4. **Label Lance's controller with tape.**
   We confused our controller with Kinetic's at least twice. Label Lance's transmitter clearly and form a habit of checking the transmitter's label before use.

5. **Ask for help on the NHRL Discord Link!**
   There are many experienced combat robotics builders willing to help on this Discord. Use this and other forums as a first resort. Other builders are an important resource for finding suitable products and knowledge sources.

6. **Address issues immediately and fully specify design decisions in the Fall before they carry over into the Spring.**
   Many of our problems in the Spring came from issues not fully addressed in the Fall. When we notice issues we must fully address them before continuing with assembly.

10 Unresolved Issues

While we were able to build a functioning robot for competition this year, we still have a few unresolved issues that may need to be addressed if Lance were to be used in future competitions. Potential solutions are presented.

- **The weapon hub set screw slips around its shaft**
  - **Potential Solution 1:** Bolt the hub through/to weapon shaft with steel screw (chance of the bolt shearing).
  - **Potential Solution 2:** Create/make parts for use with hex shafts (flipper could easily have a hex hole water jetted into it).

- **The key does not keep the weapon shaft from sliding axially**
  - **Potential Solution:** Use a hex-profile shaft (such as this) in the weapon motor instead of using a collar to join two circular shafts end-to-end

- **One drive ESC continuously burns out**
  - **Problem 1 Description:** Some motors or ESCs stopped working temporarily (perhaps due to poor connections or high current).
  - **Reason:** Some wires at their ends looked a little loose (out of their socket) and shorted.
  - **Solution 1:** Only pull on the XT-60 or other connectors when detaching wires.
  - **Solution 2:** Smaller gauge (shorter diameter) wires to fit better into XT-60 connectors.
  - **Solution 3:** Check for what part of the circuit is missing voltage with a multimeter.

  - **Problem 2 Description:** The current was too high when things did not move properly (stall torque).
  - **Reason:** Perhaps things were caught on the ground, inside the chassis, or shaft collar and stopped movement.
  - **Potential Solution 1:** Check for external factors that may be jamming motors or axles.
  - **Potential Solution 2:** Release the joystick when a motor has reached stall.

- **Nonintuitive backwards driving settings on the transmitter**
  - **Potential Solution 1:** Practice driving backwards more.
  - **Potential Solution 2:** Get a different, more customizable transmitter.

- **Weight was not maximized due to weight fluctuations in manufacturing**
  - **Potential Solution:** Have additional modular components that can be added to the robot to ensure the weight limit is properly utilized.

11 Competition Overview and Analysis

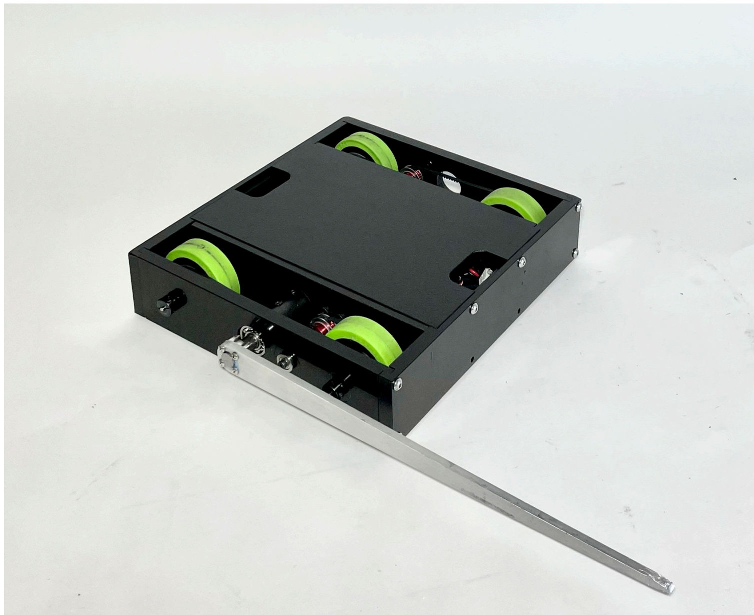

Figure 11: Lance at the Norwalk, CT, NHRL Arena Photo booth on April 23rd, 2022.

11.1 Matches and Results

At competition, Lance had one official match against Woody II and one grudge match against Woody III. In the first match Lance was able to get under Woody II relatively easily using his flipper and flipped it over. Since Woody II had no self-right mechanism, we won the match and even celebrated with a few flips for the audience.

During our second match later that night, Lance's weapon was not properly checked and the weapon shaft was rotating relative to the flipper. This meant that Lance was not able to lift the amount of weight intended. During the grudge match, Lance was able to successfully get under Woody III multiple times but due to the weapon problem, Woody III was able to force Lance into a corner where we were stuck and unable to move. It was later decided by the judges unanimously that Woody III had won that match.

11.2 Teams We Met

Some of the teams we met at competition included Worcester Polytechnic Institute (WPI) and the team behind Hotleafjuice. WPI had multiple robots that entered the competition and suggested that we try to enter the 3lb competition in the future. They claimed it was more fun and exciting.

We also gained a lot of insight talking the builders of Hotleafjuice. One specific problem she brought up was how to design to account for the inaccuracy of timing belts. Hotleafjuice's design stems from the length of the belts. Another potential solution is using a belt tensioner.

One of the most exciting people we met at competition was Ed, Woody II's builder and competition staff. He brought the team around the company that was located a few blocks away from the competition site and showed us several machines. We even found a ball pit!

12 Appendix

12.1 Circuit Diagram

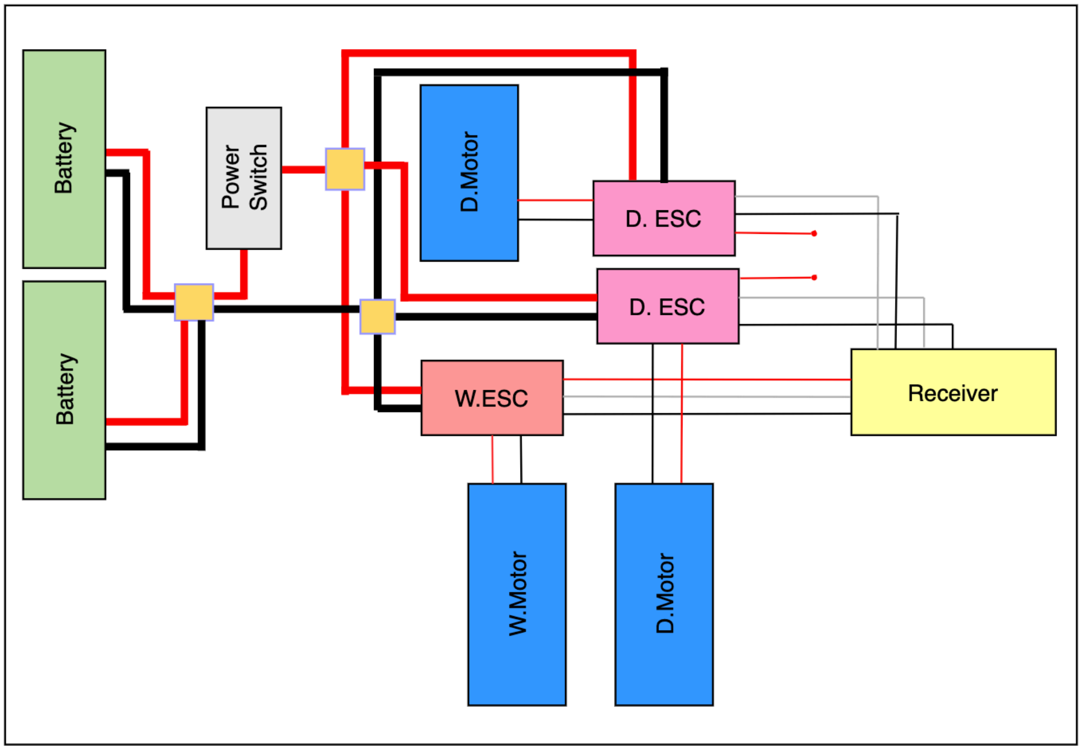

Figure 12: This is a circuit diagram showing Lance's electronics. The yellow boxes are wire junctions.

12.2 Allen Key Identification Chart

Combat Robotics @Cornell

Sportsman

Friday 4/15/2022

Allen Keys

Both red cases are metric
Orange and yellow are imperial (inches)

Part	Which set	Tape color code	Size
4-40 Pulley set screws	Orange case, imperial	Blue red blue	Smallest (0.05”)
*65mm long drive motor axle screws	Red case, black matte	Red black red	3mm
Black collar’s set screws	Red case, black matte	Red blue red	2.5mm
Chassis M5	Red case, black matte	Red black red	3mm
Chunky black weapon collar	Yellow case, black matte	Blue with 2 black stripes	⅛”
8-32 pulley-wheel assembly	Orange case, imperial	Red with 2 black stripes	3/32”
Power switch	Orange case, 0°imperial	Red with 2 black stripes	3/32”

Other tools

Part	Tool
10-32 weapon motor mount screws on bottom plate	Phillips screwdriver
6-32 weapon to hub	Phillips screwdriver
65mm long drive motor axle screws	9/32 silver wrench in red pouch
8-32 lock nuts for pulley-wheel assembly	11/32 socket wrench

Figure 13: This is the chart we made for identifying which allen keys we should use where on Lance. The Google doc can be found in the CRC drive here.