Embry-Riddle Aeronautical University

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CONDUCT OF THE DESING PROCESS, TEAM IDENTIFICATION, & TEAM ORGANIZATION

Introduction

The IGVC team's main goal is to win the 30th Annual Intelligent Ground Vehicle Competition. With this overarching goal in mind, improvements to ensure the proper running of the vehicle were made with three problems in mind. One problem was the overheating of internal components inside the case. The pelican case was painted white to reflect all wavelengths of light instead of absorbing them with the original black color of the case. Another problem identified was the vehicles' current power supply. Currently the vehicle uses a LiPo battery, which if drained too much or charged too long can cause an explosion and fire. Due to the high hazard and potential damage to the vehicle, the team decided to switch to a Li-ion alternative. The battery that was acquired has a built-in protection circuit, has a water resistance of IPx4, and is intended to be mounted outside the Pelican case to ensure overheating will not occur. The final problem addressed was reorganizing the internal wiring to ensure proper comprehension of what was inside. Wires were labeled and tape was added to denote what components wires belonged to and what exactly they provided to said component. The idea behind doing this was to ensure any member of the team would be able to identify what was going on inside the case and identify problems if they arose. With these problems being identified and addressed, the team is confident these steps will further the team towards the objective of winning the 30th Annual Intelligent Ground Vehicle Competition.

DESCRIPTION OF MECHANICAL DESIGN

Overview

GAVIN measures 29" wide, 43" front to back, and 62" tall. It is a differentially driven robot using twelve-inch diameter rear pneumatic wheels, with an eight-inch diameter pneumatic tire caster wheel in the front. To protect the sensitive electronics, a waterproof IP65 rated Pelican "Air" Case was utilized. The "Air" version of the Pelican case is 40% lighter than a standard case. While weight is not a direct factor in competition judging, a lighter vehicle increases run time and improves overall dynamic performance. Additionally, the use of a Pelican case makes the electronics more modular and easier to transport. The electrical system connections pass through a panel which uses IP65 rated connectors to allow sensor communication with the internal computing components while allowing the system to remain water resistant. The overall system is designed to be modular, allowing for easy assembly, disassembly, and transport.

Chassis

GAVIN's chassis is made of a carbon fiber platform with Nomex sandwiched between the outer layers. The combination of these materials gives the robot an incredibly rigid platform while remaining lightweight. The electronics case is mounted to the chassis using two threaded studs, making assembly quick and easy. This is the same frame used for the 2019 and 2021 coemption. While changes were considered this year, it was ultimately decided to keep the same proven chassis design.

Sensor Pole

A sensor mast carries the camera, LiDAR, safety lights, emergency stop button, and an Ubiquiti Omni-Directional Antenna. It is fabricated from a 1" square carbon fiber tubing mounted upright from the base of the frame. Carbon fiber was chosen for its rigidity, strength, and lightweight. The wires for the components are fastened to the sensor pole in a manner that allows for rapid swapping of sensors or lights. The components are fitted using 3D printed friction mounts designed to allow for secure attachment to the sensor pole. These mounts were also designed to prevent undue stress which could compromise the structural integrity of the carbon fiber, while also providing the highest amount of stability for the sensors.

Drivetrain

The drivetrain includes the motors, their mounts and adapter plates, and the sub-frame. The sub-frame is a 2-foot section of 15 series T-slot 8020 extruded aluminum that provides a strong, rigid mounting structure. An adapter plate was machined to match the size of the motor mounts and 8020 rails. The motor mounts hold the motors by clamping onto the cylindrical gearbox. The motors generate 20 in-lbs. of torque and uses a 15:1 gearhead to reach and maintain the maximum speed limit of 5MPH while going over the ramps described in the IGVC rule document while also carrying the required 20-pound payload.

Computer

The Intel NUC7i7BNH is used to process and communicate all data. It has a 3.50 GHz processor, 32 GB RAM, with an internal storage of 512 GB. The NUC runs on Linux Ubuntu 20.04, and ROS

Noetic to run the software. The system's software is written using Python as the programming language.

LiDAR

The Velodyne Puck Hi-Res is a 16-beam LiDAR capable of full 360 horizontal FOV with a resolution of 0.1-0.4 degrees, and a 20-degree Vertical FOV which gives 1.33 degrees between channels. The LiDAR generates 300,000 points per second, and can measure a range up to 100 m with an accuracy of ±3 cm. It is rated for IP67 environmental protection. An aviation passthrough connector was used to feed the LiDAR through the pelican case and into the Velodyne interface box.

IMU/GPS

The Vectornav VN-300 Rugged is a high-performance Dual Antenna GNSS-aided INS. The system uses two Tallysman GPS Antennas to give accurate heading measurements of +/- 0.2 degrees, along with the IMU to ensure accuracy and precision with and without the vehicle moving. The IMU collects data at 800 Hz while the GNSS has an update rate of 5hz. Sensor fusion occurs within the VN-300 itself to provide the most accurate data to the system.

Safety Devices

GAVIN incorporates a direct voltage cutoff system built into the power board as part of the safety system requirements. This system cuts off power to the motors but keeps the sensors running to avoid an extended restart time. E-stop buttons are located on the sensor pole and the RC controller. When the E-stop is pressed, power to the motors is killed. The addition of the circuit breaker provides a way to shut off all power from the source in the event of a safety-critical emergency, such as an electrical fire.

In addition to the hardware E-stop, the power board has a software E-stop for the motors as a secondary safety option. Whereas the hardware E-stop kills the power to the motors, the software E-stop sends a zero-speed command to the motors, which allows for a shortened restart time after removal of the stopped state. The RC controller emergency stop has a range of 0.25 miles. Should GAVIN go beyond that range and lose connection with the controller, it is automatically stopped

Design process

The team followed a similar design process as previous semesters:

1. Customer Needs
2. Requirements Definition
3. Brainstorm
4. Detailed Design
5. Creation and Testing
6. Refinement
7. Documentation

The team first sought out contact from the provided customer, Charles Reinholtz, and established a date to meet.

At the customer meeting the team created and refined the requirements directly with the customer so the team knew exactly what should be worked towards for this semester.

With requirements finished, the team discussed a number of ideas of how to achieve them. Many ideas were compared directly to see what the team could work towards in a cost effective and timely manner while addressing the requirements. The ideas that aligned with these principles the best were the ones that were chosen.

These chosen ideas were then moved to written designs and diagrams so that the team could visually understand what was trying to be achieved and get an idea of the space being dealt with.

Being on the same page, each member participated in making the design a reality. Members sought to do tasks together instead of apart so that the team could learn together and speed through tasks when necessary. Members also participated in testing to verify their understanding and provide insight into the tests. If a test did not go as planned, the team would piece together what went wrong and what might work instead. This entailed jumping back to the brainstorming phase and working all the way back to the testing phase.

If a test went well, additional factors may be considered to ensure understanding among team members and the proper understanding of the data to people outside the team. Adjustments would even be made in the interest of refining the test.

The final step of the process was creating a report to relay and outline all that was done in service to this design process.

Requirements

1. The vehicle shall meet all IGVC safety requirements from IGVC Competition Rules under the V.B3 SAFETY REQUIREMENTS AND UNIT TESTS section in the link below.
    a. http://www.igvc.org/2023rules.pdf
2. The electronics box shall not exceed 50 pounds (22.68kg).
3. The electronics box shall be IP65 rated.
4. The electronics case shall not exceed an internal temperature of 100 degrees Fahrenheit while exposed to the maximum outside temperature of 90 degrees Fahrenheit in Daytona Beach, Florida and 83 degrees Fahrenheit in Rochester, Michigan during the summer (June 2nd – 5th).
5. The electronics case shall meet standard carry-on bag dimensions for the selected airline.
6. Internal wiring shall follow a custom color code guide as shown in Figure 1

Black	Red	Orange	Yellow	Green	Blue	Purple	Brown	White
Ground	Power	Motors	Communications	LIDAR	Camera	Navigation	Monitor	NUC

Figure 1: Wiring Color Guide

7. The battery shall have a built-in protection circuit.
8. The battery shall meet TSA safety requirements.
9. While driving through the obstacle course, the vehicle shall not drop below the minimum of one mile per hour nor exceed the maximum speed of five miles per hour.
10. The software shall include lane detection and line following.
11. The software shall include obstacle detection and avoidance from construction specified in the IGVC Competition Rules in the "II.3 Auto-Nav COURSE" section.
12. The software shall include Waypoint navigation.
    a. The vehicle shall be able to find a path to a single two-meter navigation waypoint by navigating around an obstacle.
13. The housing container for components shall be accessible by anyone on the team as necessary.

Innovations

Heat Reduction

To reduce the temperature of internal electrical components, the Pelican case was painted white so heat would be reflected off of it. Figure 1 shows the temperature inside the black Pelican case and white Pelican case over the course of an hour. While the results clearly show lower internal temperature for the white pelican case, the sensors used had a high margin of error of +/- 7°F. In the future, the team will be using more accurate sensors and will normalize and label them so an exact difference in temperature measurement can be determined. Once those sensors are ready for testing, the black pelican case will be used as a controlled testing environment for new heat reduction strategies, with the decided on method being implemented onto the white pelican case. This will be done so that no unnecessary modifications are made to the white Pelican case.

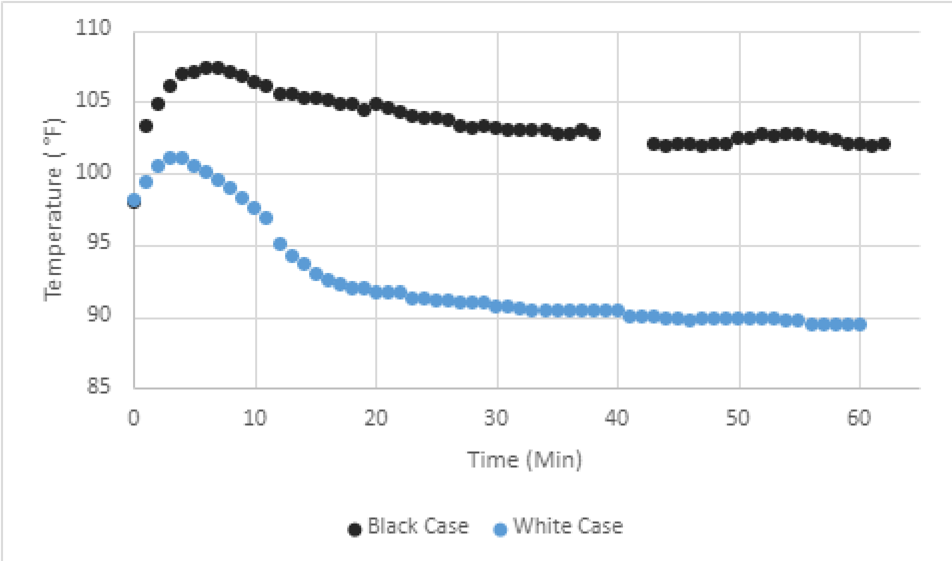
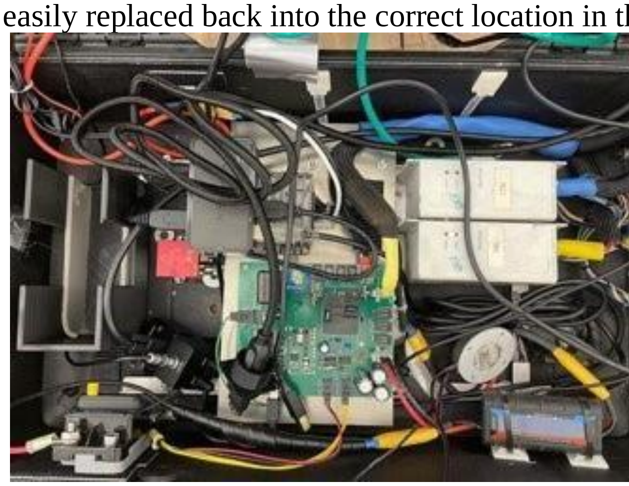


Figure 1: Internal Temperature Test of Black Case vs. White Case

Organization

All wires and electronic components were labelled and reorganized so that they could be visualized more clearly. Stripes of tape were also added to wires and color coded to indicate which components they connected. A wiring diagram, component layout sheet, and the color-coding table will be printed and added to the lid of the Pelican case so that anyone can open it and understand the layout. To ensure that components did not move or get tangled in wires, foam was left in the case with cutouts for each component to rest in. This also allows a component to be removed and easily replaced back into the correct location in the case.



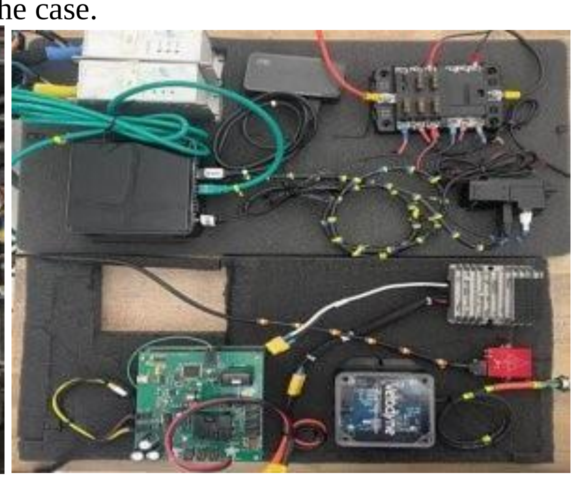


Figure 2 – Before and after wire organization

However, the foam got damaged overtime. The team's alternative to keeping the electronic components organized was to design an electronics housing as described in the next section.

Electronics Housing

With the replacement of the old pelican case, a new organizational method was also created to better house the internal electronic components. The team decided that the electronics housing needed to be lightweight, easy to remove, stable, and capable of holding the electronics in place while allowing ease of access to important components.

Upon careful consideration, the team designed a two-shelf system that would house the most critical components on the top shelf and the secondary components on the bottom. The design was 3D modeled in Autodesk Inventor, as shown in Figure 3, and was manufactured out of available wood that was deemed suitable for use. The proper materials were gathered from the lab and the electrical stand was then manufactured and assembled as shown in Figure 4.

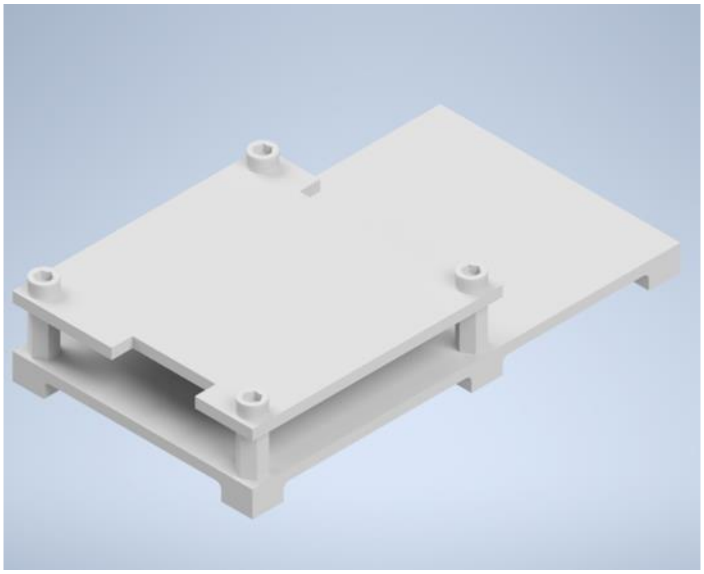


Figure 3: CAD Model of Electronics Case

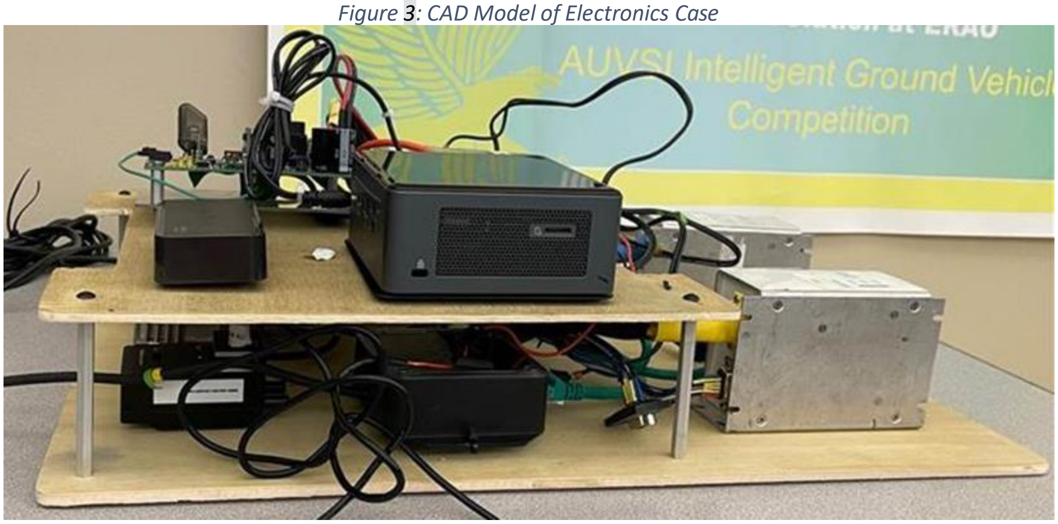


Figure 4: Assembly of Electronics Case

The wooden boards offered enough structural support to hold all the electronics in the pelican case without fracturing. However, in order to properly fasten the electronics to the board Velcro strips were glued down to the board and attached to the bottom of the components. These strips offer enough strength to hold the components in place while also allowing the components to be easily removed from the board to be replaced or reorganized.

Organization of Electrical Components

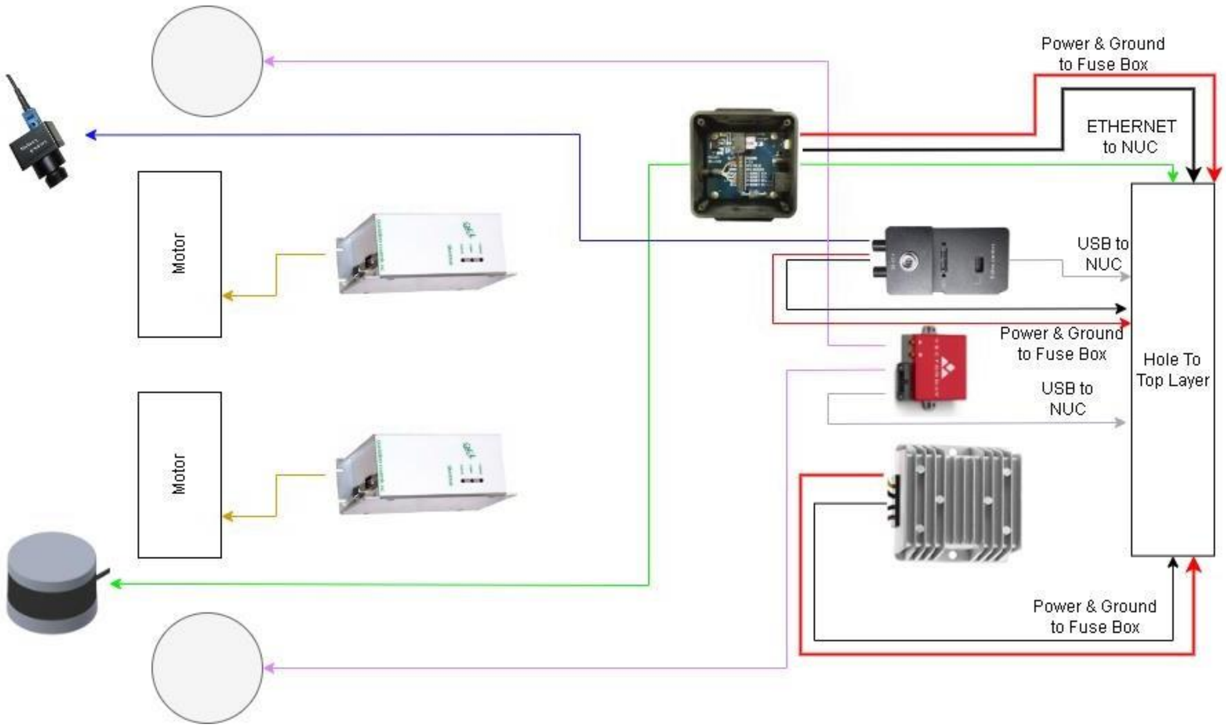


Figure 5: Electrical Schematic of Bottom Layer

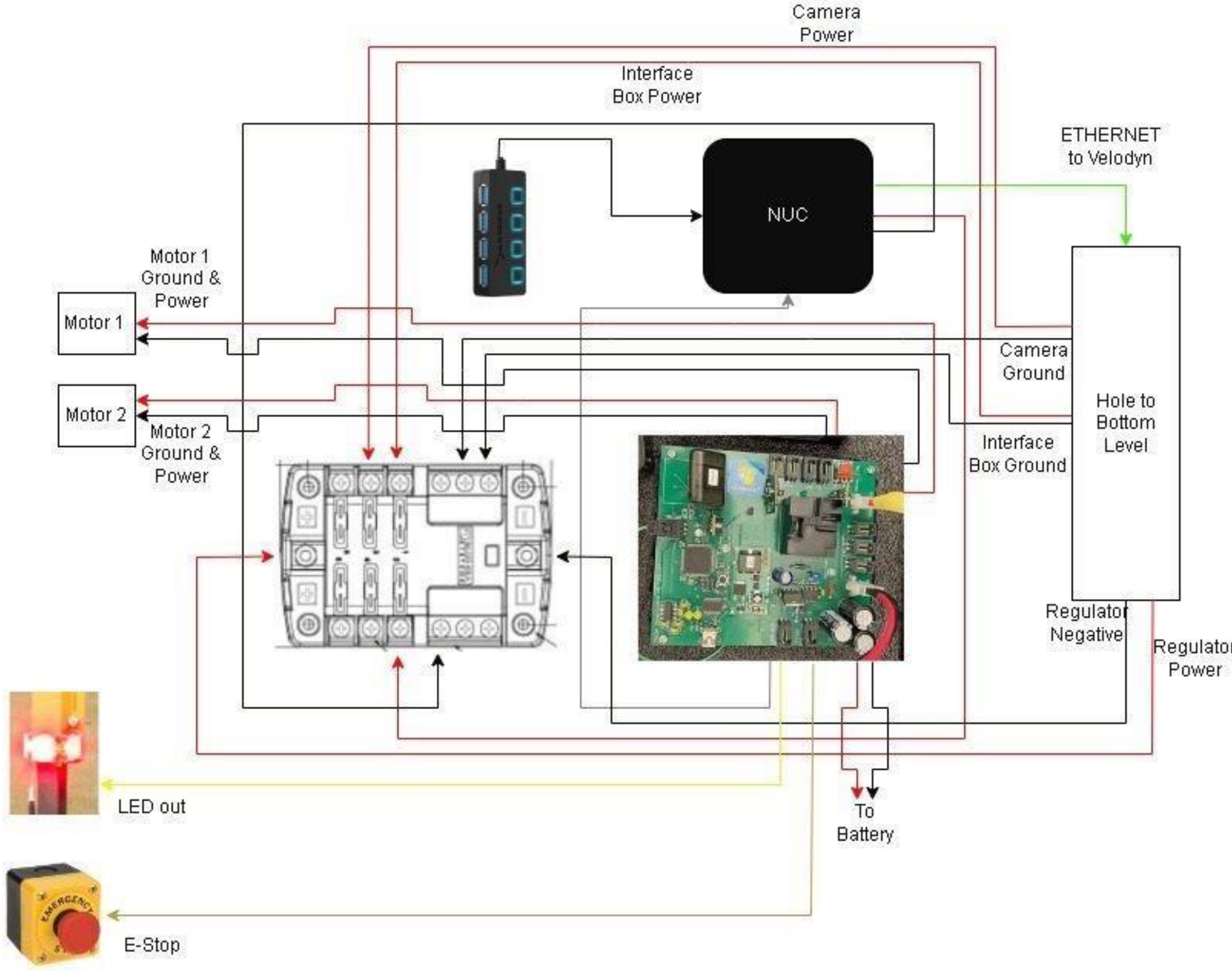


Figure 6: Electrical Schematic of Top Layer

Figures 5 and 6 show the configuration of the electrical components placed on the internal wooden structure in the Pelican case. These diagrams, along with the wiring diagram from Figure #, will be taped inside the lid of the Pelican case, so IGVC team members can open the case and easily locate a component that they are looking for.

Pelican Case Mount

By changing pelican cases, the team faced new challenges mounting the new case onto the carbon fiber platform. The previous design was composed of a bolt running through foam with a washer mounted on top and roughly 0.5 inches of thread exposed as shown in Figure 7. This assembly was then epoxied to the carbon fibers frame. Upon assessing the original mounting points, used to attach the previous pelican case, the team determined them inadequate for mounting the newly chosen pelican case.

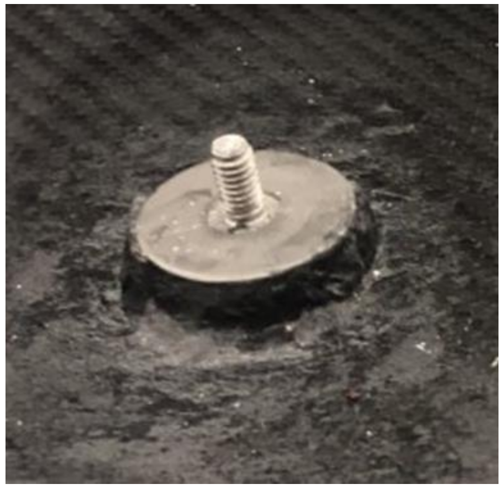


Figure 7: Previously Used Attachment Bolt

This method was applicable for the previous design, as the pelican case had a lower overall thickness. However, upon upgrading the case (the new case has a retractable handle and doubles as a traveling case to enhance transportability) its base thickness is significantly larger than that of which the bolt can accommodate. Additionally, these two points were not center aligned on the base. This misalignment, in conjunction with the design of the new pelican case, made it impossible to center the case on the base.

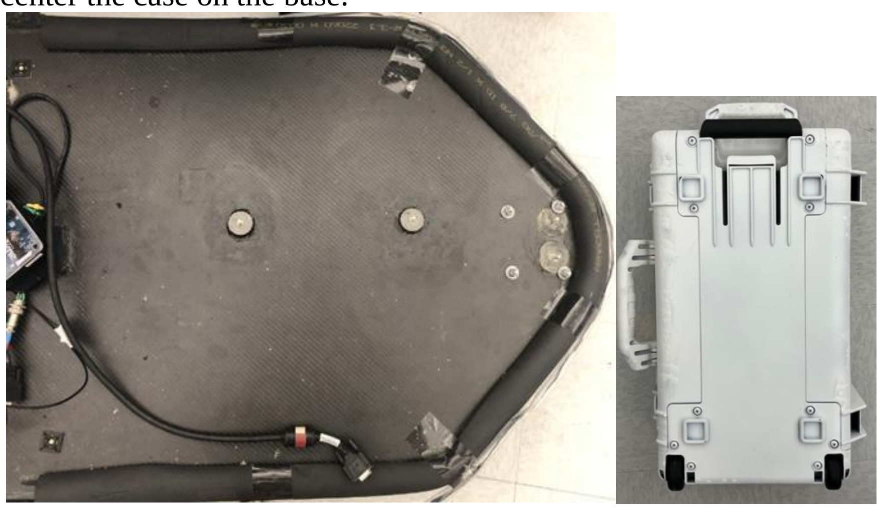


Figure 8: Composite Base and Pelican Case

With little documentation available on this design, the team determined the best course of action was to remove this assembly by cutting off the bolts and leaving roughly .25 inches of material left. Due to the epoxy bonding, cutting any lower on the disks would risk damaging the carbon fiber base. A new design was then created with the focus on ensuring future teams wouldn't run into the same challenges. This design consists of four aluminum disks, 1.5 inches in diameter, with a ¼-20 threaded interior hole that is epoxied to the carbon fiber using J-B ClearWeld Quick-Setting Epoxy. Threaded rods, with a length of approximately 1.75 inches are then threaded into the disks and a wooden board is then mounted onto these threaded rods with washers and hex nuts. The pelican case is then fastened to the wooden board. The four aluminum disks are placed in a rectangular pattern. This spacing was selected so that the wooden board would cover the most space on the base while also leaving enough room at the edges to prevent protrusion from the carbon fiber and conflict with the payload region. The rods threaded into the disks are also secured with Loctite blue to both ensure a strong connection but also allow for future teams to replace the mounting rods as necessary to the design.

Due to the modularity of the new design, if future teams decide to change the pelican case or adjust its placement, rather further destroying the carbon fiber frame, adjustments would only be made to the wooden plate. Due to the material being easy to machine and cheap to replace, future teams can drill as many mounting holes as needed or replace the hole segment with little concern for cost or time. The current team chose to cut four ¼ inch holes in the board which can be aligned to four ¼ inch holes on the bottom of the pelican case, each of which are centered in square ‘bumpers’, seen in the figure above. A
¼-20x4 bolt the runs through both the wood and pelican case holes and is then secured with a hex nut.

Batteries

The integration of drill batteries into the system is an innovative point to present during competition due to the plug-and-play feature, built-in protection circuit, and IP protection rating. The current power source of the vehicle is a six cell 25.2V lithium-polymer (LiPo) battery. The LiPo battery doesn’t have a built-in protection circuit. The LiPo battery needs to be handled carefully and avoid getting dropped. The charger itself requires the correct input parameters of mAh and battery cell before charging the battery.

As a power source alternative, the team proposed the use of drill batteries as a safer and easier-to- use tool to improve the performance of the vehicle overall. The drill batteries’ charger doesn’t require input parameters before charging and the batteries can be dropped without becoming a fire hazard. The built-in protection circuit will stop the flow of current before the voltage level drops below the minimum safety value. As a matter of fact, the built-in protection circuit provides protection against overcharging and over-discharging. According to Digi-Key Electronics, the fourth largest electronic component distributor in North America, the protection circuit will cut the circuit connection if the load current is too high to prevent the battery from discharging too quickly and will protect the battery against fire ignition if the maximum safe voltage charge value per cell has been reached (Knight, 2015).

Table 1 – Lithium Polymer and Lithium-ion Battery Comparison

	Current System Power Source Lithium Polymer Battery	Propsed Alternative Lithium-ion Drill Battery
Built-in protection circuit	x	✓
Easy to charge	x	✓
IPx4 rated	x	✓

The Lithium-Ion drill Battery has an IP protection rating of IPX4 which is the minimum protection required for outdoor use. The current LiPo battery is placed inside the Pelican case. However, for future improvements, the team will place the drill battery, the kill switch, and the voltage displayer outside the Pelican case as shown in Figure 9 for better accessibility. By placing all three components outside the Pelican case, the team can read the battery voltage, turn off the system and switch out the battery if needed without having to open the Pelican case.

Figure 9 – Components outside of Pelican case

Table 2 – Battery Specifications

Lithium Polymer battery (LiPo)	Lithium-ion Drill Battery
25.2 V	24 V
166.32 Wh	192 Wh
166.62Wh/77.3W = 2.15 hours of run time at mid speed	192Wh/77.3W = 2.48 hours of run time at mid speed

Lastly, a power draw analysis was performed to compare both batteries in terms of maximum running time. Using equation 1, the run time provided by the battery can be calculated according to the power required from the system. At medium speed (77.3 watts power draw), the lithium-ion drill battery will provide 2.48 hours of run time compared to the LiPo battery which provides 2.15 hours. Therefore, the drill battery will provide 15% more run time than the LiPo battery because of the 192Wh capacity being greater than LiPo's 166.32Wh.

$$\text{Power} = \frac{\text{Battery s watts hour}}{\text{Power required from system}} \quad (1)$$

The team took measurements of the new drill battery to create an adapter as shown in figure 6. The adapter was cadded using Catia v5 and 3d printed with a Prusa printer using PETG filament. Copper blades go into the battery's ground and power slots. Then, wires are soldered to the copper blades to be able to connect it into the system.

Figure 10: CAD Drawing of Battery Mount

Portability

One issue with the current design is the ability to travel and move the Pelican case. This applies to carry-on baggage for airlines and transportation by an individual team member. Thus, two design ideas were researched and considered.

Backpack

At times, the Pelican case will have to traverse uneven/unpaved ground. This eliminates rolling and thus must be carried. To alleviate the complications of carrying the case by hand, backpack straps are to be implemented to the bottom of the case, using its pre-existing screws that fasten the rolling handle. By allowing a user to carry the case on one's back, their hands can therefore be freed for other tasks. This feature will also aid in the carry-on process of transporting via airline, being only a hard backpack. Strap type, size, etc. have not been finalized as of yet and are still being researched.

Luggage Handle

The Pelican case chosen features an extendable luggage handle, along with wheels, so that the user can roll the case like a suitcase. This feature is handy in travel through airports, hotels, etc. This combined with the previous design of backpack straps allows the electronics and components to be transported anywhere much easier than a standard case.

Testing

A power draw analysis was performed to compare both batteries (LiPo and lithium-ion) in terms of maximum run time provided. The test was performed with the LiPo battery to power the system and the voltage reader. Then, the team recorded the values with a phone. The base power draw average is the power draw of the system on standby without drawing power from the motors. The team recorded power draw values when driving at different speeds and pivoting clockwise and counterclockwise. The spike in CCW power draw being 170 watts average is due to the castor wheel at the front of the vehicle having to correct itself before the vehicle starts turning.

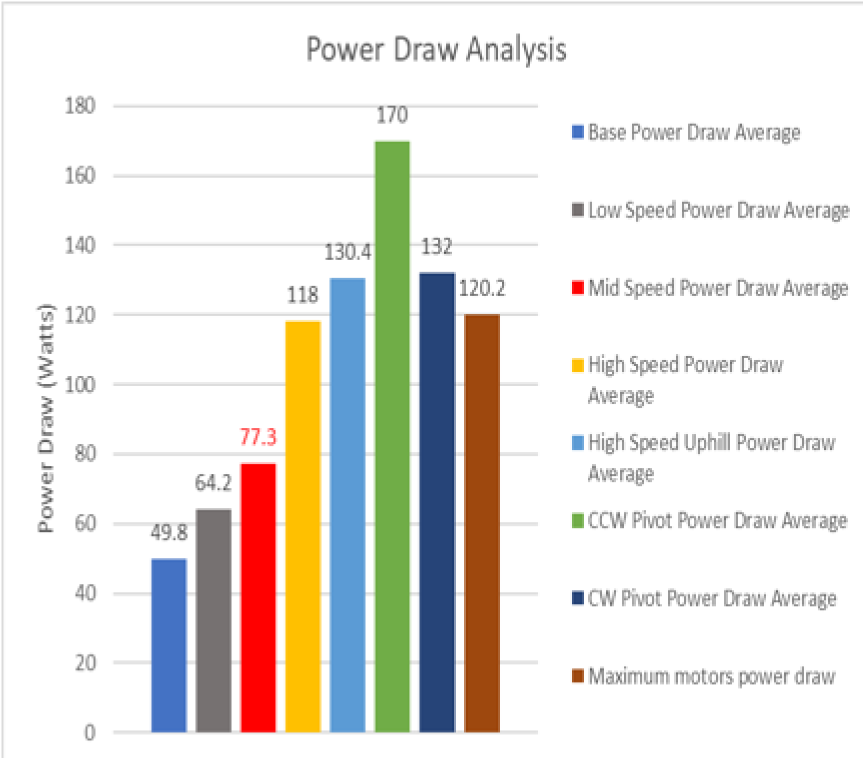


Figure 11– Power draw analysis

Medium speed is ~2.21 mph. High speed is ~3.99 mph. Low speed is ~0.89 mph. The speed of the wheels was measured with a tachometer in rpm and then converted to mph.

Future Work

For future work, the team plans on adding the hot swappable battery feature to keep improving the usability of the vehicle. The team can 3d print more battery adapters as needed, add diodes, and create a circuit that will allow to switch batteries without turning the entire system off.

Conclusion

To provide a better foundation and to move ever closer to the intended target, the team identified problems and worked toward addressing them. This was done through the creation of a new wiring key and labeling of all internal components, designing an electronics housing frame, painting the Pelican case white, and finding a Lithium-Ion battery to replace the previous LiPo.

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