The Beach Mule

Submitted to:

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EXECUTIVE SUMMARY

Going to the beach is one of the great luxuries people get to experience currently. It is a time of relaxation and a time to remove yourself from the worries of daily life, but there are still moments when a beach vacation can become more of a hassle. Having to carry belongings to the beach front can be a troublesome task that can ruin the relaxing getaway one plans. Beach Mule is designed to fix just that, allowing the user to relax sooner worry free.

Beach Mule is an automated assisted drive cart designed to carry beachgoer's belongings across any type of beach terrain. Designed with offroad tires and its central motor, Beach Mule can plow through either the sandiest or the rockiest of beaches with no trouble. Beach Mule was designed with the user in mind, and that they want to be worry free going to the beach. Hence, the Beach Mule is outfitted with an autopilot feature that will follow the user and avoid obstacles that may come between the user and the cart. All these components together help streamline one of the biggest issues for beachgoers, so they can worry less and relax more.

Approaching the problem of carrying items to and from the beach, there were multiple hurdles and problems that needed to be addressed to combat this problem. The first being the weight of all the items in the cart. After designing Beach Mule with strength in mind, next it would need to have the power to move all the items once loaded. Outfitted with a motor to propel the car through the sand with regards to the weight, the final hurdle would be its automation. To track the user, Beach Mule needed to be outfitted with a Bluetooth device to connect to a phone as well as a GPS module to understand the position of the cart with regards to the user. Both of those components would be able to communicate to the cart how to maneuver to get to the user's location, but what if something came in between the user and the cart like a child? Sensors were set to the front of the Beach Mule so that if something does come between, the cart can stop and maneuver accordingly to get back on course.

Every part of the Beach Mule works so that the main struggle of going to the beach is removed entirely out of the equation. The design focuses on all the cruxes of carrying items to and from the beach that beachgoers face. This is only the first step in solving this problem as there are some handicaps in the initial design, such as bulky and confined to only one motor. Having found the hiccups in the design, The Beach Mule can be redesigned and restructured to make it even better for the user and much more user friendly.

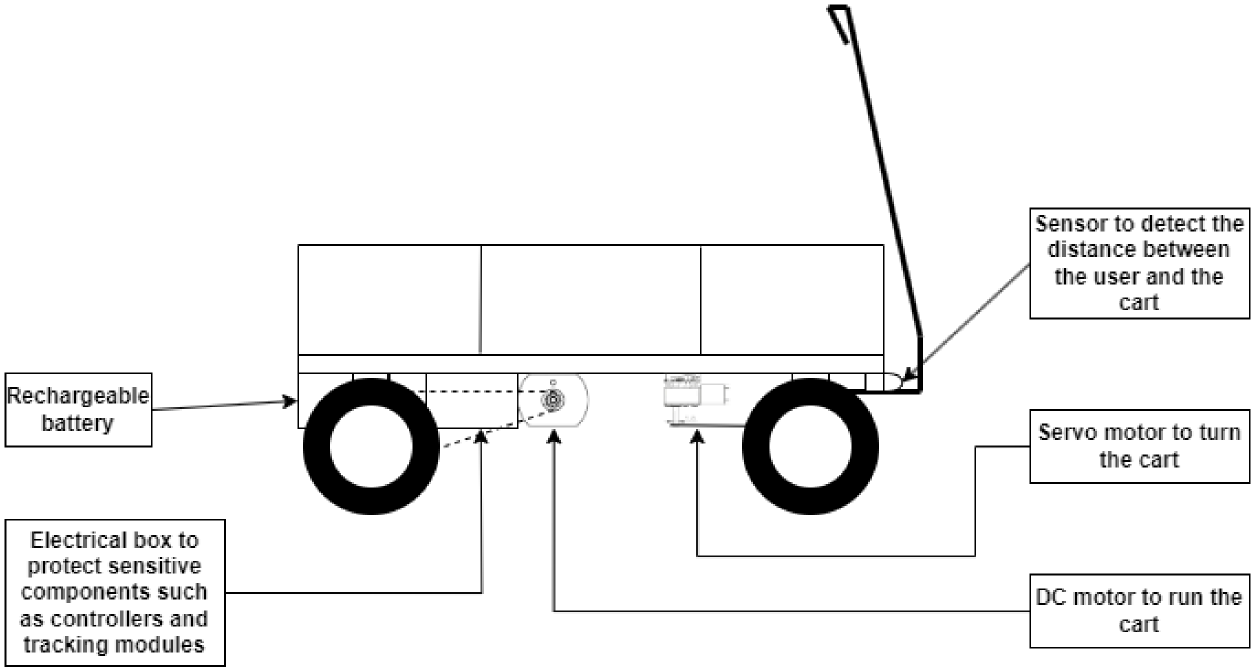

Figure 1. An Example Graphic for the Design Document Executive Summary

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1. DESIGN REQUIREMENTS/CONSTRAINTS

When designing the Beach Mule, certain requirements and constraints arose. The Beach Mule handles many different types of beach terrain. To do this, it utilizes large tires to stay above the sand and not get stuck. The cart also has a reliable power source that allows the Beach Mule to operate continuously for more than one hour. The Beach Mule showcases a sturdy frame that allows it to carry up to 120 lbs. With an autonomous feature, the Beach Mule follows its user for a stress-free experience. The following section covers in detail the required specifications of the project.

1.1. Technical Design Constraints

Below are the requirements that are fulfilled. These requirements are met to provide clarity for customers and other stakeholders while also meeting technical needs.

1.1.1. Marketing Requirements

The Beach Mule is an innovative and advanced beach cart that has an array of features to set it apart from competitors. Firstly, it has an autopilot capability that follows the user. While also being lightweight, it offers an extraordinary level of convenience and carrying capacity. The added feature of motorized wheels further amplifies its efficiency, making it a compelling choice for the consumer. What truly sets the Beach Mule apart is its economic feasibility when compared to competitors' products.

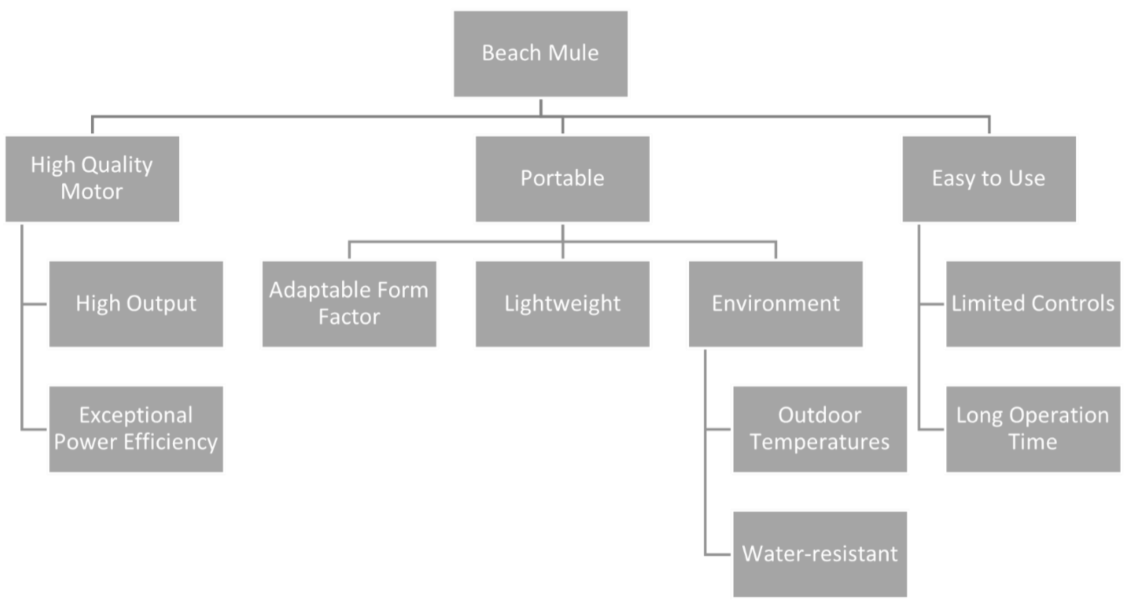

Figure 1-1. Objective Tree for Beach Mule

1.2 Practical Design Constraints

Along with the engineering requirements, the Beach Mule conforms to five constraints: economic, sustainability, manufacturability, health and safety, and environmental. These are listed below in Table 2-3 along with further details.

Table 1-1: Constraints

Type	Name	Description
Economic	Cost	The total budget of the project is $1000.
Sustainability	Reliability	This system is designed to operate over a three-year period without failure. The expected battery life is three years.
Manufacturability	Size	The physical dimensions are 38" high, 21" wide, and 12" deep. This dimension fits inside a car's trunk.
Health and Safety	Safety	The product conforms to IEC 61140, which protects the user from electrical shock.
Environmental	Weatherproof	This product has a battery that is water resistant and heat resistant up to 50°C (122°F). Components are sealed tightly to prevent sand infiltration.

The $1000 budget is set for every design group.
Every system in the Beach Mule is reliable with a long lifespan. Most components are enclosed in a safety enclosure to ensure less chance of component breaking. When a component does break, the replacement parts will be cheap and readily available.
The dimensions of the Beach Mule are large enough to fit large objects, such as chairs, coolers, beach toys and more. The dimensions of 38” high, 21” wide, and 12” deep accommodate listed objects without sacrificing portability.
The IEC 61140 is an international standard that applies to the protection of persons and animals against electric shock. It is intended to give fundamental principles and requirements which are common to electrical systems.
As mentioned above, most components are enclosed in a sealed safety enclosure to protect the components from any element and harsh temperatures. Additionally, the battery chosen (Lithium Iron Phosphate) can handle high temperatures while sustaining the required voltage output needed for the system.

1.3 Engineering Standards

The Beach Mule is designed with consumers in mind while maintaining basic engineering requirements. Table 2-1 below shows the marketing requirements for the Beach Mule as well as the corresponding engineering requirements and justification.

Table 1-2: Engineering Design Requirements

Marketing Requirements	Engineering Requirements	Justification
5	1. The total weight capacity is 130lbs.	Based on the cart's overall weight, the weight limit needed to be adjusted.
1, 2	2. Able to sustain an output power that averages 24V.	The power range provides more than adequate power throughout the cart. It is a sustainable output power for projected motor complexity.
1, 2	3. Has an efficiency of 60%.	Achievable with several different classes of motors.
3	4. Average installation time for the power connection is 30 minutes with charge.	Past trials using standard charge demonstrate that this is a reasonable installation time.
6	5. The sensitive components are enclosed in a safety box.	Due to the environment where the cart is going to be.
Marketing Requirements 1. The system has motors that work efficiently. 2. The system has a high output power. 3. The system is user-friendly. 4. The system is low cost. 5. The system is made from strong material. 6. The system has sealed enclosure.		

The Beach Mule has motors that work efficiently on beach terrain. Its high output power delivers exceptional performance. Simplicity reigns supreme, with a user-friendly interface that makes the cart operation easy and frustration free for the user to worry less, relax more. Additionally, the product weight of the Beach Mule is approximately 33 kg, and the weight capacity is scaled accordingly. Lastly, affordability is a main concern without compromising quality. The Beach Mule embodies advanced features for a fraction of the price compared to competitors.

While the Beach Mule is a beach product, certain standards are required to be implemented to ensure proper code ethics. Table 2-4 shows the required standards for the Beach Mule.

Table 1-3: Standards

Specific Standard	Standard Document	**Specification/Application**
IP-67	This product meets Ingress Protection Standard 60529 set by the International Electrotechnical Commission [1].	Beach Mule is sand-tight, immersible up to 1m in water.
IEC 60086	This product meets International Electrotechnical Commission 60086 [2].	Beach Mule has interchangeable batteries.
IEC 60757	This product meets International Electrotechnical Commission 60757 [3].	Beach Mule has color coordinated wiring for power.

IP-67 was chosen for safety purposes. This standard makes sure that the Beach Mule is water-resistant, as water could lead to the cart breaking or electrical shock.

IEC 60086 was chosen to make sure that the user will have an easy time replacing the batteries. The Beach Mule will require regular maintenance on the battery every few years, so this standard is important as it makes sure that the batteries follow a standard form and fit.

IEC 60757 requires the Beach Mule to have color coded wires. This will make the Beach Mule easier to build and will make maintenance more straightforward.

2. DESIGN APPROACH

The Beach Mule is a device that facilitates the transport of beach items to the desired destination hands-free. This product's sole purpose is to assist those who want to enjoy spending time at the beach with less hassle. To achieve this, the Beach Mule must have subsystems that can negate the difficulty of pushing through sand as well as being able to follow the user at an appropriate distance. This document provides a detailed description of the hardware and software used in the cart's design and how each subsystem functions. The following sections discuss different approaches considered and provide a product overview. Fig. 3-1 provides a visual representation of the components and systems that make up the Beach Mule.

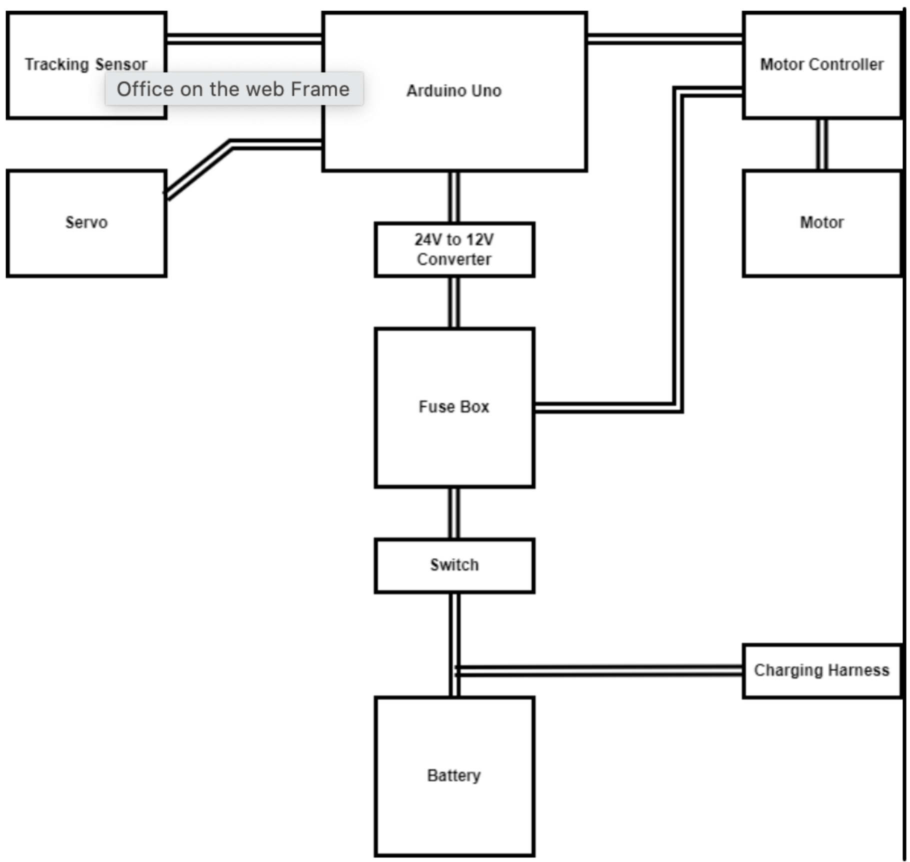

Fig. 2-1 - System Block Diagram

The following sections explain the Beach Mule's components.

The Beach Mule's configuration was narrowed down to two options. Each posed advantages and disadvantages.

Design Option 1

One consideration for the Beach Mule is a four-wheel drive configuration. This option utilizes four separate brushless DC motors. Each of the four wheels is outfitted with one motor, allowing the Beach Mule to move omnidirectionally. This design eliminates the need for a steering mechanism since the wheels act as a means of propulsion and steering. The obvious drawback to this configuration is that it exceeded the targeted expense of $750 for this semester. This configuration also weighs approximately 43 kg, which exceeds the weight limit, making the Beach Mule too heavy for a normal consumer to lift.

Design Option 2

The revised approach consists of a single brushed DC motor connected to the rear axle to provide two-wheel drive. This approach reduces the cost and weight of the Beach Mule. The weight of this new configuration is 33 kg, reducing the weight by 10 kg. Using one motor allows development of the Beach Mule to stay under $750 while still providing adequate propulsion. Some drawbacks include decreased mobility and the need for a separate steering mechanism. This approach also requires the use of a rear axle and drive chain. This is the current configuration of the Beach Mule.

2.1. Hardware

The ultrasonic sensors, GPS, and Bluetooth modules work in conjunction with the microcontroller to provide spatial awareness with respect to the user shown in Fig. 3-2. The microcontroller is responsible for controlling the speed and direction of the Beach Mule through the motor controller and servo motors. The fuse box protects the system from overcurrent and acts as the connection hub for all major components. A level 1 representation of the Beach Mule's design is shown in Fig. 3-3.

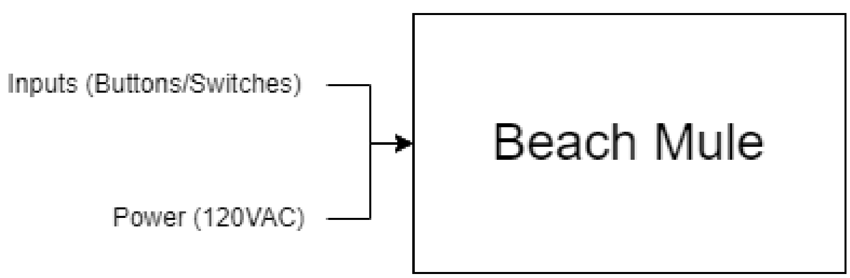

Fig. 2-2: Beach Mule System at a Glance (Level 0)

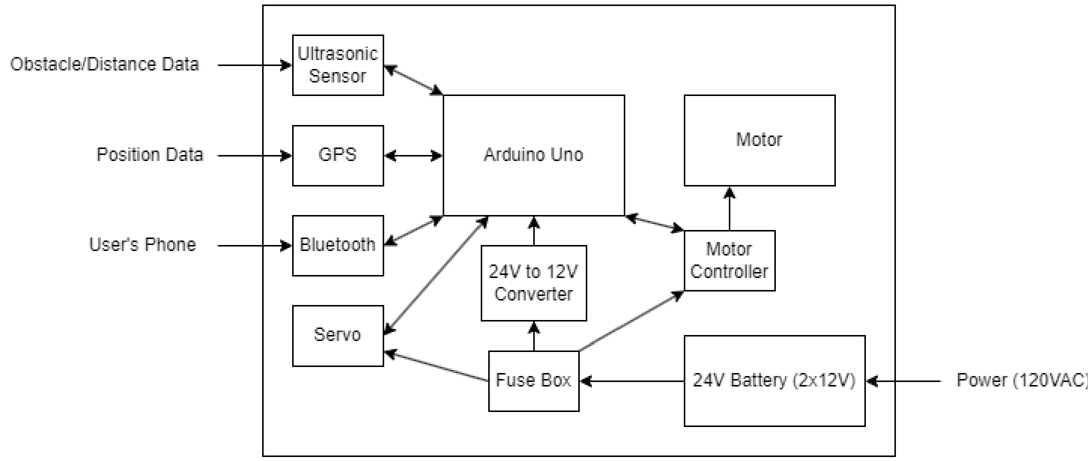

Fig. 2-3: Beach Mule Functionality (Level 1)

The components' configuration is discussed further in the next sections.

2.1.2 Microcontroller

The Beach Mule's microcontroller collects data from the ultrasonic sensor, GPS, and Bluetooth modules. The data is calculated to determine the position of the user and the cart. The microcontroller also uses this data to control the Beach Mule's movement by sending signals to the motor controller. Table 3-1 shows the specifications of the three microcontroller modules considered.

Table 2-1: Microcontroller Options

Product	Operating Voltage (V)	Memory	Clock Speed	Wireless Com-munication	Cost ($)
Requirements	5–12	≥ 32 KB	≥ 16 MHz	-	< 50
Arduino Uno R4 Wi-Fi [1]	5–12	32 KB	16 MHz	None	27.6
Arduino Mega R3 [2]	5–12	256 KB	16 MHz	None	48.4
Raspberry Pi 4 [3]	5	2–8 GB	1.8 GHz	2.4 and 5.0 GHz IEEE 802.11ac wireless, Blue-tooth 5.0, BLE	35~

Although the Raspberry Pi 4 has higher-level processing capability, the Beach Mule did not require the total computational power of the Raspberry Pi 4. The requirements were finalized based on the needs of the ultrasonic sensors, Bluetooth module, GPS module, motor controller, and any other additional devices in the future. The least expensive option on the list is the Arduino Uno, and it meets all the requirements needed to drive the components mentioned above with some room for additions in the future if necessary.

Although the Arduino Mega would also meet the specification requirements, the team chose its less expensive counterpart as the main controller for the Beach Mule.

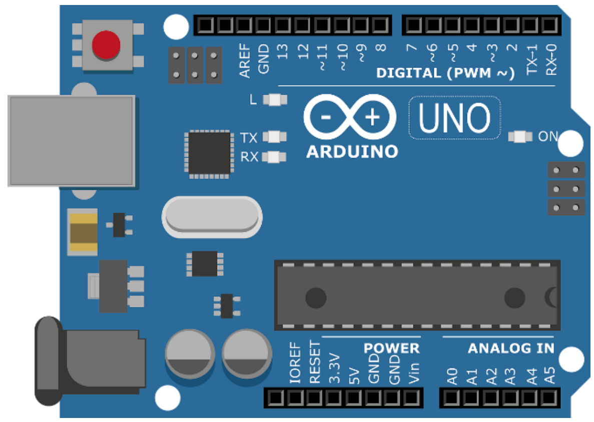

Fig. 2-4: Arduino Uno R4 Wi-Fi [1]

Fig. 3-4 shows the Arduino Uno and all the input/output pins utilized for the other subsystems.

2.1.3 Subsystems

The prototype for the Beach Mule contains five subsystems. The first subsystem is power. This subsystem manages all the power that flows to the motor, Arduino Uno, fuse box and the rest of the electric parts. The second subsystem is assisted wheels. This subsystem is broken down into three parts: the drive chain connection between the wheels and the motor, the motor controller programming, and the servo motor configuration. The third subsystem is controls. The controls subsystem focuses on connecting buttons and switches, making the Beach Mule user friendly. The next subsystem is the microcontroller. The microcontroller involves programming the Arduino Uno so that it can control the Beach Mule. The last subsystem is autonomous tracking, which involves physically implementing the ultrasonic sensor on the Beach Mule as well as programming it to follow the user through Bluetooth and a GPS module.

2.1.4 Power

The Beach Mule uses two LIPULS 12 V 22 Ah lithium iron phosphate (LiFePO4) batteries in series for the power source. Table 3-2 gives a detailed description of the Beach Mule's power options.

Table 2-2: Battery Options

Product	Voltage (V)	Energy (ah)	Weight (kg)	Dimensions (L×W×H cm)	Cost ($)
Requirements	≥ 12	≥ 22	≤ 6	≤ 20×13×18	< 150
NERMAK 12V 23ah LiFePO4 [4]	12	23	3.2	18.2×17×7.7	79.99
LIPULS 12V 22ah LiFePO4 [5]	12	22	2.5	17.8×16×7.6	69.99
ML22-12 12V 22ah SLA [6]	12	22	5.9	18.1×7.7×16.7	49.99
ML35-12 12V 35ah SLA [7]	12	35	10.5	19.5×13.0×18.0	69.99

The battery life is affected by the cart's cargo, weight, and terrain. The estimated continuous runtime provides an idea of how much battery life is left before it needs to be recharged. Assuming the current draw is continuous at the rated current of the motor, the 22 Ah battery gives the Beach Mule around one hour of continuous runtime.

$Battery\ Life = Battery\ Capacity Average\ Consumption$ $Battery\ Life = Battery\ Capacity Average\ Consumption$

Weight was also a factor in choosing a battery. Each LiFePO4 battery is 3.4 kg lighter than an SLA battery but produces the same amount of power. Fig. 3-5 shows the LIPULS 12 V 22 Ah LiFePO4 battery that is utilized for the Beach Mule.

Fig. 2-5: LIPULS 12 V 22 Ah LiFePO4 [5]

The LiFePO4 battery delivers power to multiple components within the system, including a fuse box, an Arduino Uno, a motor controller, and a motor. The Beach Mule has one brushed DC motor to drive the rear wheels.

2.1.5 Assisted Wheels

The Beach Mule's assisted wheels utilize a DC brushed motor to travel without being pulled. The Beach Mule also uses two servo motors and a motor controller to change directions and regulate the motor's performance. The Beach Mule requires 24 V and 500 W to operate. Increasing the voltage and wattage would require more batteries. The increase in batteries would be detrimental to the budget, which is why these requirements were chosen.

Table 2-3: Motor Options

Product	Rated Voltage (V)	Rated Speed (RPM)	Output (W)	Rated Current (A)	Cost ($)
Requirements	≥ 24	≥ 2000	≥ 500	≤ 40	< 200
WPHMOTO 500W 24V DC Brushed Motor [8]	24	2400	500	27.41	89.69
PLXSZ 24V 550W Brushless DC Motor [9]	24	-	550	-	223.99
Kunray 36V 1000W Brushless DC Motor [10]	36	3100	1000	27.7	209.9
BJTDLLX 36V 1000W Brush Motor [11]	36	3000	1000	35.6	78

The WPHMOTO DC Brushed Motor has been chosen to power the Beach Mule's wheels. It achieves all the operation requirements, while being less expensive than its competitors. The operation requirements include values such as rated voltage, rated speed, wattage, and rated current. While the BJTDLLX exceeds the project requirements and is less expensive, it exceeds the Beach Mule's power system. Buying more batteries to accommodate the BJTDLLX would offset the financial advantage of the motor. Listed in Table 3-3 are all the possible motor options. Below in Fig. 3-6 is the chosen motor.

Fig. 2-6: WPHMOTO 24V 500W Brushed DC Motor [8]

The Beach Mule requires a motor controller to regulate motor performance and to control the motor. The requirements primarily revolved around cost, but the voltage and current needed to be considered as well.

Table 2-4: Motor Controller Options

Product	**Rated Voltage (V)**	**Rated Current (A)**	**Cost ($)**
Requirements	≥ 24	≤ 40	< 100
SPD-YK31C [12]	24	25	-
SyRen 25A Regenerative Motor Driver [13]	24	25	74.99
SyRen 50A Regenerative Motor Driver [14]	30	50	119.99

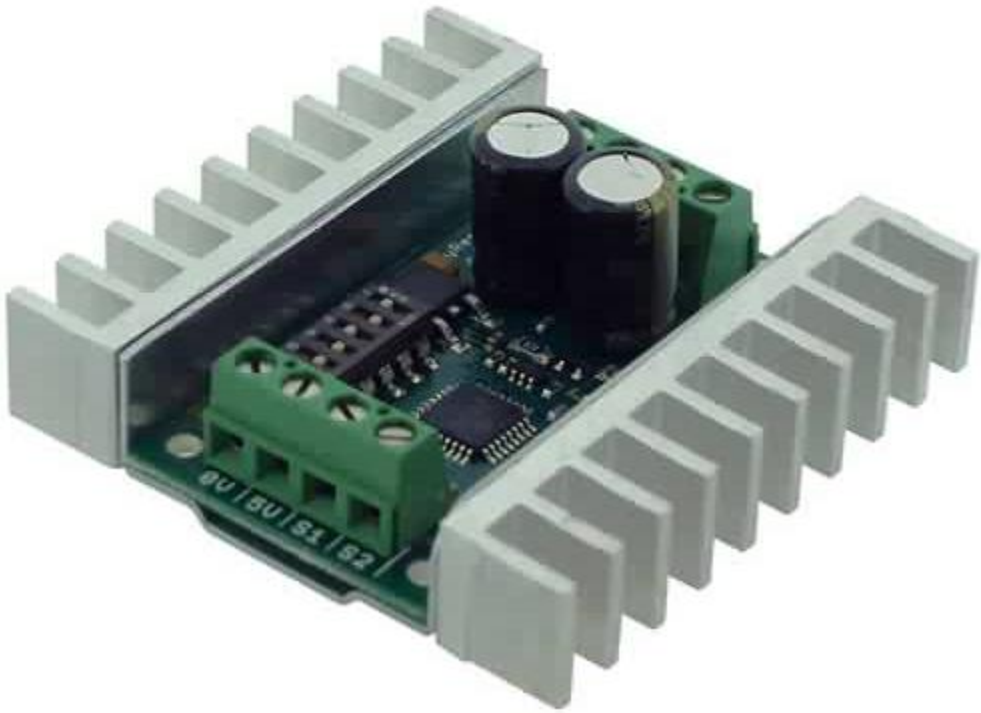

Fig. 2-7: SyRen 25A Regenerative Motor Driver [13]

The Syren 25 is the motor driver that Beach Mule utilizes. It has a properly rated voltage and current that can control the Beach Mule's motor. The SyRen 25 motor driver has a built-in library for the Arduino, and it is easily implemented within the system. Listed in Table 3-4 are all the motor controller options. In Figure 3-7, there is an image of the motor controller that Beach Mule utilizes.

Beach Mule requires a servo motor that has enough torque and rotation to make the cart change direction, regardless of where the user is heading. It also needs to fit within the voltage that is provided by the battery which is 24V. Despite the budget, the Beach Mule utilizes the most expensive option due to the amount of money saved on other parts. In Table 3-5, the motor options are listed.

Table 2-5: Servo Motor Option

Product	**Torque (kg/cm)**	**Rotation (degrees)**	**Rated Voltage (V)**	**Cost ($)**
Requirements	≥ 70	≥ 180	≥ 5	< 90
GX3370BLS Digital Servo [15]	70	180	7.4	48.99
ASMC-04B Robot Servo [16]	180	300	12	69.99

MoreOneRC 1/5 Large Scale Servo [17]	150	270	12.6	59.99

Fig. 2-8: ASMC-04B Robot Servo [16]

The Beach Mule utilizes the ASMC-04B servo motor. The ASMC-04B servo motor rotates 300 degrees and has up to 180 kg/cm of torque, while staying under $90. The ASMC-04B exceeds the torque, rotation, and rated voltage. While being more expensive than the other two options, the ASMC-04B still lands within the cost required that was set, which is why it was chosen. In Figure 3-8, there is an image of the servo motor that was chosen for The Beach Mule.

2.1.6 Control

The Beach Mule uses switches and buttons to control the settings when the user needs them. Listed in Table 3-6 are all the possible controls.

Table 2-6: Controls Options

Product	Voltage (V)	Current (A)	Weight (g)	Dimensions (L×W×H mm)	Cost ($)
Requirements	≥ 12	≥ 10	≤ 100	≤ 20×20×35	< 15

637H Apem SPDT MOM-OFF-MOM Toggle Switch [19]	24VDC	15	36.8	12×15.5×24	11.99
Joinfworld Momentary Push Button [20]	125VAC	3	89.7	18×16×30	11.99
639H Apem SPDT ON-OFF-ON Toggle Switch [21]	24VDC	15	38	13×10×33	12.39
Taiss SPST Mini Toggle Switch [22]	125VAC	6	10.5	25×15×37	14.99

Fig. 2-9 637H Apem SPDT MOM-OFF-MOM Toggle Switch **[19]**

Fig. 2-10 639H Apem SPDT ON-OFF-ON Toggle Switch
[21]

The Beach Mule has settings such as drive, stop, reverse, autonomous, manual, and off. The 637H and 639H SPDT Toggle Switch were chosen for the controls of the Beach Mule. These achieve all the operation requirements while maintaining a less expensive cost than competitors.

2.2. Software

For the Beach Mule, multiple components form the tracking subsystem to enable autopilot. In Table 3-7, all the possible choices for ultrasonic sensors are listed.

The ultrasonic sensor's role is to detect if any foreign objects or obstacles have entered in the path between the user and the Beach Mule. The ultrasonic sensor requires compatibility with the Arduino Uno microcontroller coding software as that will connect all the subsystems, so the ultrasonic sensor must integrate with the other subsystem code.

Table 2-7: Ultrasonic Sensors

Product	**Type**	**Range (cm)**	**Viewing Angle (degrees)**	**Voltage (VDC)**	**Cost ($)**
Requirements	-	100–150	-	≤ 5	< 20
JSN-SR04T [23]	Ultrasonic	25–400	70	5	13.99
GP2Y0A21YK0F [24]	Infrared	10–80	-	4.5–5.5	9.99

HC-SR04 [25]	Ultrasonic	2–450	15	5	4.50
MB1013 [26]	Ultrasonic	500	10	2.5–5	34.95
TF-Luna [27]	LiDAR	20–800	2	3.7–5.2	26.59

Fig. 2-11 JSN-SR04T **Ultrasonic Sensor [25]**

The JSN-SR04T Ultrasonic Sensor goes well above the requirements for the Beach Mule. The biggest benefits are the sensor's price and detection range. The current design for Beach Mule follows the user at one to two meters, which falls perfectly in the sensor's detection range. Table 3-8 shows options considered for the GPS module.

Table 2-8: GPS Modules

Product	Operating Voltage (V)	Update Rate (Hz)	Accuracy Error (m)	Channels	Cost ($)
Requirements	≤ 5.5	> 2	≤ 3	> 30	-
ADA4279 [28]	3.0–5.5	10	1.0–3.0	66	28.82

GPS-14030 [29]	3.3–5	10	2.0–2.5	56	17.95
GT-U7 [30]	3.6–5	5	-	50	14.99
M8Q-5883 [31]	4–6	1	2.5	72	40.99

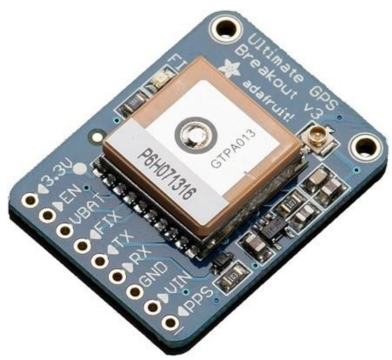

Fig. 2-12 ADA4279 GPS Module [28]

Despite the ADA4279 GPS module being one of the most expensive, the accuracy error rating is the best out of the other options. With all the user's beach belongings being in the Beach Mule, the accuracy of the distance between the user's location and the location of the Beach Mule needs to be as precise as possible, which makes the ADA4279 much more appealing as it has one of the highest refresh rates. Lastly, the ADA4279 GPS module provides a multitude of coding aid and libraries that align with the Arduino Uno. Those libraries allow the connection between the subsystems to form a smoother approach to the coding aspect of the Beach Mule. Table 3-9 shows options considered for the Bluetooth module.

Table 2-9: Bluetooth Modules

Product	Operating Voltage (V)	Enhanced Data Rate (Mbps)	Bluetooth Protocol Version	Cost ($)
Requirements	≤ 5.5	-	≥5	-
DSD TECH HM-10 [32]	3.3	10	5.0	12.00
UART RS232 [33]	2.0–3.0	2.0–3.0	2.0	7.75

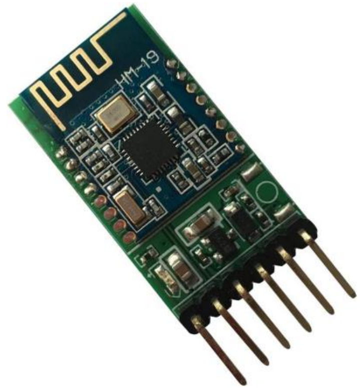

Fig. 2-13 DSD TECH HM-10 Module [32]

Lastly, the DSD TECH HM-10 Bluetooth module allows for the cart to connect directly to the user's cellular device and relays information directly to the Arduino Uno. This allows all the components in the tracking system to understand the position of the cart in relation to the user and act accordingly. The DSD TECH HM-10 Bluetooth module is the best choice as it is compatible not only with the Arduino Uno, but also with iPhone 4's and newer generations, which are being used for testing. The UART RS232 isn't a viable option for the Bluetooth Protocol Version that is older than 5.0. That means that the UART RS232 module is not compatible with newer iPhones.

Level 2 Prototype Design

The plan towards completing a full prototype in Design II is to refine the initial concept of the Beach Mule. The team intends to incorporate feedback and address potential challenges. Through planning, research, and design, the team aims to deliver a fully working prototype.
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Level 2 Diagram

The Level 2 diagram below describes all the low-level components for the final intended design of the Beach Mule. It contains the individual subsystems and shows how they connect. It also indicates all connections, inputs, and outputs for each component. Fig 3-14 shows the Level 2 diagram for the Beach Mule.

The Beach Mule has five main subsystems: power, microcontroller, assisted wheels, controls, and tracking. Each of the subsystems rely on each other. The main ones that are dependent on each other are the assisted wheels and the autonomous tracking. The best strategy for completing the Beach Mule is to focus on getting the assisted wheels working, so that the tracking can take priority. In Design I, the focus is assembly and getting each individual subsystem to work. In Design II, getting the individual subsystems to work on a larger project will be the goal. Coding the motor controller and tracking will be the main barrier that decides whether the Beach Mule will work.

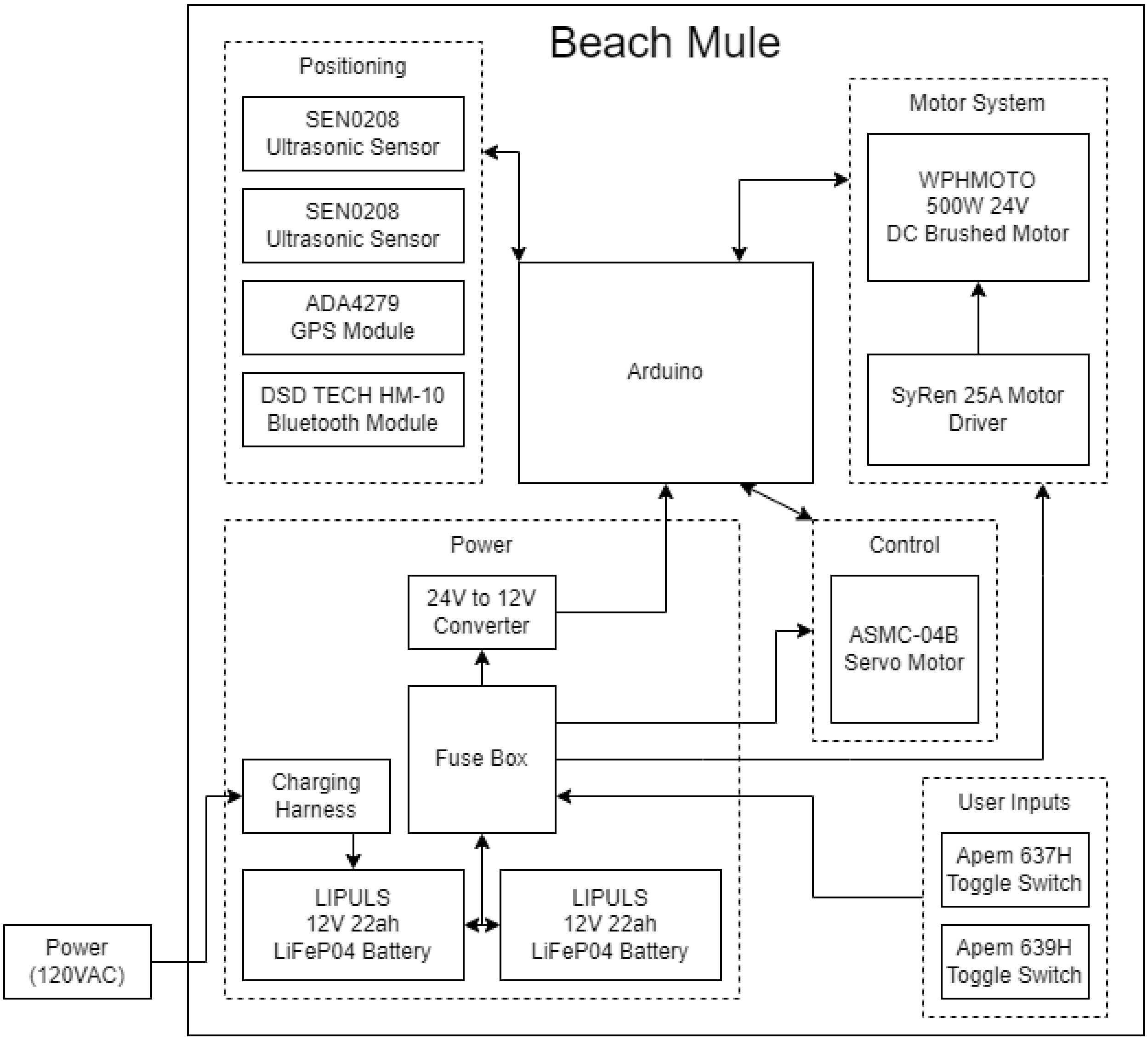

Fig. 2-14: Diagram for Beach Mule (Level 2)

The approach discussed in the preceding paragraphs has been implemented in the prototype stage of the Beach Mule. The subsystems work in unison to complete the early prototype stage of the Beach Mule. With the subsystem overview concluded, the document now addresses subsystem testing.

3. Evaluation

To evaluate the Beach Mule project thoroughly, we conducted tests on each major subsystem to verify design constraints and ensure functionality. The following sections detail the tests performed, including methodologies, results, and analysis.

Introduction: Technical Constraints

Constraint	Description
Maneuverability	The Beach Mule must navigate sandy terrains effectively.
Weight Capacity	The cart should support a load of at least 80 lbs.
Durability	Materials must withstand prolonged exposure to sun, saltwater, and wear.
Storage Capacity	One large compartment should provide sufficient storage for beach gear.
Autopilot Navigation	Autopilot feature should enable hands-free navigation using sensors and GPS.

Maneuverability Testing: We tested the Beach Mule's maneuverability on various sandy terrains, including dry and wet sand. We assessed its ability to navigate straight lines, make turns, and negotiate obstacles.

Results: The Beach Mule demonstrated excellent maneuverability, smoothly traversing different types of sand without getting stuck or losing stability. It effectively handled turns and obstacles, meeting the maneuverability design constraint.

Weight Capacity Testing: We loaded the Beach Mule with increasing weights, starting from 100 lbs up to 200 lbs and assessed its structural integrity and mobility under each load.

Results: The cart successfully supported loads up to 200 lbs without buckling or malfunctioning, surpassing the minimum weight capacity requirement of 80 lbs.

Durability Testing: We subjected the Beach Mule to simulated environmental conditions, including exposure to sunlight, saltwater, and mechanical stress. We assessed any signs of degradation or damage.

Results: The materials used in the Beach Mule construction proved resilient to prolonged exposure to sun and saltwater, with no noticeable deterioration or structural weakness observed.

Storage Capacity Testing: We evaluated the capacity and organization of the Beach Mule's storage compartment by loading them with typical beach gear, including chairs, umbrellas, and coolers.

Results: The large space provided ample storage space and efficient organization for beach essentials, meeting the storage capacity design constraint.

Autopilot Navigation Testing: We tested the Beach Mule's autopilot feature by integrating ultrasonic sensors, Bluetooth, and GPS for hands-free navigation. We assessed its ability to detect obstacles and navigate predefined routes autonomously.

Results: Initial testing of the autopilot feature encountered technical challenges, particularly in achieving seamless navigation using ultrasonic sensors. Further refinement and testing are required to overcome these obstacles and fully realize the autopilot functionality.

Conclusion: Overall, the Beach Mule project successfully met several design constraints, including maneuverability, weight capacity, durability, and storage capacity. While challenges were encountered in implementing the autopilot feature, the project has laid a solid foundation for future improvements and extensions. Further testing and refinement will be necessary to overcome technical hurdles and fully realize the Beach Mule's potential as a hands-free beach gear transportation solution.

2.2. Test Certification -- Subsystem 1 (Microcontroller – Arduino/SyRen 25A Motor Driver)

The first things that we had to test were the microcontroller and the motor driver. If the microcontroller and motor driver were not working properly, then the other parts would not be able to be controlled. To test the Arduino Uno, we powered it on and made sure all the lights were on. Then we tested to see if the microcontroller could communicate with the motor driver. We wrote basic code using the SyRen Arduino library that made the motor turn in one direction, stop, then turn the opposite direction. After writing this code, we connected the motor driver to the motor controller and the motor controller to the motor. We ran this code and confirmed that the motor was powered and effectively controlled by the motor controller and microcontroller. We repeated the same process with the servo as well.

This describes the tests for Subsystem 1. If you have more than one test for a subsystem, use subsections.

```
void ultrasonic()  {
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(20);
  digitalWrite(trigPin, LOW);
  duration = pulseIn(echoPin, HIGH);
  dist = (duration / 2) * 0.0343;
  Serial.print(dist);
  Serial.println("cm");
  if ((dist > 91.44) && (dist <= 152.4)) {
    SR.motor(30);
  } else if (dist > 152.4) {
    SR.motor(50);
  } else if (dist <= 91.44) {
    stop();
  }
  delay(1000);
}

void stop()  {
  SR.stop();
}
```

Fig. 3-1: code for motor and ultrasonic sensors communication

This code communicates between the motor and the ultrasonic sensors. If the Beach Mule is greater than 91.44 cm (about 3 ft) and less than 152.4 cm (about 5 ft), it will set the cart's speed to 30% power. If greater than 152.4 cm (about 5 ft), the cart will speed the motor up to 50% power. Lastly, if the distance measure is less than 91.44 cm (about 3 ft), the Beach Mule will come to a complete stop.

2.3. Test Certification -- Subsystem 2 (Assisted Drive – Motor/Servo)

To test the motor and servo, we had to power each system individually. The initial testing consisted of powering up each device separately and making sure that they ran. After we confirmed that all the parts were working, we had to test and see if the parts worked together. Using the Arduino Uno and the Syren 25A motor driver, we were able to program the motor and the servo. Using a custom library for the SyRen, we were able to control the servo and the motor. After this, we were able to see that the microcontroller, motor driver, motor, and servo were all working together.

This describes the tests for subsystem 2.

```
double calculateBearing(double lat1, double lon1, double lat2, double lon2)  {
  // Convert latitude and longitude from degrees to radians
  lat1 = radians(lat1);
  lon1 = radians(lon1);
  lat2 = radians(lat2);
  lon2 = radians(lon2);

  // Calculate bearing using atan2 function
  double dlon = lon2 - lon1;
  double x = cos(lat1) * sin(lat2) - sin(lat1) * cos(lat2) * cos(dlon);
  double y = sin(dlon) * cos(lat2);
  double bearing = atan2(y, x);
  bearing = degrees(bearing);
  bearing = fmod((bearing + 360), 360);

  return bearing;
}
```

Fig. 3-2: Code for GPS

The code above calculates the bearing of Beach Mule using the latitude and longitude from the GPS module and the phone GPS sensor. It returns the value to the next part below.

```
void servo(double bearing, double prevBearing)  {
  int servoPosition;
  double bearingDiff = bearing - prevBearing;
  if (bearingDiff > 0) {
    // If the difference is positive, it's moving counterclockwise
    servoPosition = map(bearing, 0, 360, 0, 50);
  } else {
    // If the difference is negative, it's moving clockwise
    servoPosition = map(bearing, 0, 360, 50, 0);
  }
  myServo.write(servoPosition);
  Serial.print(", Servo Position: ");
  Serial.println(servoPosition);
}
```

Fig. 3-3: Code for going left or right

The bearing is then compared to the last bearing reading and determines if the user is going left or right. Beach Mule has a max turn radius of about 80 degrees and that is paired with the value of the bearing to be mapped accordingly on the servo.

2.4. Test Certification -- Subsystem 3 (Self Drive Technology – Sensors)

Next, we had to make sure the sensors worked alone and in combination with the other parts. First, we took a similar approach to the way we tested the motor/servo. We wrote very simple code that made sure the sensor was picking up data. We put our hand in front of the sensor and slowly moved it backwards, so that we could make sure it detected our hand and how far/close it was. After we confirmed this, we chose a range and made the motor turn off/on based on how close/far our hand was to the ultrasonic sensor. Once this was finished, we knew that all the parts were working together.

This describes the tests for subsystem 3.

```
void gpsModule()  {
  clearGPS();
  while (!GPS.newNMEAreceived()) {
    c = GPS.read();
  }
  GPS.parse(GPS.lastNMEA());
  gps = Location(GPS.latitudeDegrees, GPS.longitudeDegrees);
  lat = GPS.latitudeDegrees;
  lon = GPS.longitudeDegrees;
  double bearing = calculateBearing(lat, lon, phoneLat, phoneLon);
  Serial.print("BeachMuleGPS: ");
  Serial.print(lat, 6);
  Serial.print(", ");
  Serial.println(lon, 6);
  Serial.print("RawBearing: ");
  Serial.print(bearing);
  Serial.print(", RawPrevBearing: ");
  Serial.println(prevBearing);
  if (abs(bearing - prevBearing) > tolerance) {
    servo(bearing, prevBearing);
    prevBearing = bearing;
  } else {
  }
}
```

Fig. 3-4: Code to gather data from GPS module and Phone

The latitude and longitude of the Beach Mule comes from the parsed data coming from the Adafruit Ultimate Breakout GPS Module and is sent to the bearing calculation along with the GPS from the phone sensor.

4. Summary and Future Work

Throughout Senior Design II, significant progress was made in developing the Beach Mule, addressing the challenge of cumbersome beach gear transportation. Key accomplishments include the successful integration of all-terrain wheels and a robust frame design. Testing revealed the effectiveness of the Beach Mule in navigating sandy terrains and carrying various beach essentials.

The Beach Mule's all-terrain wheels proved highly effective in maneuvering over sand, providing users with smooth navigation. The incorporation of a motor allowed for easy transport of beach gear, enhancing user convenience. Additionally, the robust frame design ensured durability and stability, even under load.

Despite the successes, there were challenges encountered during the project. One area of improvement is the integration of the autopilot feature. Initial attempts faced technical hurdles in achieving seamless navigation using ultrasonic sensors, Bluetooth, and GPS. Further refinement is needed to fully realize this functionality.

Looking ahead, several avenues for project extension exist beyond Senior Design II. Enhancements to the autopilot feature could involve advanced sensor technologies and machine learning algorithms to improve obstacle detection and navigation accuracy. Additionally, integrating smart connectivity features, such as mobile app controls and remote monitoring, could further enhance user experience and convenience. Furthermore, exploring sustainable materials and manufacturing processes aligns with environmental consciousness and product longevity goals.

To improve project outcomes, a more iterative approach to development and testing could be adopted. This would allow for early identification and resolution of technical challenges, reducing delays and optimizing project timelines. Additionally, fostering stronger collaboration with industry partners and experts could provide valuable insights and resources for overcoming complex engineering obstacles.

In hindsight, a more comprehensive feasibility analysis at the outset could have helped anticipate technical complexities and mitigate risks early in the project lifecycle. Additionally, a more robust project management framework, including regular progress reviews and milestone tracking, would have facilitated better project oversight and resource allocation. In summary, while significant accomplishments were achieved during Senior Design II, there are opportunities for further improvement and extension of the Beach Mule project. By addressing technical challenges, enhancing features, and adopting a more iterative approach, the Beach Mule can continue to evolve as a leading solution for beach gear transportation, delivering unparalleled convenience and enjoyment to users.

5. Acknowledgements

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