3. 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.

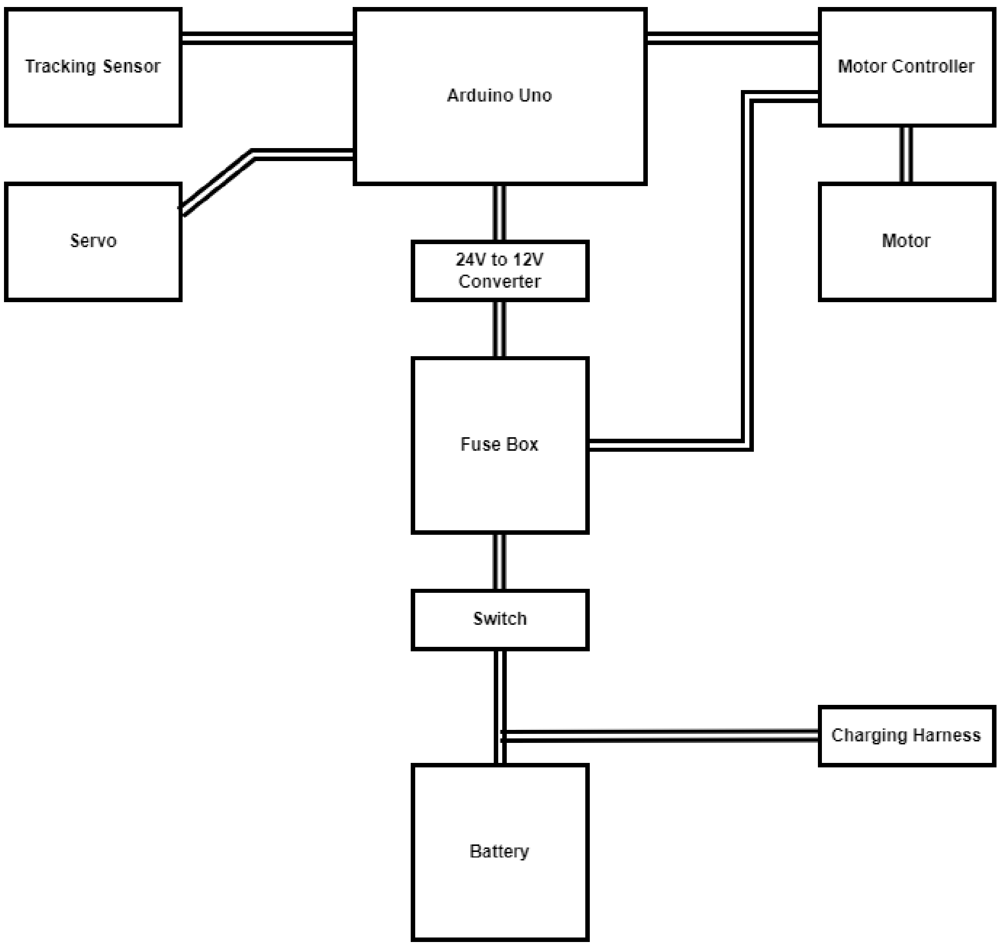

Fig. 3-1 - System Block Diagram

The following sections explain the Beach Mule's components.

3.1. Design Options

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

3.1.1. 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.

3.1.2. 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.

3.2. System Overview

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.

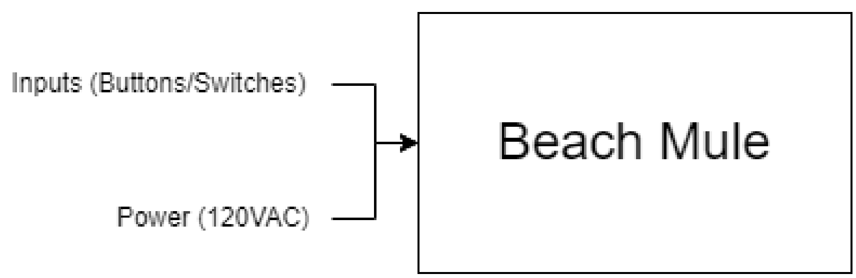

Fig. 3-2: Beach Mule System at a Glance (Level 0)

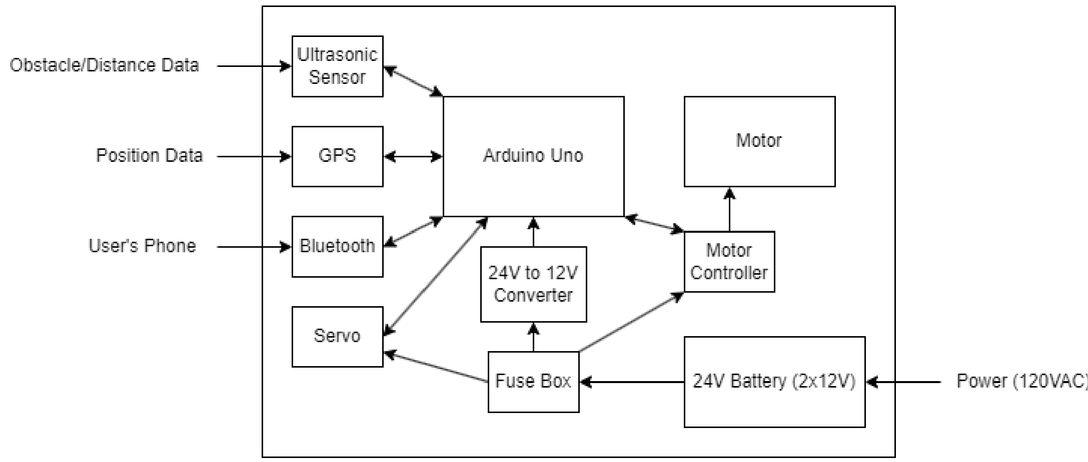

Fig. 3-3: Beach Mule Functionality (Level 1)

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

3.2.1. 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 3-1: Microcontroller Options

Product	Operating Voltage (V)	Memory	Clock Speed	Wireless Communication	Cost ($)
Requirements	5–12	≥ 32 KB	≥ 16 MHz	-	< 50
Arduino Uno R3 [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, Bluetooth 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.

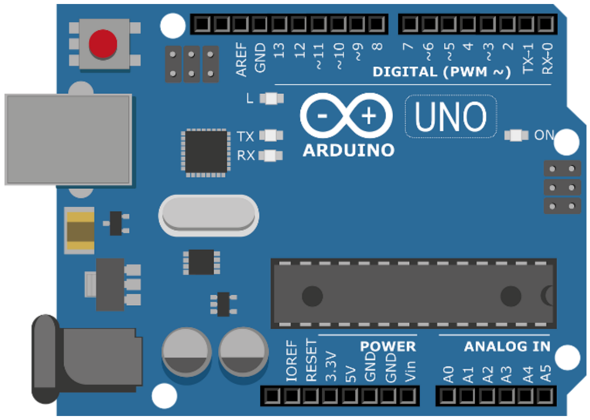

Fig. 3-4: Arduino Uno R3 [1]

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

3.3. 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.

3.3.1. 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 3-2: Battery Options

Product	Voltage (V)	Energy (ah)	Weight (kg)	Dimensions (L×W×H cm)	Cost ($)
Requirements	≥ 12	≥ 22	≤ 6	$\leq 20\times13\times18$	< 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.

$$Battery\ Life\ =\ \frac{Battery\ Capacity}{Average\ Consumption}$$

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. 3-5: 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.

3.3.2. 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 3-3: 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. 3-6: 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 3-4: 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

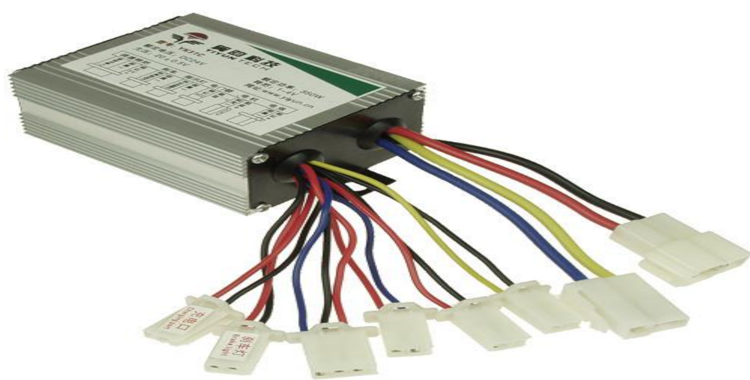

Fig. 3-7: SPD-YK31C 24V [12]

The SPD-YK31C is the motor controller that the Beach Mule utilizes. It has a properly rated voltage and current that can control the Beach Mule's motor, while being free because it comes with the motor. The SyRen motor controllers are much more expensive in comparison to the SPD-YK31C, while achieving similar operation performance. Listed in Table 3-4 is all of the motor controller options. In Figure 3-7, there is an image of the motor controller that the Beach Mule utilizes.

The Beach Mule requires a servo motor to make the wheels turn and change direction. The 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 and DC-DC converter. 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 3-5: 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. 3-8: 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.

3.3.3. 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 3-6: Controls Options

Product	Voltage (V)	Current (I)	Weight (g)	Dimensions (L×W×H mm)	Cost ($)
Requirements	≥ 12	≤ 10	≤ 100	≤ 20×20×35	< 15
Weideer Momentary Push Button [19]	125	6	82	12×15.5×24	9.99
Joinfworld Momentary Push Button [20]	125	3	89.7	18×16×30	11.99
Taiss Mini Toggle Switch [21]	125	6	49.8	13×10×33	7.99
Taiss SPST Mini Toggle Switch [22]	125	6	10.5	25×15×37	14.99

Fig. 3-9 Weideer Momentary Push Button [19]

Fig. 3-10 Taiss Mini Toggle Switch [21]

The Beach Mule has settings such as drive and reverse, power on/off, autopilot on/off, and a full stop. The Weideer Momentary Push Button and Taiss Mini 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.

3.3.4. Tracking

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 3-7: 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. 3-11 HC-SR04 Ultrasonic Sensor [25]

The HC-SR04 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 3-8: 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

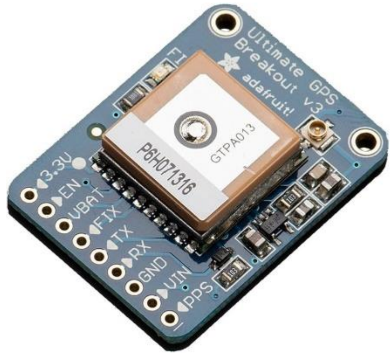

Fig. 3-12 ADA4279 GPS Module [28]

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 3-9: Bluetooth Modules

Product	**Operating Voltage (V)**	**Enhanced Data Rate (Mbps)**	**Bluetooth Protocol Version**	**Cost ($)**
Requirements	$\leq$ 5.5	-	$\geq$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

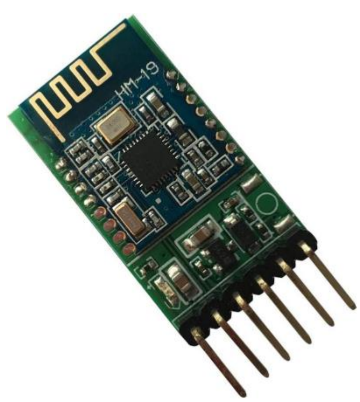

Fig. 3-13 DSD TECH HM-10 Module [32]

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.

3.4. 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.
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.

3.4.1. 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.

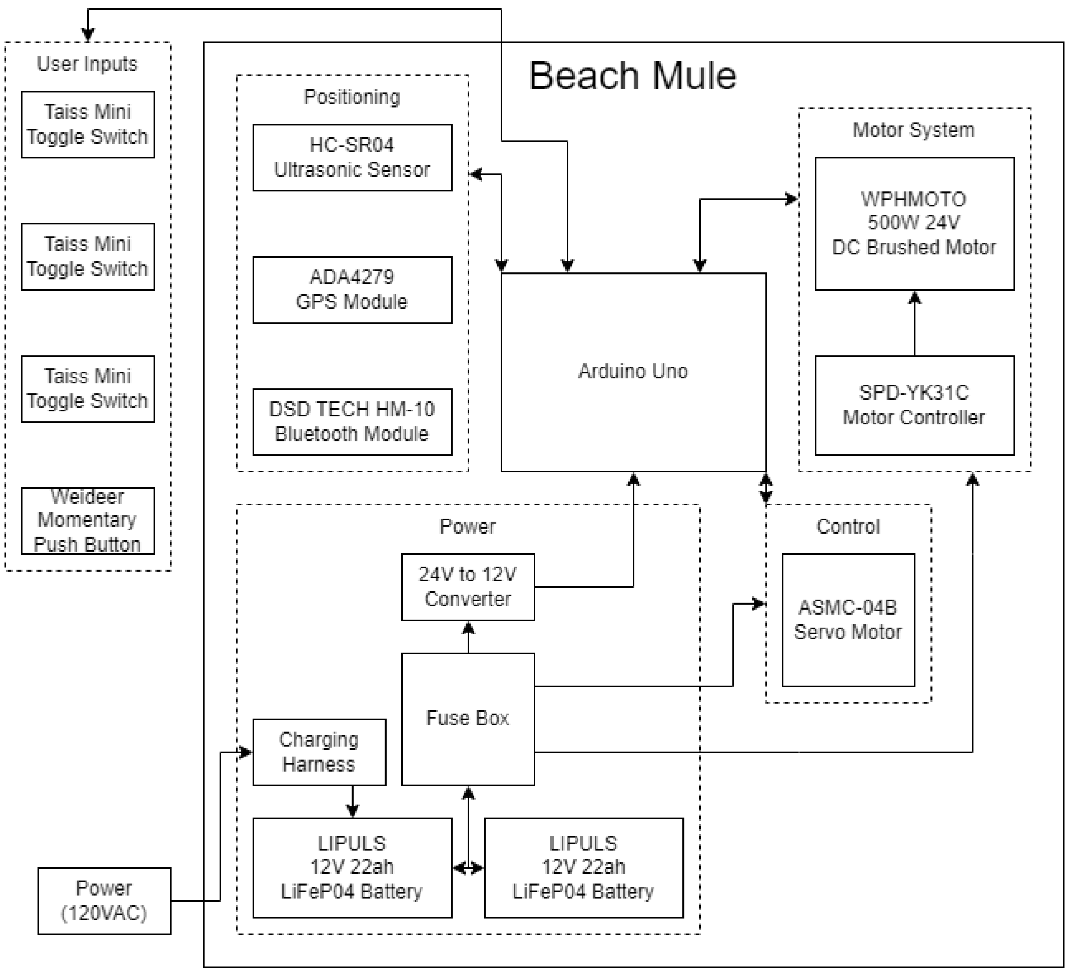

Fig. 3-14: Diagram for Beach Mule (Level 2)

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.

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