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. This document provides a detailed description of the hardware and software used in the cart's design and how each subsystem functions. Fig. 3-1 provides a visual representation of the components and systems that make up the Beach Mule.

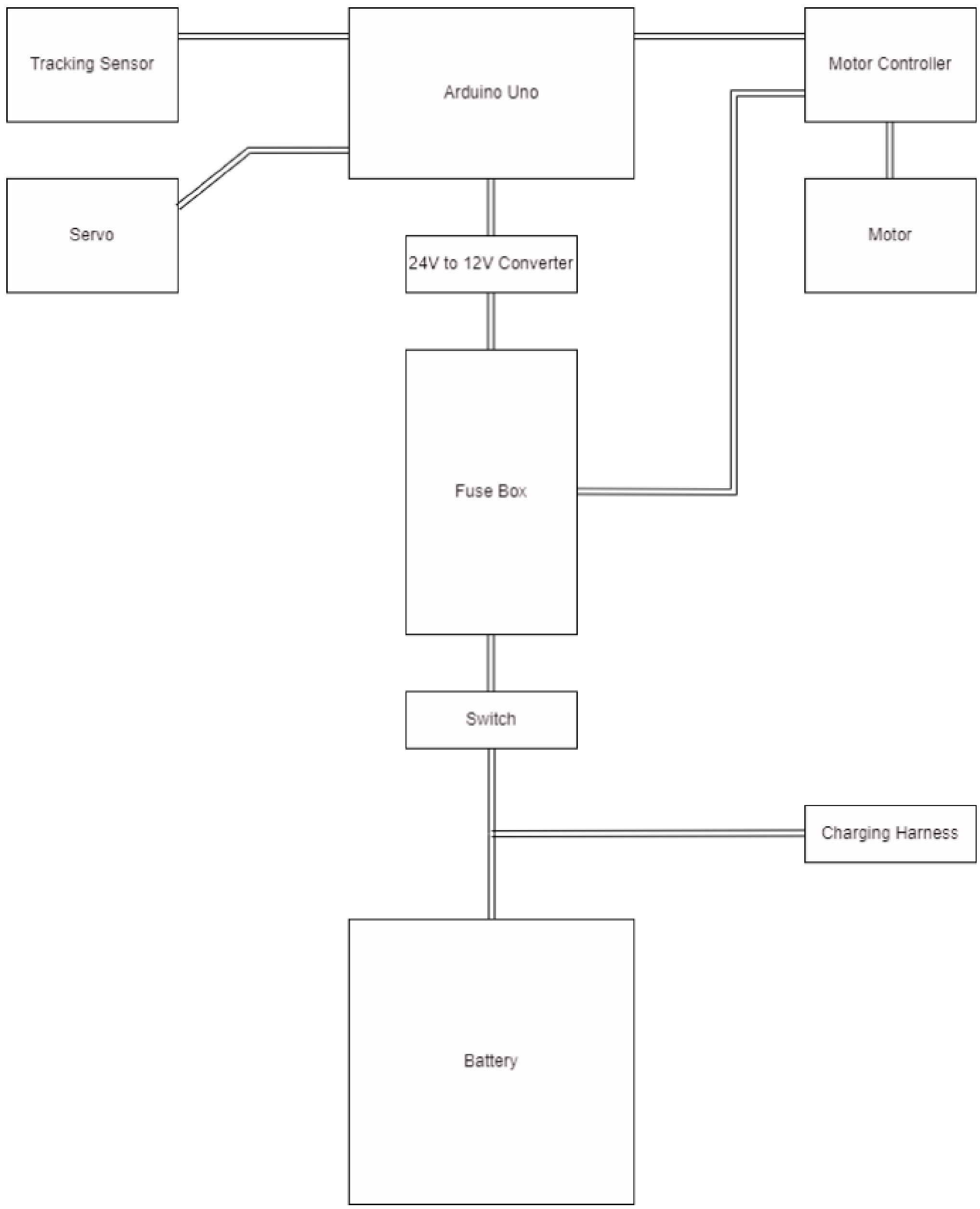

Fig. 3-1 - System Block Diagram

The following sections explain why the Beach Mule's components were selected.

3.1. Design Options

The Beach Mule's configuration was narrowed down to a couple of options. The paragraphs below explain the two design options' advantages and disadvantages, along with which was utilized.

3.1.1. Design Option 1

One consideration for Beach Mule was a four-wheel drive configuration. This would have utilized four separate brushless DC motors. Each of the four wheels would have been outfitted with one motor, allowing Beach Mule to move omnidirectionally. This would have eliminated the need for a steering mechanism since the wheels would have acted as a means of propulsion and steering. The obvious drawback to this configuration was that it exceeds the budget of $750 for this semester. This configuration would have weighed approximately 43kg, which would have been 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 Beach Mule. The weight of this new configuration is 33kg, reducing the weight by 10kg. Using one motor allows development of Beach Mule to stay under budget 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, GPS, and Bluetooth modules work in conjunction with the Arduino Uno to provide spatial awareness with respect to the user. The Arduino Uno microcontroller is responsible for controlling the speed and direction of 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.

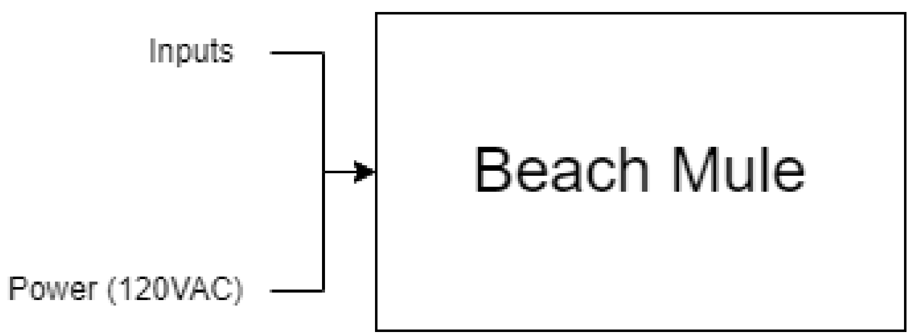

Fig. 3-2: Beach Mule System at a Glance (Level 0)

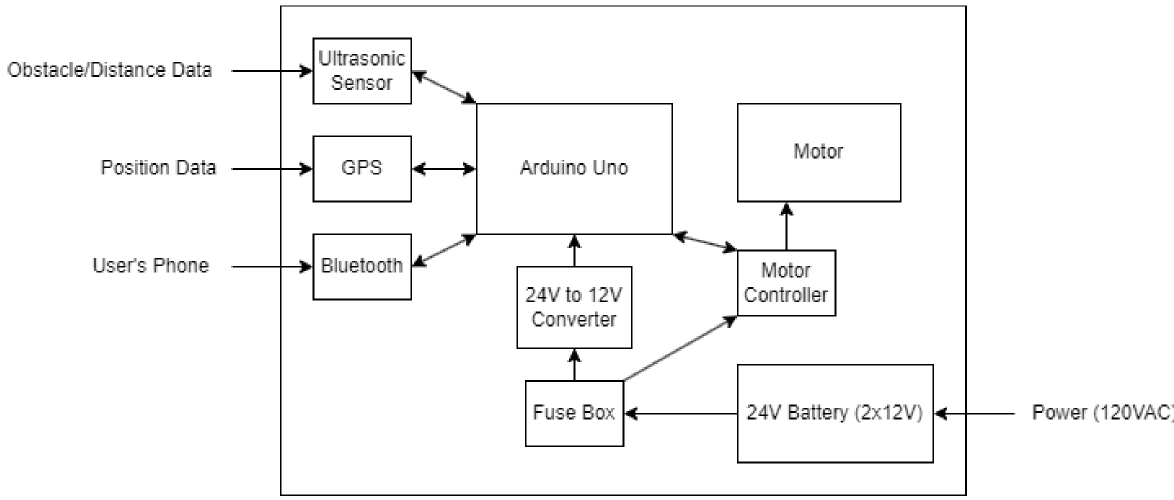

Fig. 3-3: Beach Mule Functionality (Level 1)

3.2.1. Microcontroller

The Beach Mule's microcontroller collects data from the ultrasonic sensor, GPS, and the 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 two microcontroller modules considered.

Table 3.1: Microcontroller Options

Product	Operating Voltage (V)	Clock Speed	Memory	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 a 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 sensors, Bluetooth, GPS, motor controller, and any other additional devices in the future. The cheapest 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 cheaper counterpart as the main controller for Beach Mule.

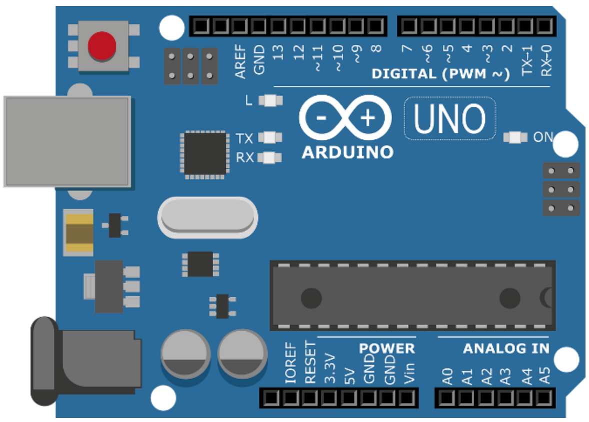

Fig. 3-4: Arduino Uno R3 [1]

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 12V 22ah lithium iron phosphate (LiFePO4) batteries in series for the power source. Table 3.2 gives a detailed description of Beach Mule’s total current draw.

Table 3.2: 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 25ah SLA [7]	12	35	10.5	19.5×13.0×18.0	69.99

The battery chosen provides at least one hour of runtime. The battery life is affected by the cart's cargo weight and terrain. The estimated runtime provides the user with an idea of how much battery life is left before the battery needs charging. 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.

Fig. 3-5: LIPULS 12V 22ah LiFePO4 [5]

Fig. 3-5 shows the LIPULS 12V 22ah LiFePO4 battery that will be utilized for the Beach Mule.

3.3.2. Assisted Wheels

The Beach Mule's assisted wheels utilize a DC brushed motor to travel without being pulled. It also uses two servo motors and a motor controller to change directions and regulate the motor's performance.

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. The Beach Mule requires 24V and 500W to operate, which is why the WPHMOTO motor was chosen. It achieves all the operation requirements, while maintaining a much cheaper cost than its competitors. The operation requirements include values such as rated voltage, rated speed, wattage, and rated current. Listed in Table 3-3 are all the possible motor options.

Fig. 3-6: WPHMOTO 24V 500W Brushed DC Motor [8]

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

The SPD-YK31C is the motor controller that the Beach Mule utilizes. It has a high rated voltage and current to 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.

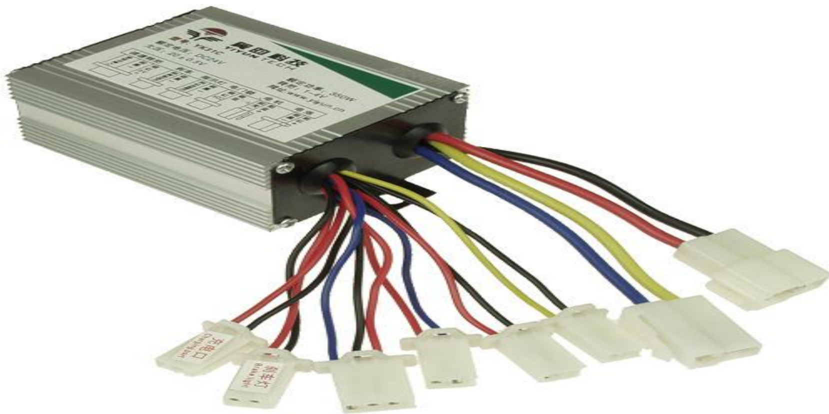

Fig. 3-7: SPD-YK31C 24V [12]

Table 3.5: Servo Motor Option

Product	**Torque (kg/cm)**	**Rotation (degrees)**	**Rated Voltage (V)**	**Cost ($)**
Requirements	≥ 50	≥ 180	≥ 5	< 90
GX3370BLS Digital Servo [15]	70	180	7.4	48.99
BETU RC Servo [16]	25	270	6.8	31.99
ZOSKAY Torque Coreless Motor [17]	35	270	7.4	28.99
MoreOneRC 1/5 Large Scale Servo [18]	150	270	12.6	59.99

The Beach Mule utilizes the GX3370BLS servo motor. The servo motor is a necessity because it allows the Beach Mule to change directions with its autonomous tracking. The Beach Mule only needs to rotate 180 degrees and have up to 50 kg/cm of torque. The GX3370BLS fits the torque, rotation, and rated voltage while maintaining the cheapest price. In Table 3.5, the other motor options are listed.

Fig. 3-7: GX3370BLS Digital Servo [15]

3.3.3. Controls

The Beach Mule uses switches and buttons to control the settings when the user needs them. Listed in Table 3.4 are all the possible motor options.

Fig. 3-8 Taiss Mini Toggle Switch [21]
Fig. 3-9 Weideer Momentary Push Button [19]

Table 3.4: 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

The Beach Mule has settings such as drive and reverse, power on/off, and autopilot on/off. The Weideer Momentary Push Button and Taiss Mini Toggle Switch were chosen for the controls of the Beach Mule. It achieves all the operation requirements, while maintaining a cheaper cost than its competitors.

3.3.4Tracking

For Beach Mule, multiple components form the tracking subsystem to enable autopilot. In Table 3.5, all the possible choices for ultrasonic sensors are listed.

Table 3.5: 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

The HC-SR04 Ultrasonic Sensor goes well above the requirements for the Beach Mule. The biggest selling points 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 3.6: 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

Despite the ADA4279 GPS module being 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 location user and the location of the Beach Mule needs to be as close as possible, which makes the refresh rate much more appealing as it has one of the highest. Lastly, the ADA4279 GPS module provides a multitude of coding aid and libraries that allign with the Arduino Uno. Those libraries allow the connection between the subsystems to form much smoother on the coding aspect of the Beach Mule.

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 microcontroller in the Beach Mule. 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 iPhones higher than an iPhone 4, which are being used for testing.

3.4. Level 2 Prototype Design

Insert a paragraph here to open the discussion on your intentions for your full prototype to be completed in Design II.

3.4.1. Level 2 Diagram

The Level 2 diagram describes all the low-level components of your final intended design and how they are related. It should also clearly indicate all connections and any inputs and outputs for each component. This design may change for Design II as you continue to work on your prototype. However, document your intended approach here and briefly discuss any potential enclosure if your project requires one. You may also include any circuit or breadboard diagrams that will assist you in documenting your project. Please number them accordingly as Fig. 3-4.x and provide a paragraph describing each image. Refer to Fig. 3-4 as an example of a Level 2 diagram.

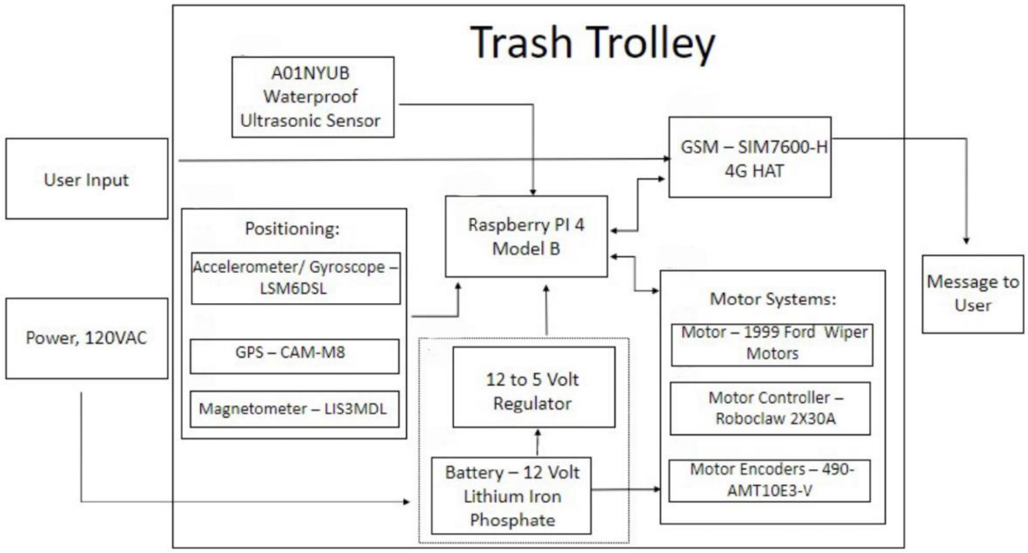

Fig. 3-4: Diagram for Trash Trolley (Level 2) (EXAMPLE)

Once you have discussed your final intended design, space down a few lines. Then provide a short paragraph here, for two reasons: 1) to close this section gracefully and 2) to prepare your reader to transition to the subsystem testing section of your design document.

As always, references cited throughout the paper should be listed here in IEEE format. For example, you may have cited product specs or graphics. Acknowledgement or attribution statements are provided here. These elements are not included in page minimums or maximums.

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