# Approach

Train and Go is a wheelchair accessory that sends orientation and movement data in the form of controller input over Bluetooth to a VR headset. To ensure user safety, Train and Go is also capable of object detection and providing feedback in order to prevent collisions while in VR. The following sections describe the approach used to accomplish these tasks. Figure 2.1 depicts the overall design of Train and Go.

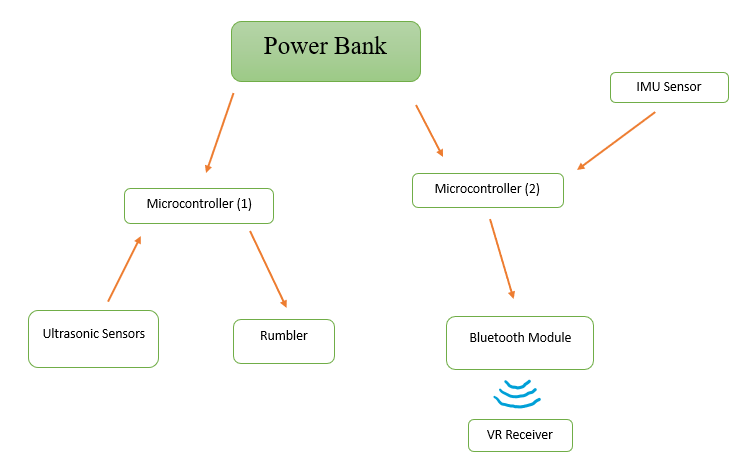


Figure 2.1 – Train and Go System Diagram

Train and Go is divided into four design subsystems. The object detection subsystem notifies the user when they are approaching an obstacle. The motion tracking subsystem is responsible for capturing the wheelchair’s movement and translating it into VR control signals. The wireless communication subsystem is responsible for facilitating communication between Train and Go and the VR headset. The power distribution subsystem handles the distribution of power from the battery to each component of Train and Go.

## Hardware

Train and Go utilizes two microprocessors to input sensor data and interpret it appropriately. One of these microprocessors facilitates orientation tracking and wireless communications, while the other microprocessor handles object detection and provides feedback. This isolation allows each system to process continuously at maximum efficiency. Figure 2.2 presents an overview of the hardware placement and functionality.

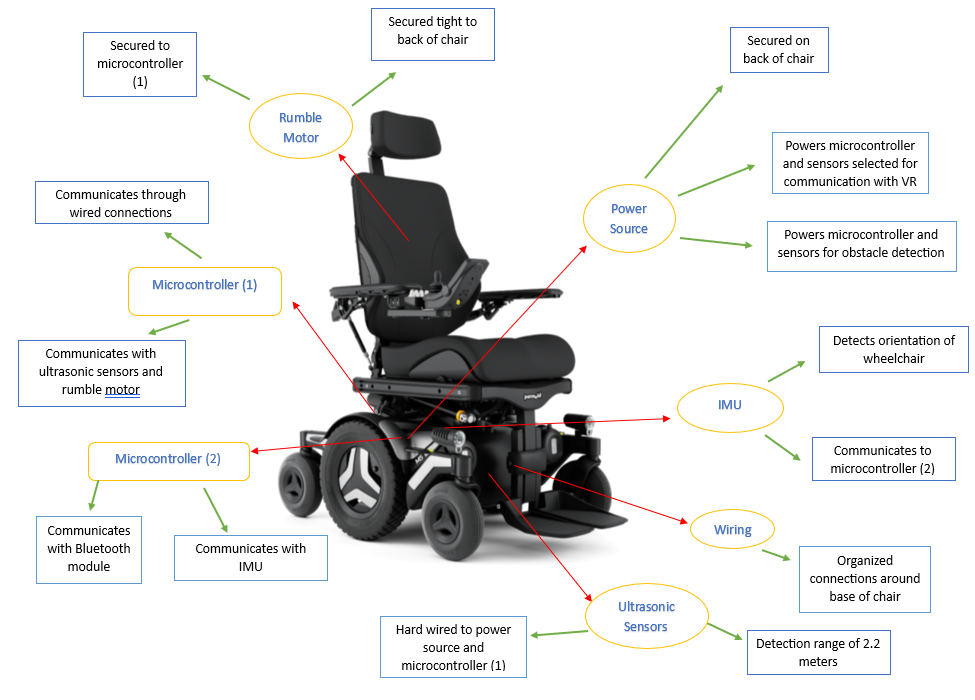


Figure 2.2 – Train and Go Hardware Diagram

Components are selected to satisfy processing and power requirements that allow Train and Go to operate efficiently.

### Inertial Measurement Unit (IMU)

The motion tracking subsystem is required to measure orientation and speed to be translated into controller signals for the VR training system. Orientation measurement is achieved using an IMU. The IMUs compared for Train and Go utilize a gyroscope to measure angular velocity and an accelerometer to measure linear velocity. IMU options that were considered can be found in Table 2.1.

Table 2.1 – IMU Comparison

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Product** | **Input Voltage (V)** | **Current Usage (mA)** | **Angular Rate Zero-Rate (degrees per second)** | **Linear Acceleration Zero-g offset value (mg)** | **Maximum Operating Temperature (degrees C)** | **Cost (USD)** |
| Requirements | 3.3 | 5 | 10 | 25 | 40 | 50.00 |
| ISM330DHCX [1] | 3.3 | 1.2 | 1 | 10 | 105 | 20.00 |
| LSM6DSOX [2] | 3.3 | 0.55 | 1 | 20 | 85 | 12.00 |
| LSM6DSO32 [3] | 3.3 | 0.55 | 0.5 | 20 | 85 | 12.50 |

The ISM330DHCX IMU is being used for its greater linear acceleration accuracy and temperature range despite its current usage being twice as much as the other options. With a higher temperature range, the IMU is less susceptible to a change in accuracy at different temperatures. When working in a virtual environment, these tiny differences in sensitivity can lead to a significant difference in user experience.

### Orientation Microcontroller

Orientation tracking requires the processing of raw IMU data to create control signals usable by a VR headset. This processing is achieved on a microcontroller that takes IMU data in and sends it to the wireless communication subsystem to be sent to VR. Options for orientation processing microcontrollers are listed in Table 2.2.

Table 2.2 – Orientation Microcontroller Comparison

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Product** | **Working Voltage (V)** | **Working Current (mA)** | **Clock Speed (Hz)** | **GPIO Pins** | **Cost (USD)** |
| Requirements | 3.3-5 | 1,000 | 4,000 | 2 | 100.00 |
| Raspberry Pi 4B [4] | 5 | 3,000 | 1,500,000,000 | 40 | 152.00 |
| ESP32 [5] | 2.3-3.6 | 500 | 60,000,000 | 22 | 6.67 |
| Libre Le Potato [6] | 5 | 800 | 1,500,000,000 | 40 | 35.00 |

The microcontroller requires 1,000 clock cycles to process each wireless refresh, which happens 4 times a second. This means the microcontroller requires 4,000 clock cycles per second. Serial communications require a power, ground, data, and clock pin, so the microcontroller requires 2 GPIO pins to handle data and clock. The ESP32 has a much lower cost and power consumption than other alternatives that satisfy these requirements.

### Ultrasonic Sensors

Train and Go must detect objects within a 2.2 meter radius to meet design specifications. Train and Go has opted to use ultrasonic sensors for object detection. Ultrasonic sensors are more economically viable than LiDAR or stereo camera systems. Their accuracy is within ±3 centimeters. Table 2.3 presents the ultrasonic sensors considered for Train and Go.

Table 2.3 – Ultrasonic Sensor Comparison

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Product** | **Working Voltage (V)** | **Working Current (mA)** | **Working Frequency (kHz)** | **Max Range (m)** | **Min Range (cm)** | **Measuring Angle (Degrees)** | **Cost (USD)** |
| Requirements | 3.3-5 | X≤15 | X | X≥2.2 | X | X | X |
| RCWL-1601 [7] | 3.3-5 | 15 | 40 | 4.5 | 2 | 15 | 3.95 |
| US-100 [8] | 3.3-5 | 15 | 40 | 4.5 | 2 | X<15 | 6.95 |
| HC-SR04 [9] | 3.3-5 | 15 | 40 | 4 | 2 | 15 | 1.30 |
| A02YYUW [10] | 3.3-5 | 8 | 40 | 4.5 | 3 | 60 | 17.88 |
| Grove [11] | 3.3-5 | 8 | 40 | 3.5 | 3 | 15 | 3.95 |

The HC-SR04 was chosen due to it being very economical and using pulse width modulated (PWM) signals. It had the same specifications and quality as the other sensors that used PWM signals to communicate, but it was a third of the price of its closest competitor.

### Rumble motor

To provide feedback to the user of Train and Go, a rumble motor was chosen. A rumble motor is less obtrusive and faster than audio feedback. The main parameters considered for choosing a rumble motor are the working voltage, working current draw, and the rated speed of the motor. Equation (1) models the effect of motor speed on vibration amplitude [12]. A faster motor speed results in stronger vibrations. The rumble motors considered for Train and Go are listed in Table 2.4.

(1)

Table 2.4 – Rumble Motor Comparison

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Product** | **Working Voltage (V)** | **Working Current (mA)** | **Rated Speed (rad/s)** | **Cost (USD)** |
| Requirements | X≥3 | X≤25mA | X≥1675 | X |
| Tatoko [13] | 3 | 20 | 1675 | 2.14 |
| BestTong [14] | 1.5 | 20 | 837 | 1.19 |
| BOJACK [15] | 3 | 20 | 1675 | 3.50 |

The Tatoko rumble motor was chosen because it had a higher motor speed rating at a lower price point. It also operates at 3 volts, which is preferred over 1.5 volts. A higher voltage is preferred because bucking the battery voltage to a much lower voltage can cause excessive heat due to a large amount of power dissipation in the converter.

### Detection Microcontroller

The parameters considered in the decision to choose the microcontroller responsible for object detection were the input voltage, current rating of the input/output (I/O) pins, the clock speed, and the number of analog general purpose input output (GPIO) pins. A total number of sixteen analog GPIO pins is required to ensure that at least eight ultrasonic sensors can be controlled simultaneously. A clock speed of 16 megahertz is sufficient for object detection. The microcontrollers considered for object detection are listed in Table 2.5.

Table 2.5 – Detection Microcontroller Comparison

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Product** | **Input Voltage (V)** | **Max Current per I/O pin (mA)** | **Clock Speed (MHz)** | **Analog GPIO Pins** | **Cost (USD)** |
| Requirements | X | X≥20 | X≥16 | X≥16 | X |
| Elegoo Mega [16] | 7-12 | 40 | 16 | 16 | 21.00 |
| Shield Buddy [17] | 7-12 | 40 | 300 | 16 | 129.94 |
| Arduino Mega [18] | 7-12 | 40 | 16 | 16 | 48.20 |

The Elegoo Mega was chosen because it meets all necessary requirements and is significantly more economical than the other options. The Elegoo Mega is essentially a clone of the Arduino Mega that provides the same quality without the increase in price associated with the Arduino brand.

### Wireless Communication

Train and Go will communicate with a VR headset via Bluetooth. By using Bluetooth, Train and Go will transmit the orientation data interpreted from the IMU to the VR headset. Table 2.6 presents the Bluetooth transmitters considered for Train and Go.

Table 2.6 – Bluetooth Transmitter Comparison

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Product** | **Working Voltage**  **(V)** | **Working Current**  **(mA)** | **Connectivity** | **Type** | **Cost**  **(USD)** |
| Requirements | ≤5 | <500 | Bluetooth | Microcontroller | <30 |
| DSD Tech HM-10 BT Module[19] | 3.6 - 6 | 50 | Bluetooth 4.0 BLE | Module | 10.99 |
| ESP32 [5] | 2.3 - 3.6 | 500 | Bluetooth 4.2 | Microcontroller | 6.67 |
| Adafruit Feather nRF52840 Express [20] | 3.7 | 500 | Bluetooth LE | Microcontroller | 24.95 |
| Raspberry Pi 4 Model B [4] | 5 | 1300 | Bluetooth 5.0 | Microcontroller | 152.00 |

The chosen microcontroller has a built-in Bluetooth transmitter. The ESP32 was selected because of its low power draw, flexibility, and low cost. The ESP32 has dual cores that can run independently. This means one core can be used to handle the Bluetooth communication, while the other can convert IMU sensor readings.

### Virtual Reality Headset

Train and Go was developed in collaboration with a team in the Computer Science department at Mississippi State University (MSU). Table 2.6 lists the VR headsets considered for both the Computer Science team and the Train and Go development team to work with.

Table 2.7 – Virtual Reality Headset Comparison

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Product** | **Weight**  **(lbs)** | **Connection** | **Tracking** | **Cost (USD)** |
| Requirements | N/A | Wireless | N/A | N/A |
| Valve Index [21] | 1.78 | Wired | Steam VR Base Stations | 750.00 |
| Meta Quest 2 [22] | 1.11 | Wireless | On-board | 400.00 |
| HTC Vive XR Elite [23] | 1.38 | Wireless | On-board | 1,100.00 |
| Meta Quest Pro [24] | 1.59 | Wireless | On-board | 1000.00 |

The Meta Quest Pro is used by Train and Go for its ease of use, inside-out tracking, fast processing, low weight, and high resolution. Additionally, the Computer Science team has a familiarity with the software that runs on Meta headsets, so the Meta Quest series was of preference. The Meta Quest Pro has a better processor and more comfort than the Meta Quest 2, so the Meta Quest Pro was purchased by the department.

### Power Source

It can be challenging to find space for a power source on a wheelchair. The power supply should not exceed 150x150x150mm to minimize space requirements. Additionally, Train and Go must operate for 5 hours. Train and Go’s power source requires 2906mAh to function for 5 hours per equation (2). A capacity of 3000mAh has been selected to ensure this requirement is met. The power source must also be rechargeable.

(2)

Table 2.8 – Power Source Comparison

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Product** | **Working Voltage**  **(V)** | **Working Current**  **(mA)** | **Capacity**  **(mAh)** | **Size**  **(mm)** | **Cost (USD)** |
| Requirements | 7.4 | 3000 | 3000 | 150x150x150 | 100.00 |
| SoloGood RadioMaster TX16S [25] | 7.4 | 5000 | 5000 | 72x42x22 | 25.00 |
| Zeee 2S Lipo [26] | 7.4 | 5000 | 5400 | 138x47x25 | 38.00 |
| Razepony [27] | 7.4 | 5000 | 4800 | 73x20x41 | 22.00 |
| HXJNLDC [28] | 3.7 | 800 | 800 | 6x30x40 | 15.00 |

The Zeee 2S Lipo was selected as it contains an adequate capacity at an acceptable size under the target price. It can be recharged and allows Train and Go to operate for the necessary 5 hours.

### Power Conversion

Train and Go requires multiple voltages for its circuits due to its use of two microcontrollers. To provide these differing voltages, a DC-DC converter has been selected to adjust the voltage level for the object detection microcontroller and the ultrasonic sensors. The converter transforms the voltage from 7.4 volts to the 3.3 volts that the orientation processor and ultrasonic sensors require. The object detection microcontroller is powered by the power supply’s default voltage.

Table 2.9 – Power Conversion Comparison

|  |  |  |  |
| --- | --- | --- | --- |
| **Product** | **Working Voltage**  **(V)** | **Working Current**  **(mA)** | **Cost**  **(USD)** |
| Requirements | 7.4 to 3.3 | 3000 | 20 |
| YIPIN HEXHA [29] | 24-5 to 2-18 | 3000 | 12 |
| Drok [30] | 8-22 to 3-15 | 3000 | 15 |
| Red Wolf [31] | 12 to 3.3 5 6 9 | 3000 | 14 |

The YIPIN HEXHA has been chosen because it offers a range of voltage that is closest to the requirement. It operates within the desired current level and is the most cost-effective option. The potentiometer allows the voltage level to be shifted easily and gives the user specific tuning capabilities.

### Power Rail

Train and Go’s ultrasonic detection system requires many connections to a 3.3-volt power source. To isolate these connections and supply each sensor with power, Train and Go uses a power rail. The power rail needs at least 10 outputs to supply each sensor separately.

Table 2.10 – Power Rail Comparison

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Product** | **Working Voltage**  **(V)** | **Working Current**  **(mA)** | **Number of Outputs** | **Cost**  **(USD)** |
| Requirements | 3.3 | 3000 | 10 | 20 |
| Evemodel [32] | 24 | 10000 | 12 | 7 |
| OONO [33] | 48 | 16000 | 12 | 11 |
| HCDC [34] | 300 | 30000 | 12 | 18 |

The Evemodel was chosen due to it offering the closest values for the voltage and current requirements. It also meets the number of required outputs while remaining the most cost effective.

## Software

Train and Go utilizes two microprocessors running independent software to provide object detection, haptic feedback, and input to a VR environment. Figure 2.3 outlines the software that runs on these microprocessors.

Diagram

Description automatically generated

Figure 2.3 – Software Diagram

The orientation process handles the wheelchair’s orientation and transmits a signal over Bluetooth. The object detection protocol handles object detection and provides haptic feedback to the user of Train and Go.

### Orientation Processing

The process handling orientation translates velocity data into 2-dimensional axis values that are transmitted over Bluetooth, emulating a video game controller for the VR headset. Figure 2.4 depicts how this processing loop operates in a block diagram format.

Chart, diagram

Description automatically generated

Figure 2.4 – Orientation Processing Diagram

Upon start up, the software calibrates the accelerometer and gyroscope. The microcontroller then enters a processing loop to gather data, translate the data, and output the data. Data is retrieved from the IMU using the Inter-Integrated Circuit (I2C) communication protocol. This is translated with respect to the calibration vectors into a single two-dimensional vector parallel to the ground. This is then communicated over Bluetooth as a video game controller axis, and the data processing cycle repeats.

### Communication Protocol

With a required update time of 250 milliseconds, a minimum of 4 full updates occur each second. The I2C Protocol, with a maximum bit rate of 400 kilobits per second [35], allows IMU data to be transmitted at a much higher speed than 4 times each second. Train and Go’s orientation processing system utilizes the I2C protocol to retrieve IMU data to ensure this speed is possible.

### Object Detection Protocol

Train and Go’s object detection protocol must take in sensor data to detect obstacles and output haptic feedback to the user. Figure 2.5 outlines this protocol in block diagram form.

Diagram

Description automatically generated Figure 2.5 – Object Detection Protocol

Train and Go’s object detection protocol begins with the setup state, where variables are declared and functions are defined. The ultrasonic sensors are then sent a signal that causes them to begin transmission. The time it takes the reflected waves to return is then measured. This distance can be calculated using this time. The distance of the detected object is then compared to the haptic range of the system to determine if haptic feedback will occur. If the distance of the detected object is outside the haptic range, then no feedback will occur. If the object is less than or equal to the haptic range, haptic feedback will occur.

# REFERENCES

1. “Adafruit ISM330DHCX – 6 DoF IMU.” adafruit.com. <https://www.adafruit.com/product/4502> (Accessed: Mar. 03, 2023)
2. “Adafruit LSM6DSOX 6 DoF Accelerometer and Gyroscope.” adafruit.com. <https://www.adafruit.com/product/4438> (Accessed: Mar. 03, 2023)
3. “Adafruit LSM6DSO32 6-DoF Accelerometer and Gyroscope.” adafruit.com. <https://www.adafruit.com/product/4692> (Accessed: Mar. 03, 2023)
4. “Buy a Raspberry Pi Model B.” raspberrypi.com. <https://www.raspberrypi.com/products/raspberry-pi-4-model-b/> (Accessed: Mar. 03, 2023)
5. “ESP32 datasheet.” adafruit.com. <https://cdn-shop.adafruit.com/product-files/3269/esp32_datasheet_en_0.pdf> (Accessed: Mar. 03, 2023)
6. “AML-S905X-CC (Le Potato).” libre.computer. <https://libre.computer/products/aml-s905x-cc/> (Accessed: Mar. 03, 2023)
7. “RCWL-1601 Ultrasonic Distance Sensor.” digikey.com. <https://www.digikey.com/en/products/detail/adafruit-industries-llc/4742/16584032> (Accessed: Mar. 03, 2023)
8. “US-100 Ultrasonic Distance Sensor.” adafruit.com. <https://www.adafruit.com/product/4019> (Accessed: Mar. 03, 2023)
9. “HC-SR04 Ultrasonic Distance Sensor.” amazon.com. <https://www.amazon.com/ACEIRMC-HC-SR04-Ultrasonic-Distance-ElecRightt/dp/B09J4BN46F/r> (Accessed: Mar. 03, 2023)
10. “A02YYUW Ultrasonic Distance Sensor.” digikey.com. [https://www.digikey.com/en/products/detail/dfrobot/SEN0311/11202577](https://www.digikey.com/en/products/detail/dfrobot/SEN0311/11202577?s=N4IgTCBcDaIIIAYwE1kFUDqIC6BfIA) (Accessed: Mar. 03, 2023)
11. “Grove Ultrasonic Distance Sensor.” seedstudio.com. [https://www.seeedstudio.com/Grove-Ultrasonic-Distance‑Sensor.html](https://www.seeedstudio.com/Grove-Ultrasonic-Distance-Sensor.html?queryID=39eb6a11e8a817cc697b03c1e5350ba0&objectID=2281&indexName=bazaar_retailer_products) (Accessed: Mar. 03, 2023)
12. “Vibration Motors: Voltage vs Frequency vs Amplitude.” precisionmicrodrives.com. <https://www.precisionmicrodrives.com/ab-029> (Accessed: Mar. 03, 2023)
13. “Tatoko Rumble Motor.” amazon.com. <https://www.amazon.com/tatoko-vibration-Waterproof-8000-16000RPM-toothbrush/dp/B07KYLZC1S/> (Accessed: Mar. 03, 2023)
14. “BestTong Rumble Motor.” amazon.com. <https://www.amazon.com/dp/B073JKQ9LN/> (Accessed: Mar. 03, 2023)
15. “BOJACK Rumble Motor.” amazon.com [https://www.amazon.com/dp/B09KBCY3FQ/](https://www.amazon.com/dp/B09KBCY3FQ/ref=twister_B09KGS7MPC?_encoding=UTF8&th=1) (Accessed: Mar. 03, 2023)
16. “Elegoo Mega Microcontroller.” amazon.com. <https://www.amazon.com/ELEGOO-ATmega2560-ATMEGA16U2-Arduino-Compliant/dp/B01H4ZDYCE/> (Accessed: Mar. 03, 2023)
17. “Shield Buddy Microcontroller.” digikey.com [https://www.digikey.com/en/products/detail/infineon‑technologies/KITA2GTC375ARDSBTOBO1/13563717](https://www.digikey.com/en/products/detail/infineontechnologies/KITA2GTC375ARDSBTOBO1/13563717) (Accessed: Mar. 03, 2023)
18. “Arduino Mega Microcontroller.” amazon.com. <https://www.amazon.com/ARDUINO-MEGA-2560-REV3-A000067/dp/B0046AMGW0/> (Accessed: Mar. 03, 2023)
19. “HM-10 Bluetooth Module.” amazon.com. <https://a.co/d/dheFiz2> (Accessed: Mar. 03, 2023)
20. “Adafruit Feather Microcontroller with Bluetooth.” adafruit.com. [https://www.adafruit.com/product/4062](https://www.adafruit.com/product/4062#technical-details) (Accessed: Mar. 03, 2023)
21. “Valve Index.” amazon.com. <https://www.amazon.com/Valve-Release-Headset-Stations-Controllers/dp/B07VPRVBFF/> (Accessed: Mar. 03, 2023)
22. “Meta Quest 2.” amazon.com. <https://www.amazon.com/Oculus-Quest-Advanced-All-One-Virtual/dp/B099VMT8VZ/> (Accessed: Mar. 03, 2023)
23. “HTC Vive XR Elite.” amazon.com. <https://www.amazon.com/Vive-Elite-Virtual-Reality-Headset-Controllers/dp/B0BQXDFLJ6/> (Accessed: Mar. 03, 2023)
24. “Meta Quest Pro.” amazon.com. <https://www.amazon.com/Meta-Quest-Pro-Oculus/dp/B09Z7KGTVW/> (Accessed: Mar. 03, 2023)
25. “Radio Master Battery.” amazon.com. <https://www.amazon.com/RadioMaster-5000mah-Control-Transmitter-Endurance/dp/B08DNRSKRP> (Accessed: Mar. 03, 2023)
26. “Zeee 2S Lipo Battery.” amazon.com. <https://www.amazon.com/dp/B092CZGW2P> (Accessed: Mar. 03, 2023)
27. “Razepony 2S Battery.” amazon.com. <https://www.amazon.com/dp/B0BHYTFNVN> (Accessed: Mar. 03, 2023)
28. “HXJNLDC Battery.” amazon.com. <https://www.amazon.com/603040-Rechargeable-Lithium-Replacement-Electronic/dp/B09YQ2C1KR> (Accessed: Mar. 03, 2023)
29. “YIPIN HEXHA Voltage Converter.” amazon.com. <https://www.amazon.com/dp/B0BS5ZCP1N> (Accessed: Mar. 03, 2023)
30. “Drok Voltage Converter.” amazon.com. <https://www.amazon.com/DROK-Waterproof-Converter-Adjustable-Transformer/dp/B00C0KL1OM> (Accessed: Mar. 03, 2023)
31. “Red Wolf Voltage Converter.” amazon.com. <https://www.amazon.com/dp/B0945X9JHK> (Accessed: Mar. 03, 2023)
32. “Evemodel Power Rail.” amazon.com. <https://www.amazon.com/PCB007-Position-Distribution-Outputs-Voltage/dp/B07DW2C4ZB> (Accessed: Mar. 03, 2023)
33. “OONO Power Rail.” amazon.com. <https://www.amazon.com/OONO-Position-Terminal-Distribution-Module/dp/B08TBXQ7H6> (Accessed: Mar. 03, 2023)
34. “HCDC Power Rail.” amazon.com. <https://www.amazon.com/dp/B0876W456F> (Accessed: Mar. 03, 2023)
35. “Speed – I2C bus.” i2c-bus.org. <https://www.i2c-bus.org/speed/> (Accessed: Mar. 03, 2023)