3. DESIGN APPROACH

This section discusses the design options considered, the system overview, the system's subsystems, and the potential design considerations for the future. Regarding these sections, the information within was driven by major requirements, constraints, and standards. The most critical of these criteria are that Halo Helmet is visible, can be worn comfortably, and can detect an approaching object; the device is legal, safe, and economical; and the device conforms to ingress protection, universal serial bus (USB), and modular transmitter standards. The overall design solution is a product of these requirements, constraints, and standards.

3.1. Design Options

The design team considered two design options for a wearable safety device for motorcyclists. The first was a vest that included blind spot monitoring and lighted indicators; the second was a helmet with the same features that the team ultimately selected after market research.

3.1.1. Design Option 1

The first design option was a wearable vest called ViziVest, with blind spot monitoring and lighted indicators on the back of the vest to increase the rider's visibility to other motorists on the road. This implementation would have a large surface area to help the rider be more visible on the road. The ViziVest would have also had less of a weight constraint when compared to other possible implementations, as it is much more feasible to carry weight on one's torso than on most other places where protective gear is necessary on a motorcycle, such as one's head. The team ultimately eliminated the vest idea due to feedback from market research. This market research indicates that riders did not want to wear an extra vest and would, specifically, much prefer an addition to their helmet.

3.1.2. Design Option 2

The second design option was an addition to a helmet, called Halo Helmet, that would include blind spot monitoring and lighted indicators that are contoured to the back of the helmet to increase the visibility of the rider and display the rider's intentions to other motorists on the road. This implementation is more size and weight constrained than the first design option, as the product must then fit in and on a helmet without causing discomfort and strain to the motorcyclist. Despite concerns about adding weight to a rider's head, the design team is going with a helmet-based design due to market research indicating that riders would prefer an addition to their helmet more than any other area.

3.2. System Overview

Figure 3-1 is a level zero diagram showing the bare basic design. Figure 3-2 is a more aesthetically pleasing version of Figure 3-1, but it was necessary to include it because Figure 3-1 shows this information without any chance of confusion. The team selected Halo Helmet as the preferred design option because of the market feedback given towards the original pitch. Additionally, a helmet approach means simpler design and lower cost. A side effect of a helmet approach is the need for the system to be split into two sections. One section is on the motorcycle itself, and the other is on the helmet. Figure 3-2 shows the components on both the helmet and the motorcycle.

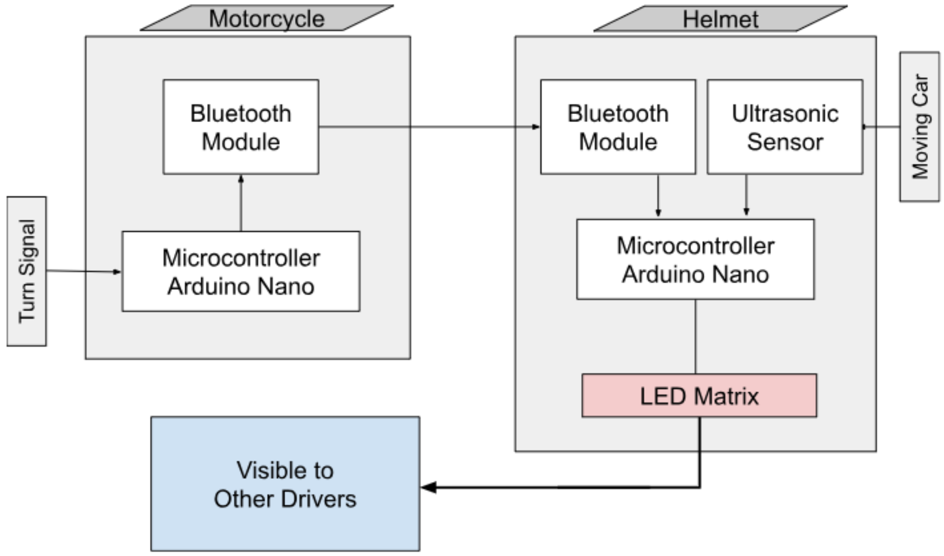

Fig. 3-1: Halo Helmet Level Zero Overview

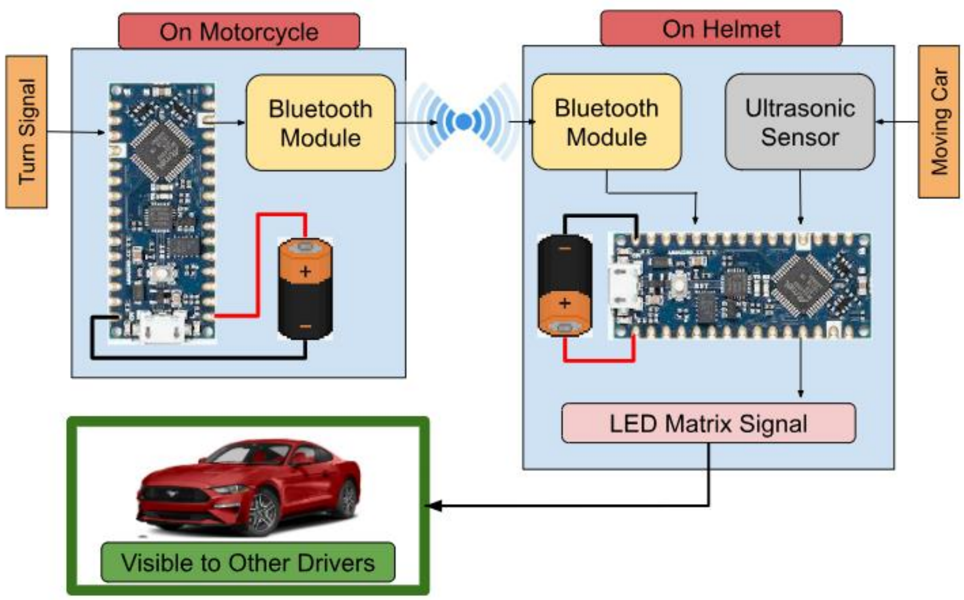

Fig. 3-2: Halo Helmet System at a Glance

Both sections require the use of a microcontroller powered by a battery. This setup controls all of the systems at the respective places. The helmet includes an ultrasonic sensor to detect cars in the blind spot of the motorcyclist and an LED matrix to convey information to other drivers. The user's input tells the matrix to display turn signals, brake lights, or emergency signals. The helmet and motorcycle microcontrollers communicate through Bluetooth since wired connections are unsafe for the rider, and Bluetooth creates hassle-free and hands-free communication between devices. In Figure 3-3, the Bluetooth functionality is described further.

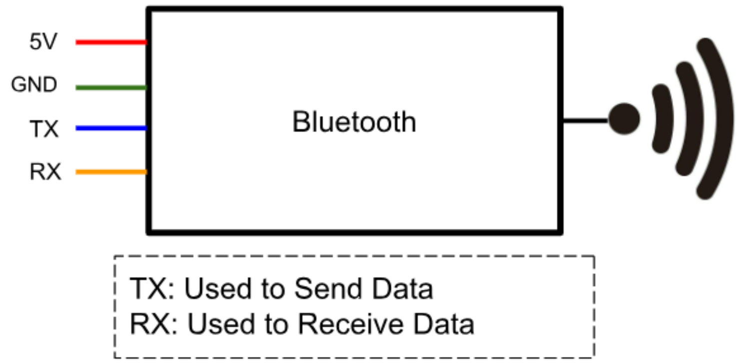

Fig. 3-3: Bluetooth Functionality

Since the user is riding a motorcycle while using Halo Helmet, wires cannot be outside of the helmet, posing a safety hazard to the motorcyclist and others. Bluetooth functionality is further explored in the communication section, but overall, Bluetooth provides the best microcontroller-to-microcontroller interaction and safety.

3.2.1. Microcontroller

Halo Helmet requires a Bluetooth compatible, somewhat small, and inexpensive microcontroller without conflicting with its main purpose of protecting the user. Table 3-1 shows several devices the team researched.

Table 3-1: Microcontroller Options

Product	**Size**	**Cost**
Requirements	As small as possible	Less than $10
Arduino Uno R3 [1]	68 mm (about 2.68 in) by 53 mm (about 2.09 in)	$27.60
LAFVIN Nano [2]	18 mm (about 0.71 in) by 45 mm (about 1.77 in)	$6.67
Teensy 4.0 [3]	6.06 x 4.21 in	$31.21
ESP32 [4]	4.61 x 2.95 in	$9.99

All of these devices are Bluetooth compatible and use Arduino IDE so neither of those aspects can differentiate them. Then the team selected the device that was the smallest and least expensive. As shown in Figure 3-4, the Nano's size is so small that it can fit seamlessly into the helmet, unlike the Uno or ESP32.

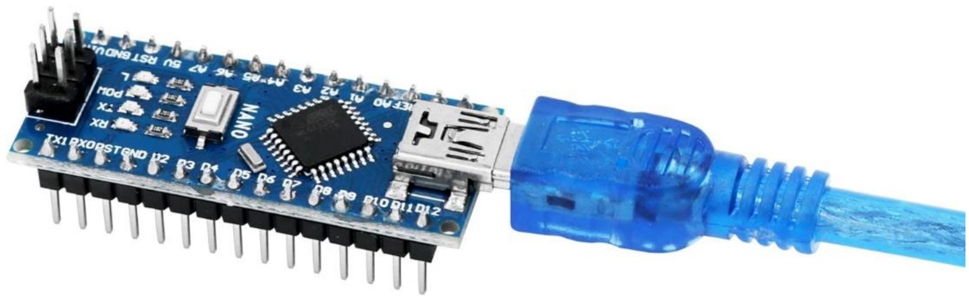

Figure 3-4: LAFVIN Nano V3 Board [2]

The price is less than all other microcontrollers the team researched. Any microcontroller cost saving is doubled because Halo Helmet needs two to function. A concern raised because of the size is missing features, but the Nano has all of the pins the components need to function.

3.3. Subsystems

In addition to the microcontroller, the prototype for Halo Helmet includes four subsystems: communications, lighting, sensing, and power supply. The communications subsystem is responsible for wirelessly transmitting information from the motorcycle to the helmet. Lighting displays bright turn signals to other drivers and provides visual warnings of nearby vehicles to the user. The third subsystem, sensing, is responsible for detecting vehicles within the user's blind spots. Finally, the power supply provides power for all of Halo Helmet's subsystems without compromising the comfort of the Halo Helmet's wearer.

3.3.1. Subsystem 1: Communications

To achieve communication between the two Halo Helmet modules, the design team chose Bluetooth connectivity over other wireless standards, such as Wi-Fi, due to its relatively low complexity and low power consumption. Two Bluetooth modules are used, one in the helmet module and one in the bike module, to facilitate communication without connecting the rider to the bike with wires. These Bluetooth modules are able to initiate a pairing signal without using an external device, like a smartphone or laptop. This pairing requirement necessitates using a module that can be designated as the Bluetooth pairing signal initiator, which is why an HC-05 Bluetooth module was chosen specifically for this application, as it can be set as the signal initiator. Listed in Table 3-2 are potential options for Bluetooth transmitters.

Table 3-2: Bluetooth Transmitter Options

Product	Size	Reliability (Reviews)	Arduino Compatible	Voltage	Cost / Item
Requirements	-	Adequate	Yes	5 Vdc	<$10.00
DORHEA 5PCS HC-05 Wireless Bluetooth Receiver [5]	Not Listed	Suspect	Yes	3.6 Vdc – 6 Vdc	$3.80
HiLetgo 2pcs HC-05 Wireless Bluetooth RF Transceiver [6]	37.3 mm L x 15.5 mm W	Adequate	Yes	3.6 Vdc – 6 Vdc	$8.00
HiLetgo HC-05 Wireless Bluetooth RF Transceiver [7]	37.3 mm L x 15.5 mm W	Adequate	Yes	3.6 Vdc – 6 Vdc	$10.39
DSD TECH HC-05 Bluetooth Serial Pass-through Module [8]	27.94 mm L x 15.24 mm W	Good	Yes	3.6 Vdc – 6 Vdc	$9.99

The HiLetgo 2pcs HC-05 Wireless Bluetooth RF Transceivers are used to communicate between the bike module and helmet module so that the turn signal actuation data can be sent to the main microcontroller in the helmet module to control the indicator lights on the back of the helmet. The logic behind the programming to accomplish the necessary light control is explored in Figs. 3-5 and 3-6. The Arduino reads data from two switches, one for each turn signal direction, and one button, actuating the brake lights. This data is then encoded and sent over Bluetooth to the other Arduino, where it is decoded and used to control the necessary lights.

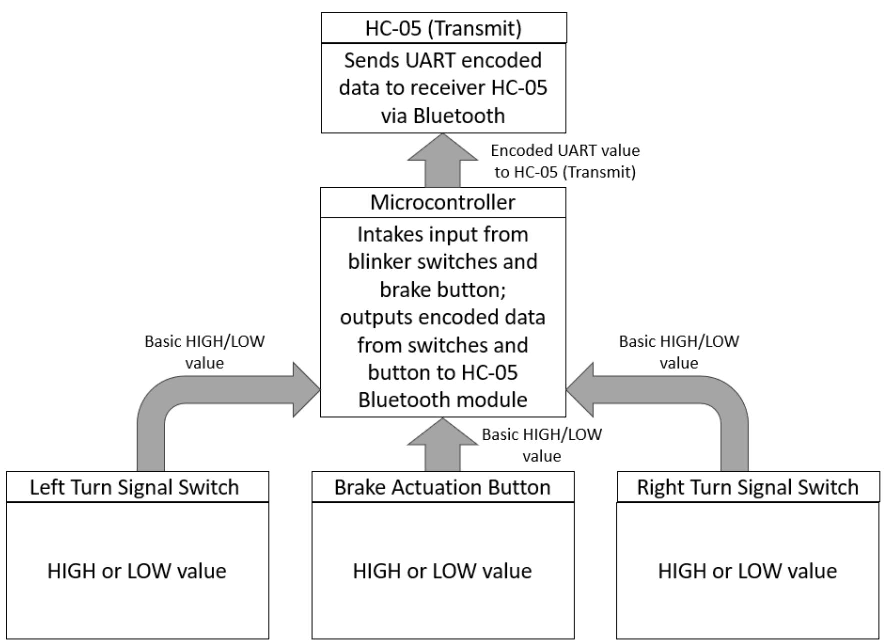

Fig. 3-5: Code Logic Diagram for the Transmit Side

In Fig. 3-5, data originates from physical actuation of a switch or button. The data is then sent to the microcontroller where it is encoded and sent via universal asynchronous receiver/transmitter (UART) to the HC-05 Bluetooth transmitter.

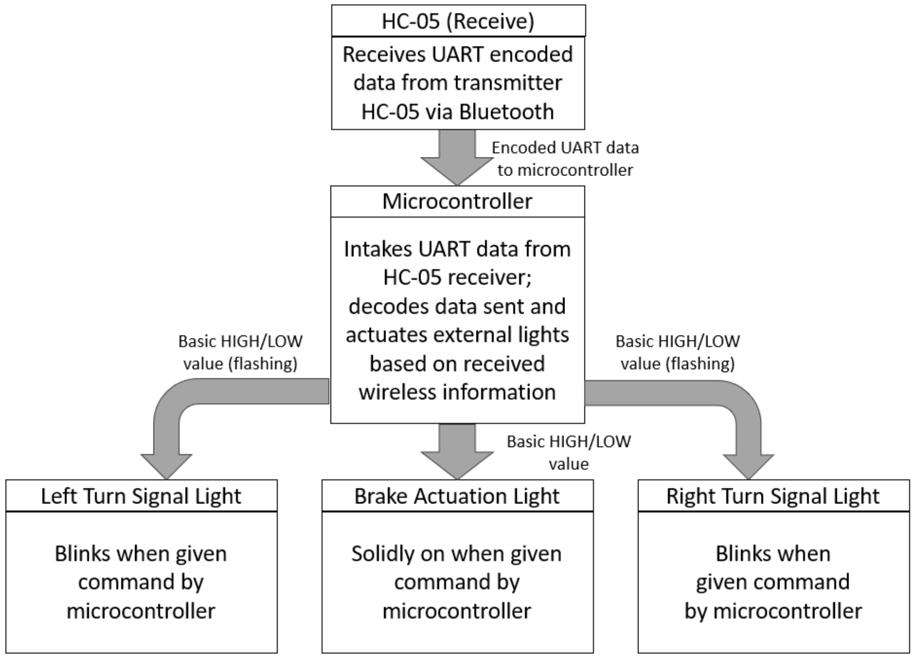

Fig. 3-6: Code Logic Diagram for the Receive Side

In Fig. 3-6, data originates from the data received by the HC-05 receiver. The data is then sent to the microcontroller via UART where it is then decoded and used to actuate turn signal lights or a brake light.

The team considered several major factors when choosing a Bluetooth transceiver. An essential consideration when selecting an HC-05 module is the compatibility with the microcontroller used in this project. All HC-05 modules considered are compatible with an Arduino. Reliability is also a crucial factor regarding the primary lane for communication between the two modules that make up Halo Helmet. The only way to measure reliability without testing and statistical analysis, which is outside of the scope of this project, is to rely on the qualitative information produced by reviews. This qualitative information is scaled between "suspect" to "good," with "adequate" in the middle. The minimum reliability acceptable is "adequate" as this level primarily entails an odd setup process, as denoted in most reviews. "Good" indicates easy setup and a reliable product, but typically comes at a higher cost. Finally, "suspect" denotes a near-impossible setup with a product that typically is dead on arrival or fails shortly after arrival or a product that does not meet typical HC-05 specifications. The necessity for this style of judgment of reliability is also because many of these products have a similar "star" rating in their reviews; however, the words in the reviews indicate a different story. With these "star" ratings, each product also has a vastly different number of reviews comprising this average rating, which makes the different listings hard to properly compare numerically. These concerns about ratings ultimately led the team to judge the listings on this qualitative standard. Voltage is the next most important requirement, as the Arduino output voltage is regulated, and the HC-05 module is required to accept the 5 Vdc regulated output from the Arduino. Lastly, size is a consideration as this device fits comfortably on a helmet, but it is not heavily weighted in the decision-making process.

Overall, the HiLetgo 2pcs HC-05 Wireless Bluetooth RF Transceivers (shown in Fig. 3-7) are an excellent choice because they meet all the requirements while being nearly two dollars less per unit than the only option that surpasses it in reliability. The cost benefit comes from this specific listing having two HC-05 modules, which brings the cost per item down when compared to buying a single HC-05 module. This cost benefit and the level of reliability are ultimately why the design team made the choice to implement the HiLetgo transceivers over the DSD TECH transceivers.

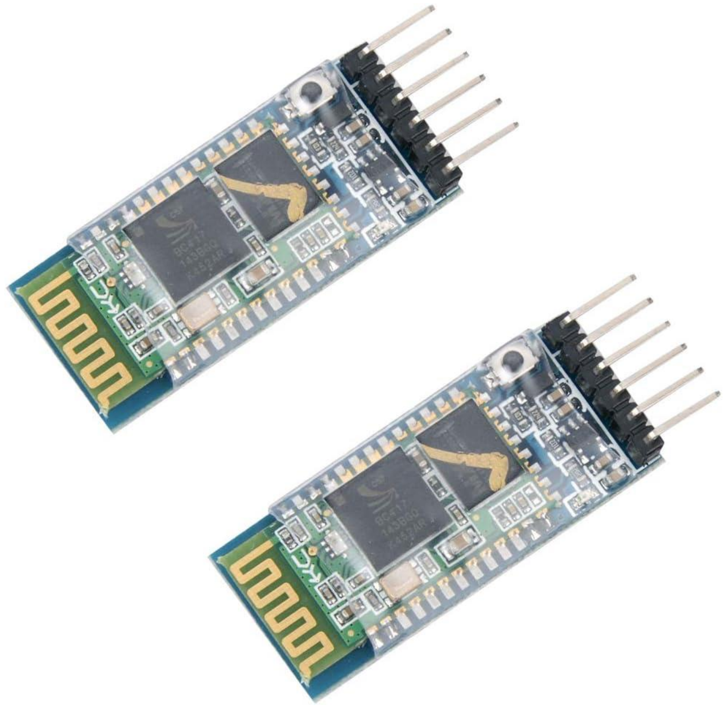

Fig. 3-7: HiLetGo 2pcs Wireless Bluetooth RF Transceivers Adapted From [6]

In Fig. 3-7, the HC-05 modules have the correct button to enable attention (AT) mode for the design team to set parameters within the modules without using a dedicated Bluetooth module programming chip. Correct 6-pin UART communication is also available, as shown in the image.

3.3.2. Subsystem 2: Lighting

The lighting of Halo Helmet is affected by its location on the helmet and its purpose as an indicator for other motorists. For the helmet to convey different kinds of signals, an LED matrix is used. Table 3-3 shows the factors that the matrix needs to fulfill to operate.

Table 3-3: LED Matrix Options

Product	Size	Flexible	Cost
Requirements	Less than 6 in by 18 in	-	Less than $20
HiLetgo MAX7219 Dot Matrix Module [9]	12.8 cm by 12.8 cm	No	$8.99
WESIRI 8x32 LED Matrix 256 Pixels WS2812B [10]	12.5 in by 3.1 in	Yes	$16.99

The team decided to use the WESIRI LED matrix. Due to the back of the helmet being the location for the lighting, the LED matrix is flexible to match the curve helmets have. The matrix is also small enough to not obstruct the helmet in any way. Both of these options produce enough brightness to meet the product's standards. These important factors informed outside helmet lighting choices. As a bonus, the LED matrix is functional with a microcontroller, including the Arduino Nano. The lighting on the outside is particular, but the inside helmet lighting is basic. LEDs serve as the only light source in the helmet because these are inexpensive and can be dimmed. A graphic of the flexible LED matrix is in Figure 3-8.

Figure 3-8: WESIRI LED Addressable Matrix [10]

The matrix is controlled through each of its individually addressable LEDs through an Arduino Nano. Halo Helmet converts a signal from the motorcycle to the matrix to display turn signals, brake lights, and various pieces of information to other motorists. Figure 3-9 gives an overview of the operations of the matrix.

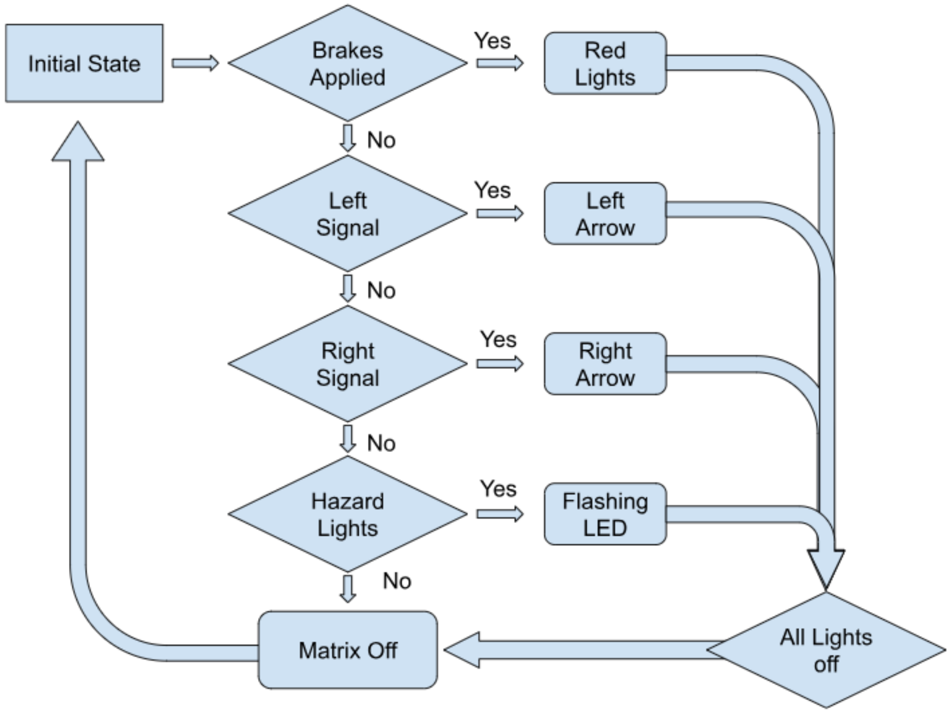

Figure 3-9: LED Matrix Operation Flowchart

The LED displays different lights and shapes depending on the state of the motorcycle. If the user is pressing on the brake, a red section on the LED matrix lights up. An orange arrow displays on the matrix depending on which direction the motorcyclist toggles like a traditional turn signal. The most important state for the matrix is the emergency lights which are toggled by a button on the motorcycle.

3.3.3. Subsystem 3: Sensing

For blind spot detection, Team 2-Stroke has opted to implement ultrasonic sensors in Halo Helmet's design. Because the sensors attach to the outer surface of the helmet, environmental protection is vital to accurate remote monitoring. Additionally, these sensors are compact enough to avoid unnecessary extensions along the helmet's outer shell. Although Team 2-Stroke also considered implementing radar sensors, ultrasonic sensors are more appropriate due to size, cost, and implementation simplicity. Table 3-4 lists possible ultrasonic sensor options.

Table 3-4: Sensor Options

Product	Operating Voltage	Detection Range	Weatherproof	Cost
Requirements	3.3 – 5 Vdc	≥ 10 ft	Desired	≤ $30
Adafruit HC-SR04 [11]	5 Vdc	13.1 ft	-	$3.95
MaxBotix MB1040 [12]	2.5 – 5.5 Vdc	21.1 ft	-	$29.95
DFRobot SEN0311 [13]	3.3 – 5 Vdc	14.7 ft	IP-67	$15.90
DFRobot SEN0312 [14]	5 Vdc	14.7 ft	IP-67 ≤ 80% Humidity	$13.00
DFRobot SEN0313 [15]	3.3 – 5 Vdc	24.6 ft	IP-67	$27.00

Although all the ultrasonic sensors meet the minimum requirements, the DFRobot SEN0311, shown in Figure 3-10, is the best selection for Halo Helmet. DFRobot's ultrasonic sensors are more appealing options than other ultrasonic sensors due to a manufacturer ingress protection of IP-67. This prebuilt protection allows the sensors to integrate into Halo Helmet's sensing subsystem without any protection modifications. The DFRobot SEN0313 has a higher, but possibly excessive, range than the DFRobot SEN0311. However, the price of the DFRobot SEN0313 is considerably more expensive. The DFRobot SEN0311 and SEN0312 are very similar, with the SEN0312 model costing less than the SEN0311. However, the DFRobot SEN0312 may malfunction when operating in a humid environment. With these slight advantages, the DFRobot SEN0311 becomes the most appropriate sensor for Halo Helmet.

Figure 3-10: DFRobot SEN0311 Ultrasonic Sensor [16]

The programming for this subsystem involves a simple data transaction. Each sensor sends distance data to the microcontroller through a digital pulse-width modulation (PWM) port. The microcontroller collects this data and compares it with a distance threshold. If the returned distance is within the detection threshold, the microcontroller recognizes this positive detection and relays the information to the lighting subsystem. The sensors send constant data updates to ensure an accurate data supply to Halo Helmet. Figure 3-11 provides an overview of the data exchange within the sensing subsystem.

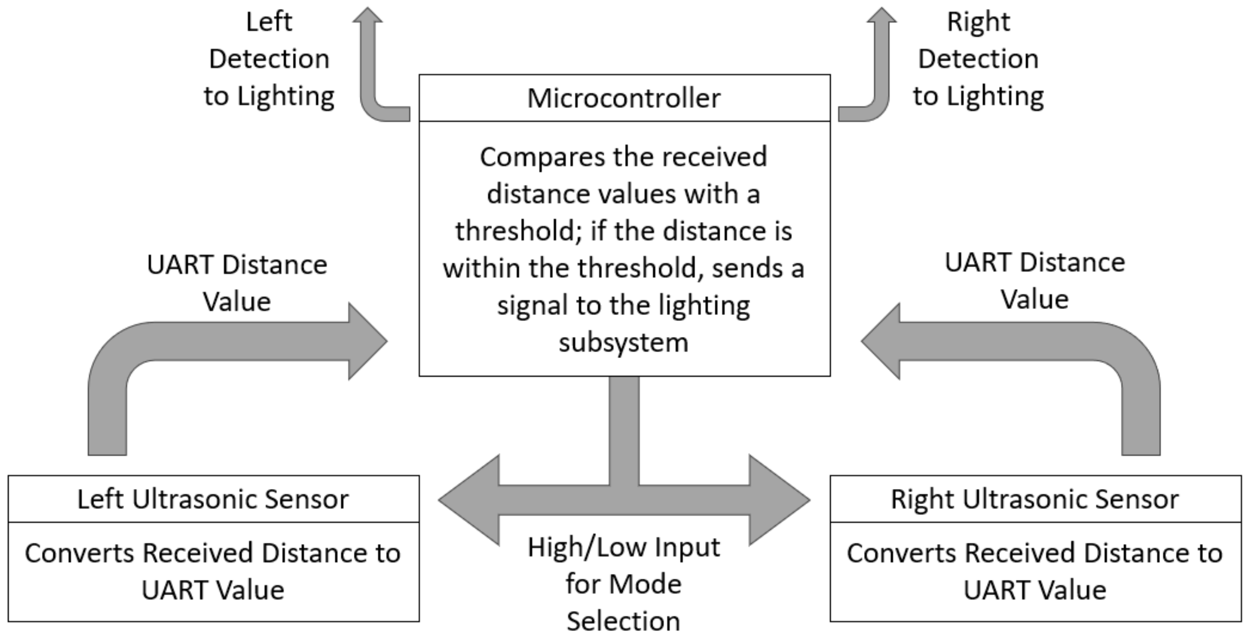

Figure 3-11: Sensor Code Diagram

As shown in Figure 3-11, each sensor receives a simple high or low value from the microcontroller. This value determines the ultrasonic sensors' output modes. A high value commands the sensors to output processed values, which provide more steady data at a slightly lower response time. A low input allows the sensors to send raw real-time data to the microcontroller.

3.3.4. Subsystem 4: Power Supply

Halo Helmet is powered by a portable power bank. It features dual-USB output ports; however, the two microcontrollers being powered are too far apart in the system to be powered by one power bank. For this reason, an extra power bank is implemented into the system. One USB port on the device outputs 5 V and 2.1 A, while the other port outputs 5 V and 1 A. A built-in multi-protection system protects the power bank against overcurrent and short circuit. The power bank automatically turns itself off when short circuit or overloading occurs. Table 3-5 shows the comparison between the chosen power bank and alternatives.

Table 3-5: Power Supply Comparison

Product	Output/Rating	Dimensions	Weight	Cost
Requirements	≥ 3.3 V-5 V/30 Ah	≤ 1 x 3 x 6 in.	≤ 1 lb.	≤ $50.00
QTshine Power Bank [17]	5 V, 3.1 A/ 26.8 Ah	0.6 x 2.95 x 5.91 in.	11.8oz	$25.95
Pocket Juice Slim Pro [18]	5 V, 2 A/ 20 Ah	1 x 2.75 x 5.5 in.	14oz	$19.88
Evolved Power Bank [19]	5 V, 3 A/26.8 Ah	1 x 3 x 6 in.	1.2 lb.	$99.95

The power supply chosen is the QTshine Portable Power Bank. The device matched or exceeded the requirements and was available for an affordable price through a reliable source. Alternative options were eliminated due to price and output. Figure 3-12, provided below, shows the chosen power supply.

Figure 3-12: QTshine Portable Power Bank Adapted From [17]

Figure 3-12 shows the chosen power bank. As shown, the device has battery life LED indicators to help the user know about how much time is available before a charge is needed.

3.4 Level 2 Prototype Design

The ideal prototype of Halo Helmet includes all hardware incorporated or attached to the helmet and bike. Currently, there are no bikes available. For now, the portion of the prototype that would ideally be attached to, and receiving signal from the bike is not attached to anything. This portion receives signals from the user manually mimicking the bike. This imitation is done by pressing buttons or flipping switches connected to the microcontroller, or by running code that already has the turn signals programmed to the microcontroller. Although a bike is not available, a helmet is. Having a helmet allows all components involving the helmet to be placed in their ideal designated area of the helmet. Without a bike, Halo Helmet still functions properly. However, Team 2-Stroke has full intentions of completing the prototype during Design II by incorporating a bike into the project.

3.4.1 Level 2 Diagram

The Level 2 diagram (Fig. 3-13) highlights the major subsystems for the final intended design and where these subsystems are located. There are two major sides of Halo Helmet, one on the motorcycle and one on the helmet. The components on the motorcycle side are in a water-resistant enclosure that mounts to the motorcycle in a convenient location. Regarding the helmet side, as many components as possible are mounted inside the helmet to reduce potential extrusions from the helmet. Some components are necessary to be external, such as the sensors and the turn signal matrix. These external components will be mounted to the helmet via Velcro as an easy and safe solution. As for overall operation, the motorcycle side will intake turn signal input from the user and convert that to a Bluetooth signal to be received by the helmet side, where it is then decoded and used to display relevant information on the LED matrix on the back of the helmet. The helmet side also takes object detection data from the sensors on the back of the helmet to inform the rider via internal LEDs as to if there is a vehicle approaching behind the motorcyclist in their blind spot.

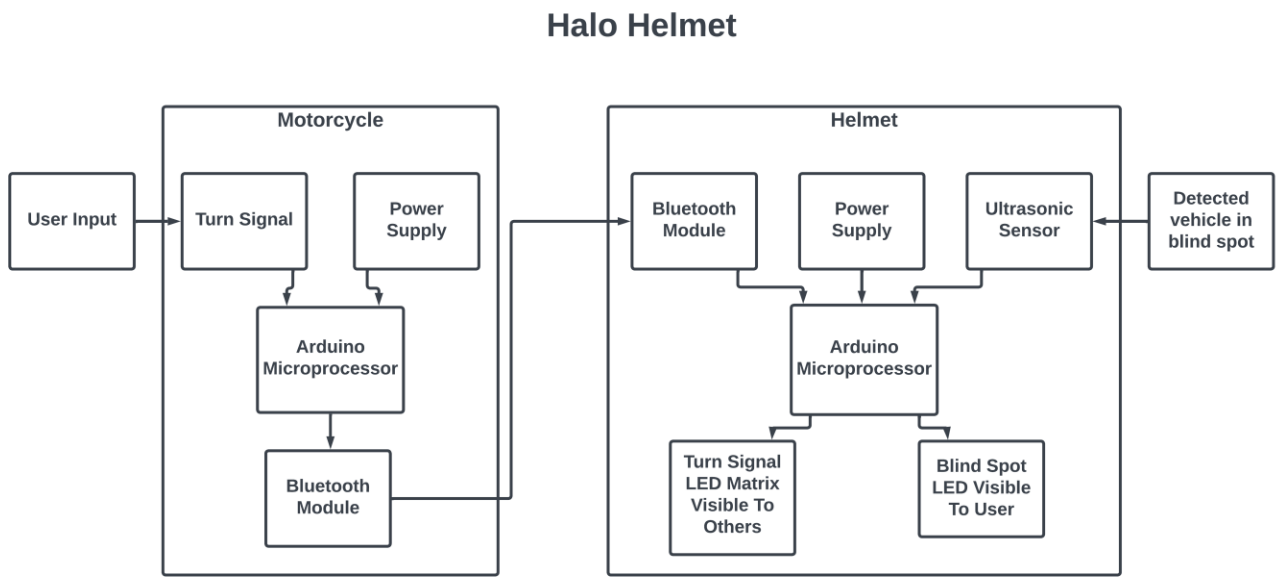

Fig. 3-13: Diagram for Halo Helmet (Level 2)

Figure 3-13 shows all components included in Halo Helmet and the connections between them. The components and connections contained on the motorcycle are separate from the components and connections contained or attached to the helmet. The motorcycle and helmet components are separated by boxes as the figure shows.

Team 2-Stroke takes pride in ensuring that Halo Helmet meets all requirements to keep users safe, comfortable, and visible to others. The requirements and constraints for Halo Helmet inspired the hardware, software, components and design of both the overall system and subsystems. The next step in the design process involves testing each subsystem and then fully integrating the prototype. All test descriptions, data and interpretation of the test results are described in the next section.

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