AFTERMARKET HAZARD DETECTION SYSTEM FOR BICYCLES

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Team 19

Abstract

Our Aftermarket Hazard Detection System aims to provide cyclists with a reliable and inexpensive safety setup for their bikes. As students we have encountered countless instances where cyclists have had close calls or wrecks on the busy streets of Urbana-Champaign. Our system is built around a LiDAR sensor, which is the sole sensing mechanism to drive the system. Using a dual microcontroller setup information from the LiDAR sensor is processed and passed to the indication unit through ESP-NOW where an LED array and buzzer are housed to inform the rider of any hazard. The LED array and buzzer both have the capabilities to communicate the severity of a detected hazard through scaling of indication.

Contents

1. Introduction

According to a study from the U.S. Department of Transportation, only 17 percent of personal vehicles have blind spot technology as a standard feature and 57 percent have it as an upgrade option [1]. The number of personal vehicles equipped with the capabilities is on the rise, preventing an estimated 50,000 accidents [2]; the same can't be said for cyclists. Cyclists are in harm's way every time they decide to go for a ride on a public road. As urban cyclists, we've experienced situations where hazard detection would have prevented close encounters, especially on campus.

Collision detection technology in the cycling industry severely lags behind that of the automotive industry. Currently, Garmin dominates the cyclist market for blind spot and hazard detection technology. We believe that market competition is essential to avoid monopolization and to protect consumers. Therefore, we advocate for the development of more products in this field to ensure cyclist safety, enforce market fairness, and drive innovation.

To address this problem, we developed and implemented a hazard detection system for bicyclists. The system will utilize LiDAR technology to detect objects in the bicycle's rear and an audio-visual handlebar display system to notify cyclists, with the capability for indicating directional and severity based on LiDAR data. The main goal of our project is to create a market-competitive product to ensure rider safety, where reliability and accuracy alongside comfort and usability are paramount to the success of our project. In the following sections, we will dive more into the planning, design, and makeup of our system with final testing and results later in the report.

1.1 High-Level Overview

Our three high-level requirements deal with different areas of our system varying from sensing and ranging to indication to power and integrity. The first requirement on sensing and ranging states that we should be able to track any hazards in the sensor's operational range of 6 m with an accuracy of +/- 5 cm. This is the backbone of our sensor unit providing input data to the entire system and allowing the system to react to whatever the sensor sees. Without an accurate sensor, the system would probably do more harm than good. The second requirement on the indication front promises that the LED array and buzzer will be bright enough and loud enough to alert the cyclist of danger approaching. The severity of danger will be shown by the intensity of each alerting component. This requirement specifically correlates to the usability of the system from a rider's perspective. The alerts a rider is receiving must be visually and/or audibly great enough to provide useful information while in the field otherwise, the indication unit has failed its primary purpose. The third requirement speaks on power and integrity in the sense that the entire system should function on independent power from a LiPo battery pack providing 3.3 V and 5 V power wherever needed with the help of buck-boost converters. The system runtime on a single charge should last 6 hours as well. This requirement aims to fulfill the practical aspect of our hazard detection system. For the system to be feasible and used in a practical sense, it must have the ability to run isolated from a test bench power source. Our design provides the necessary power to run the system on any roadway out in the field.

1.2 Subsystem Overview

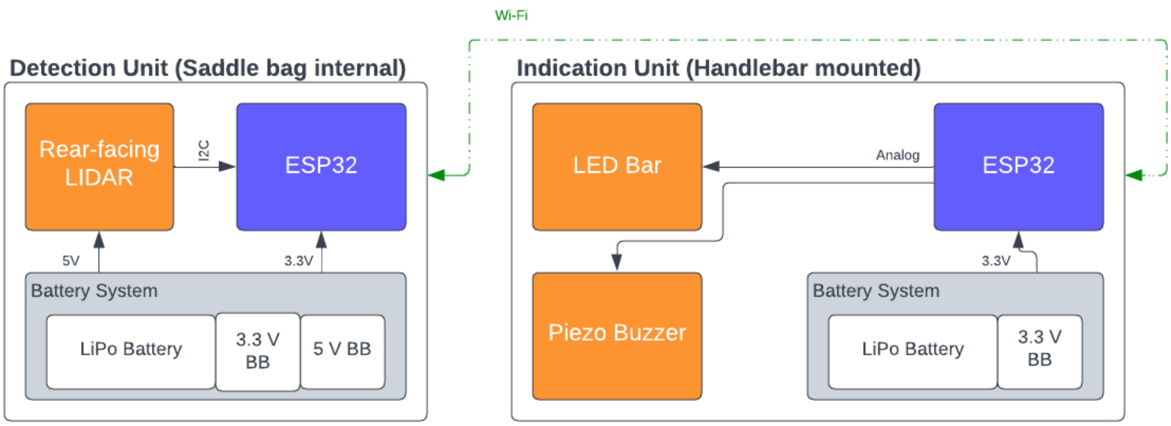

Figure 1.2.1: Block Diagram of Hazard Detection System

Our hazard detection system consists of two subsystems: the detection/sensor unit and the indication unit. The sensor unit includes an ESP32 microcontroller which reads in data from the LiDAR sensor using I2C protocol and passes it along to the indication unit for processing. This data transfer is done using ESP-NOW. The sensor unit is powered by a LiPo battery pack which outputs 3.7 V [3]. A 3.3 V buck-boost converter paired with a 5 V buck-boost converter converts the 3.7 V input to provide power to the ESP32 and LiDAR sensor, respectively. The main goal of the sensor unit is to track hazards in the LiDAR sensor's range as mentioned in the high-level requirements. The unit will be placed in an orientation to pick up any object approaching from the rider's rear blind spot continuously watching until the unit is powered off.

The indication unit has some similar features as the sensor unit, stealing the same power system design and microcontroller module. In this unit, the ESP32 microcontroller receives data from the sensor unit's ESP32 via ESP-NOW. Decisions are made based on the sensor information and passed to the rider via the LED array and the buzzer. It can be seen in the block diagram above that both the "LED Bar" and the "Piezo Buzzer" are outputs from the indication unit's microcontroller. As mentioned, power is provided by a smaller 3.7 V LiPo battery pack in the same way that a 3.3 V buck-boost converter is used to convert the voltage and power the ESP32. The goal of the indication unit is to provide the rider with the necessary alerts to reduce harmful situations and convey the information the sensor is receiving. This is done using a handlebar-mounted system where the visual and audio will be easily seen and heard. These two subsystems will work together to effectively achieve the requirements we set forth and provide a reliable system to cyclists out on the roads.

2. Design

In the design section we will mainly focus on two areas: hardware design and software design. The hardware portion will focus on the circuit design, PCB layout, and PCB development along with enclosure design. The software section will focus highly on the network communication between the two microcontrollers, the processing code, and the reading of the I2C data.

2.1 Hardware Design

2.1.1 Sensor Unit

The sensor unit was the first portion of the project to be designed. Using our block diagram, hours of research, examples from the ECE 445 website, and team collaboration a preliminary design was made. The power system was built according to documentation found on the TPS63020 buck-boost chip data sheet with an on/off switch and header added for ease of use. The programming circuitry for the ESP32 was modeled similarly to an example board found on the ECE 445 website. Aside from the ESP32 itself, the last major piece in the schematic was the LiDAR connection which would need 4 pins. Two pins were 5 V and ground while the other two were the data and clock ports. The schematic for the programming circuit can be found below in Figure 2.1.1.1. To control the length of our report the other schematics have been withheld from this section. The full sensor unit schematic diagram along with zoomed-in visuals on each section can be found in Appendix B. We recommend looking there if reading values or inspecting certain schematics is desired.

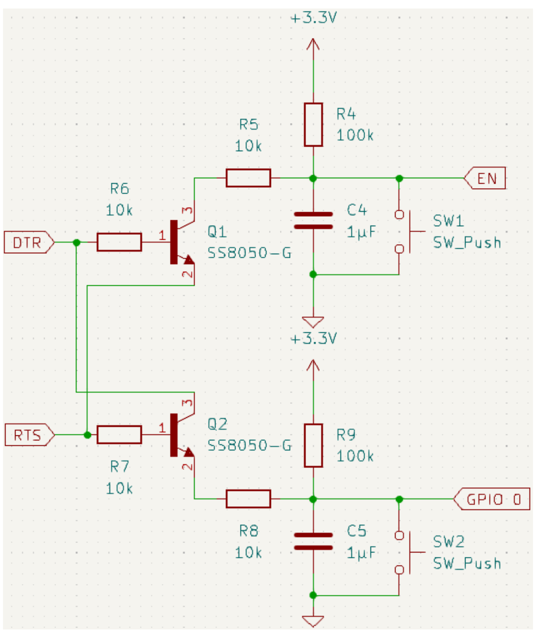

Figure 2.1.1.1: Programming Circuit for Sensor Unit

The only noteworthy problem found in our sensor unit circuitry was the direction of one transistor. Component Q2 in Figure 2.1.1.1 is an NPN transistor with its collector on pin 3 and its emitter on pin 2, this is exactly the opposite of the desired orientation. The emitter should be pointed up and connected to DTR while the collector should be pointed down connecting to R8. After some circuit analysis and testing we found that the programming mechanism for our sensor unit still worked, but it would need to be manually put into download/boot mode. With the transistor in the correct orientation, ideally, the ESP32 would automatically start in download mode. An alternative fix was used in the indication unit which will be discussed further shortly.

After completing the circuit schematics came the PCB design which involved the layout of components as well as routing on the board itself. There were many iterations of our design each time improving small details and adding in needed adjustments. We wanted to highlight a few major things we learned and important ideas we implemented along the way. The two figures below represent the first PCB we designed for the sensor unit shown in Figure 2.1.1.2 and our final version which is currently used shown in Figure 2.1.1.3.

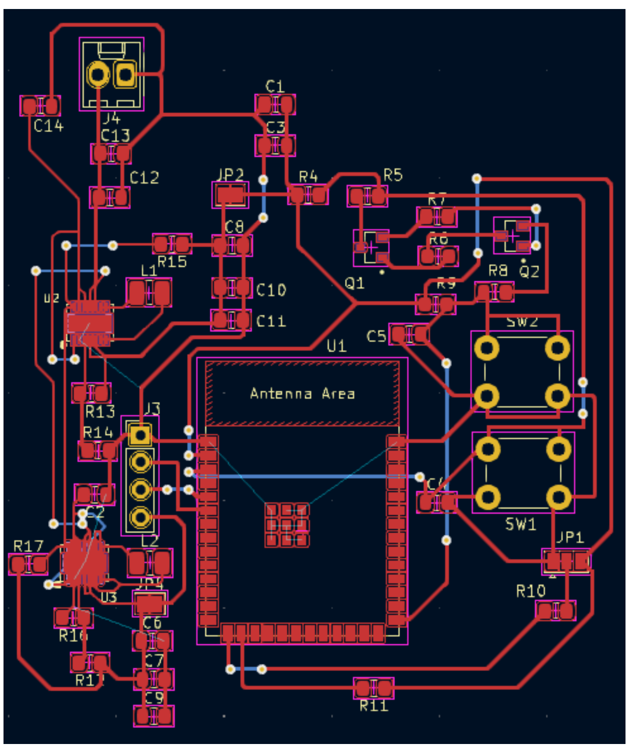

Figure 2.1.1.2: Initial Sensor Unit PCB Design

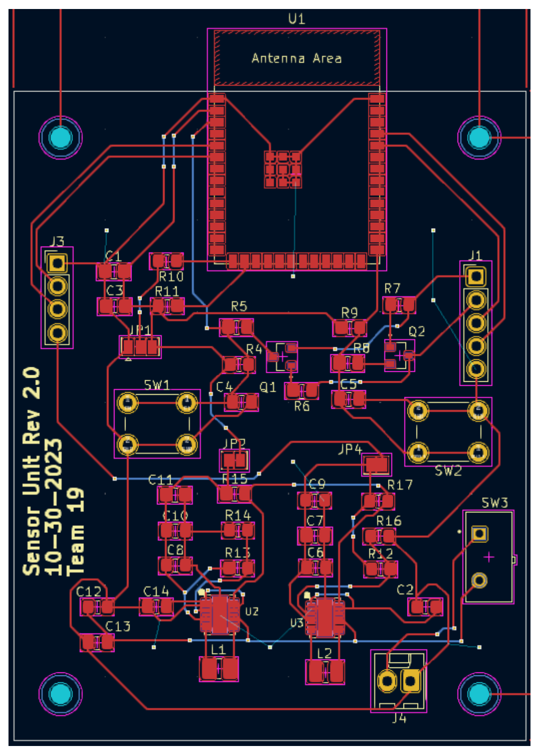

Figure 2.1.1.3: Final Sensor Unit PCB Design

The most obvious change we made was the location of our ESP32. When laying out the design initially, the designer didn't take into consideration possible noise that could affect the transmitting or receiving of data. Noise if not dealt with properly could lead to erroneous information being passed to and from each microcontroller. During the PCB review we learned that keeping the antenna as far away from circuitry as possible, especially noise, is the best practice. In Figure 2.1.1.3, it can be seen that this is exactly what we did. Sliding the ESP32 to the top allowed for it to be somewhat isolated from all other circuitry with the most noisy power systems towards the bottom farthest away. The final design is not only neater which led to easier testing and debugging, it also grouped systems on the PCB to help isolate potential issues. The 3.3 V and 5 V power systems can be found at the bottom with the 3.3 V housed on the left side and the 5 V housed on the right side.

After waiting on and verifying parts, PCB assembly went relatively smoothly. One major dilemma we encountered was the 5 V power system failing to output the desired voltage. We tried to implement the 5 V system on numerous boards using 4 or 5 buck-boost converters to see if it would work. All but 1 unit failed immediately upon testing, the final unit did briefly read 5 V as desired but soon failed as we started running diagnostics. We believe these failures were due to pins being shorted on the buck-boost itself. The pins on the buck-boost converters were less than a millimeter apart so even with the stencils, paste, and oven for PCB baking we think human error along with basically no forgiveness led to the chips' faultiness. As a backup plan to ensure we still had an independent power system, we found a small external 5 V boost converter to attach which worked exactly how the on-board 5 V system was supposed to. It can be seen along with the entire sensor unit assembly in Figure 2.1.1.4 below.

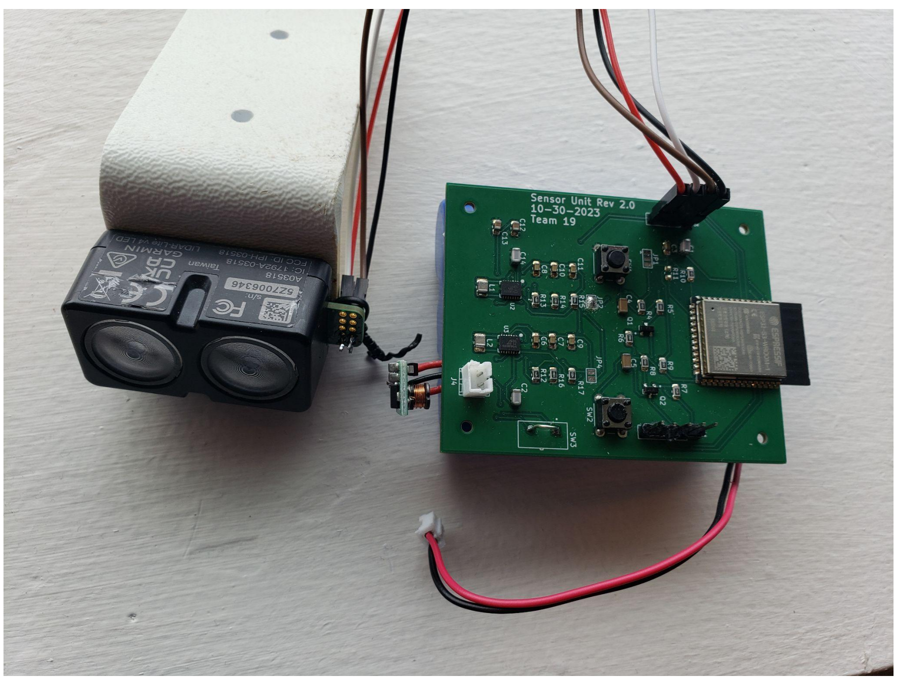

Figure 2.1.1.4: Sensor Unit without Enclosure (Battery Underneath PCB)

2.1.2 Indication Unit

The other big hardware piece was the indication unit. The indication unit went much smoother in all aspects of the design as it was done after many issues had been found and corrected in the sensor unit. The circuit schematic is very similar to the unit we just analyzed with the removal of the 5 V power system and LiDAR header and the addition of the LED array and buzzer. The programming circuitry, ESP32, and 3.3 V power system are all carried over from the first unit. Even with some key alterations, since the schematic closely resembles that of the sensor unit, no figures will be shown here. However, the entire indication circuit schematic can be found in Appendix C. We highly recommend reviewing these schematics if you are unsure about any changes or additions between units.

The PCB design for the indication unit was able to resemble the sensor unit in some ways as well, due to many similarities in circuit design. Using what was learned from the first PCB development, this PCB had many fewer iterations and was reliable from the start. The only two minor details that changed between the first and last iterations were the addition of an on/off switch and the buzzer. Figure 2.1.2.1 shows the final schematic for the indication unit.

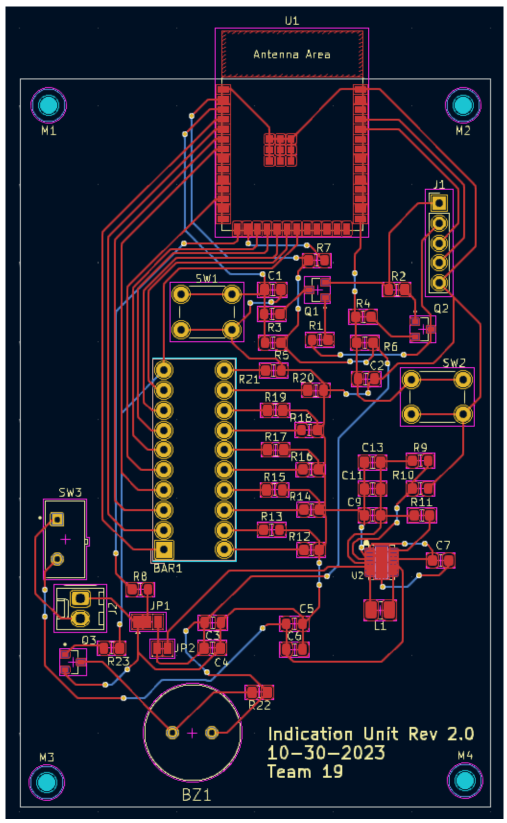

Figure 2.1.2.1: Final Indication Unit PCB Design

Fleshing out and solving many issues that arose on the sensor unit PCB, led PCB assembly to go rather quickly for this board. We knew ahead of time that one transistor was flipped the wrong way so we were able to flip it over and bend the pins to attach it in the correct orientation. Everything on this board worked according to plan during the initial testing after assembly. A couple oversights we had that we would change were we to build another board would be to attach the LEDs, buzzer, and on/off switch to the back side of the board. This would allow for a simpler enclosure design and easier usability of the system as the PCB could be mounted so all those components were flush with the enclosure surface and accessible externally. We will talk about this more in the enclosure design section. Below in Figure 2.1.2.2 is the final PCB assembly of the indication unit.

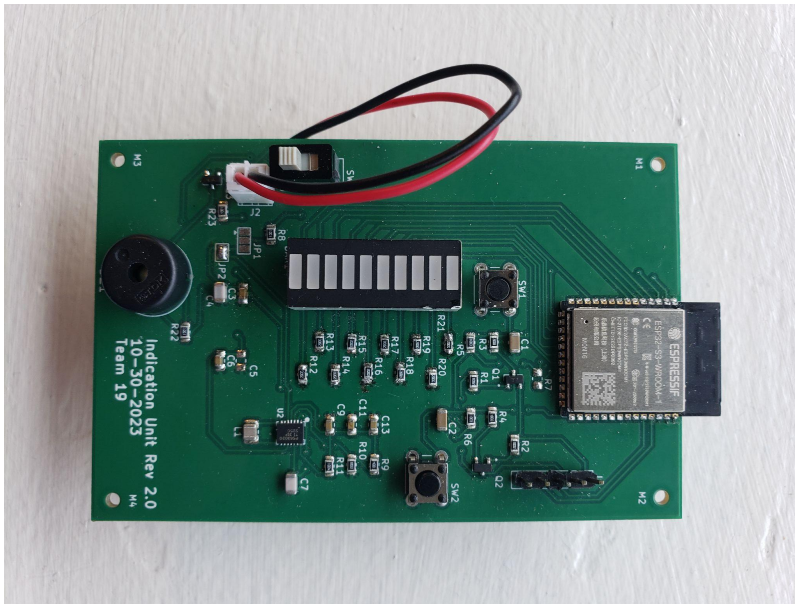

Figure 2.1.2.2: Indication Unit without Enclosure

2.1.3 Enclosure Design

The last component on the hardware side of the project was the building of enclosures. In the beginning of the semester, the plan was to design and 3D print custom enclosures to use for housing the units. As the semester went on it was apparent that the custom enclosures would not be done by demo time, but could be done before our presentation and report. We decided to modify the purchased enclosures and attach them to the bike to use for testing and demoing purposes which ended up working out well. Below in Figure 2.1.3.1 is the setup of the indication unit enclosure.

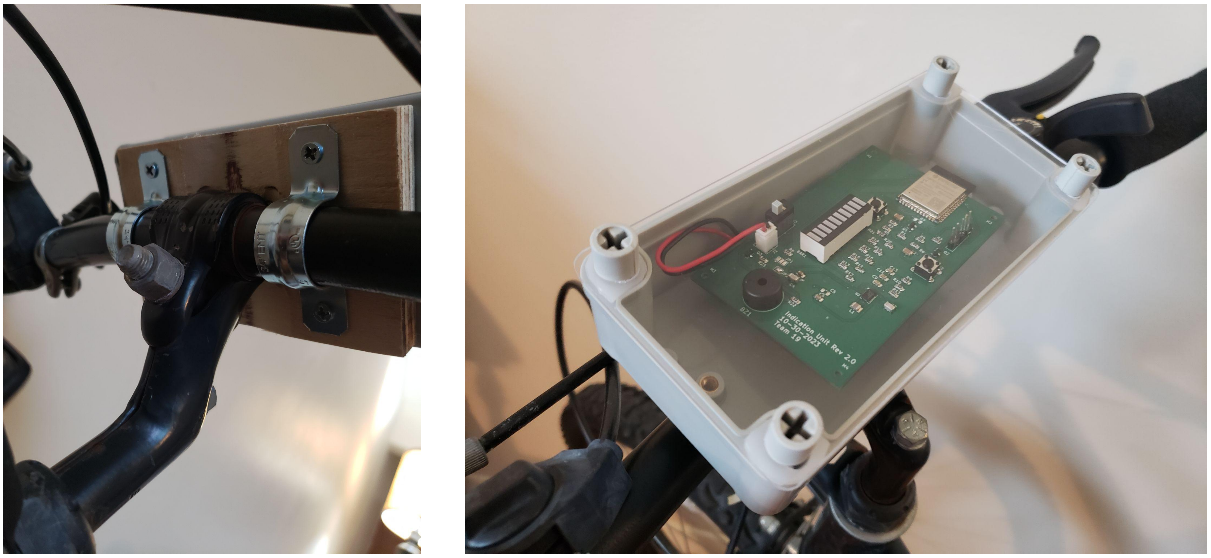

Figure 2.1.3.1: Indication Unit Enclosure Attached to Handlebar

As previously mentioned the indication unit attaches to the handlebar. In this testing design PVC clamps were used to ensure the enclosure was held in place firmly. A Lexan lid was used so the rider could easily see the LEDs in the field while keeping some of the protective nature a regular enclosure would provide. This modified enclosure isn't waterproof because it is sealed completely and submersible, but it could shed water in a rain shower for a little while. It's important to note, this design doesn't affect the bike functionality. Now to look at the sensor unit setup as seen in Figure 2.1.3.2 below.

Figure 2.1.3.2: Indication Unit Enclosure Attached Under the Seat

The sensor unit is attached under the seat in a saddle bag-type orientation. The left picture shows how the enclosure is primarily attached. We initially thought we could use two velcro straps, one to the seat and one around the seat frame. As we were testing with the Velcro setup it was apparent that there was unwanted movement of the enclosure in all directions.

This was solved by adding a PVC clamp around the seat frame which could securely hold the enclosure and upon more testing we found little to no movement. While this was a little bulkier of an addition we decided it paid off as we would be able to gather much more reliable sensing data and have better functionality in our system out in the field. The LiDAR sensor itself is tapered so the cutout in the enclosure was made so that when the sensor is smashed in between the bracket and enclosure, there is a relatively tight seal to meet our durability requirement. On top of that, there is one less potential area for movement. The last thing to note is the bracket the LiDAR sensor is attached to. It is made of hardened plastic, but can easily be altered so the LiDAR can tilt one way or another if desired. This would be up to the user's discretion, but it wouldn't take but a couple of minutes to amend.

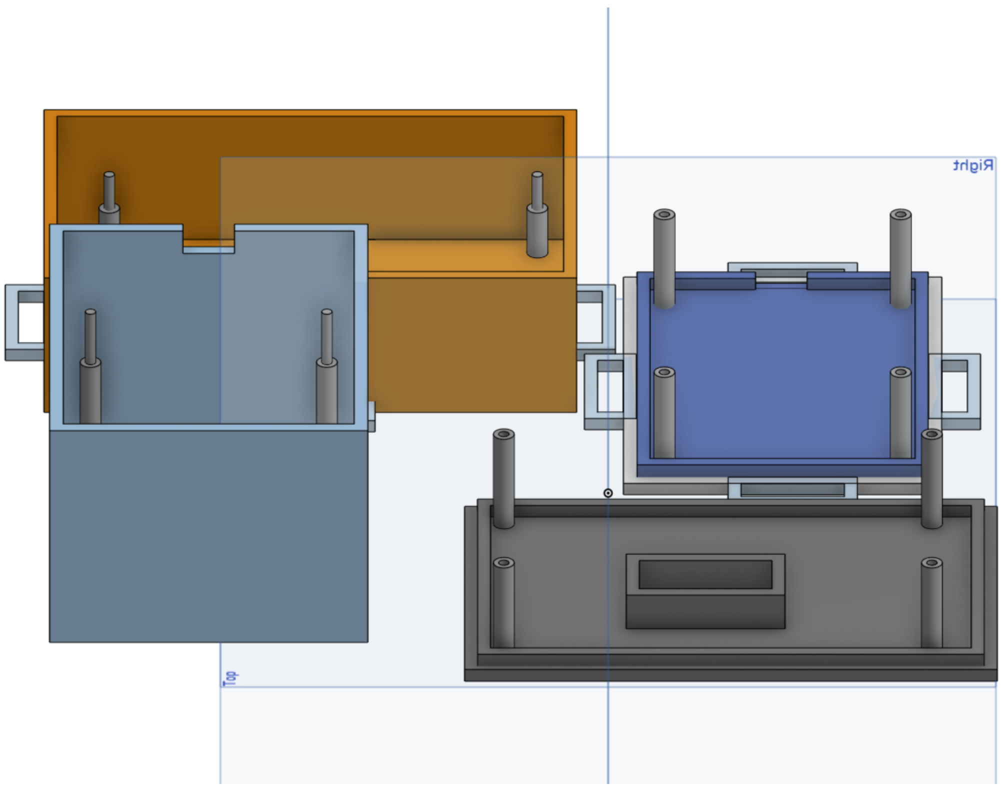

Figure 2.1.3.3: Indication and Sensor Unit Custom 3D Enclosure

The 3D-printed custom enclosures are shown in Figure 2.1.3.3. These custom enclosures have been measured and created in CAD software with the goal of minimizing the footprint of the units. Apart from redesigning the PCB to be more space-efficient, these custom enclosures follow the minimum space needed to stay functional. There is a cutout for the sensor cable for the Sensor Unit (Bottom Left and Top Right) so that the sensor can be attached to the slim side of the enclosure (top right) and the cable be long enough to be connected to the PCB. Likewise, the Indication Unit (Top Left and Bottom Right) has a cutout specifically for the LED array so that it hides the rest of the PCB for a more "final" product design. This was only one iteration of the design and more iterations were needed as the 3D-printed product showed some design flaws (such as not enough tolerance for the antenna of the PCB and some sizing issues) which would be ironed out through more iterations and printing. That being said, the flawed enclosure was available at the time of the presentation and was handed out to the audience for review.

2.2 Software Design

Both the sensor unit and the Indication unit use a modified version of the ESP-NOW protocol to communicate with each other. The ESP-NOW protocol is used for its low latency and its low-power features that stood out from the available communication choices. In fact, it was the smallest latency that the ESP32 architecture supported. The main drawback of the communication protocol comes from its low transfer rate of 250 bytes per payload, however, it was plenty for our use case since the sensor only returned a distance reading instead of needing more calculations.

2.2.1 Sensor Unit

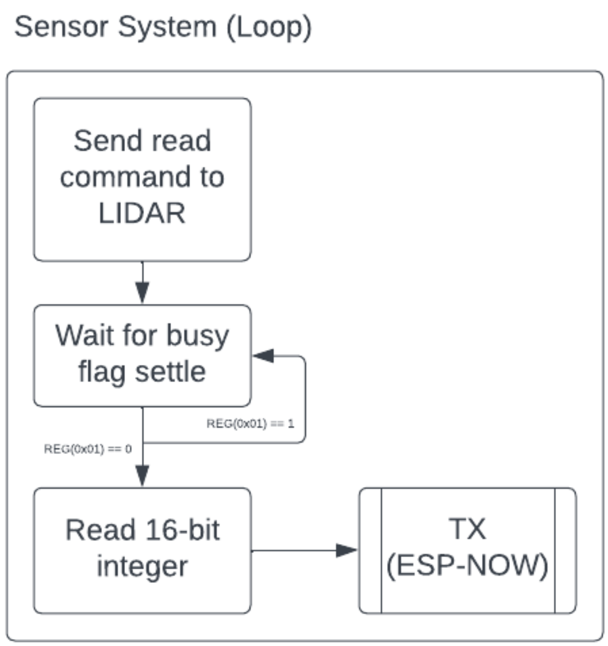

Figure 2.2.1.1: Block Diagram of the Pseudocode of the Sensor Unit

As visible from Figure 2.2.1.1 above, the sensor unit applies a simple-yet-efficient method for the setup and maintenance of the connection between itself and the indication unit. It initially sets up the I2C communication pins, defines the I2C address for LiDAR Lite V4 LED, and specifies the receiving MAC address for the ESP-NOW communication. Now that the setup phase is complete, it defines a struct_message data structure to hold the message and starts polling the LiDAR sensor at a predefined interval. This happens by initially setting a specific register in the LiDAR unit and continuously polling the status register of the LiDAR sensor until it settles. When it does, the 16-bit integer is read and sent to the indication unit through the struct_message data structure and ESP-NOW. This main loop is repeated until the intentional loss of power through a switch.

2.2.2 Indication Unit

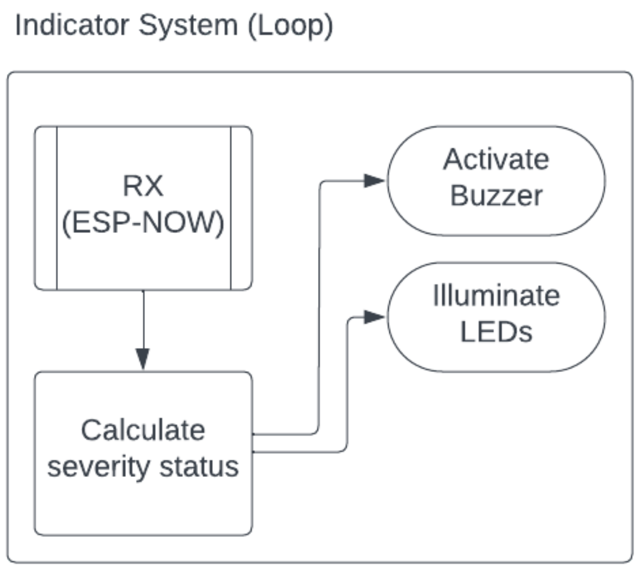

Figure 2.2.2.1: Block diagram of the Pseudocode of the Indication Unit

Like the sensor unit, the indication unit follows a similar setup with a different main loop. As seen from Figure 2.2.2.1 above, after the code sets initial variables such as the buzzer frequencies for high and low tones, GPIO pins for the LEDs and the buzzer, and the setup phase of the ESP-now communication, it creates a callback function called OnDataRecv which gets executed when data is received from the sensor unit. The distance reading received from the sensor is then mapped into a severity status which determines how loud the buzzer should make noise and how many LEDs to light up. Depending on the result of this calculation, it sends the relative GPIO pins the correct signals to turn on the buzzer and light on the LEDs respectively.

3. Design Verification

3.1 LiDAR Accuracy Testing

To measure the accuracy of our LiDAR unit against our requirements, we performed a simple set of tests. In this experiment, we fixed the LiDAR unit onto a table and performed measurements at varying distances across our range of movement.

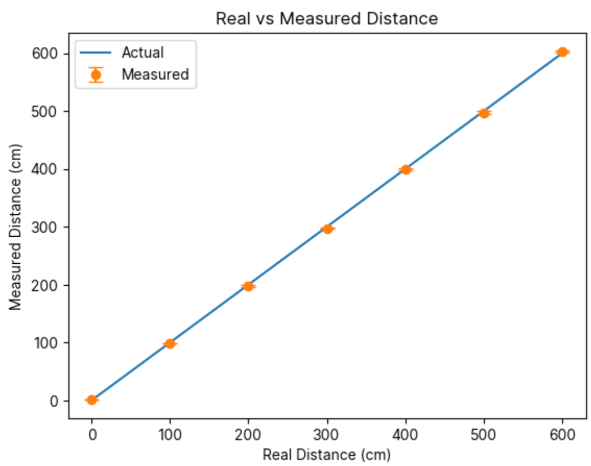

Figure 3.1.1: LiDAR Accuracy Chart

- Fixed LiDAR ranging against static medium/high reflectivity targets
  - Fabric clothing
  - Automotive plastics
- Moved target to specified stop
- Read out measurements from LiDAR sensor via I2C
- Preliminary trials data
- 3 trials at 7 distances
  - 0-600 cm

From our testing, we were able to verify the accuracy of our LiDAR unit within our requirements, and discovered potential issues we had to mitigate via software or in future iterations.

Verification

This experiment verified requirements 2 and 3 regarding LiDAR readout accuracy (see Appendix A, Table 1), showing its accuracy throughout the required range.

3.2 Battery & Power System Integrity Testing

A series of battery tests were performed to ensure both the sensor and indication units could reach our six-hour power-on requirement. In this experiment, we simply placed both units, running on full power, in a high-traffic area to simulate usage, taking measurements of the battery and power conversion outputs hourly.

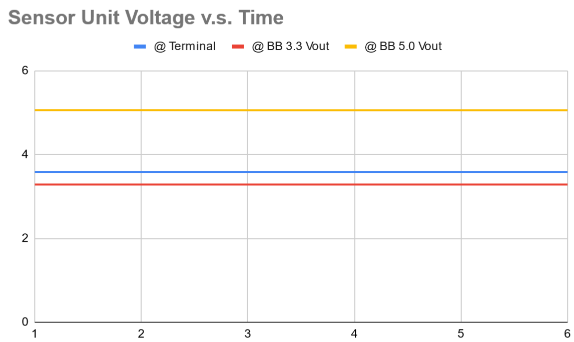

Figure 3.2.1: Sensor Unit Power Measurements

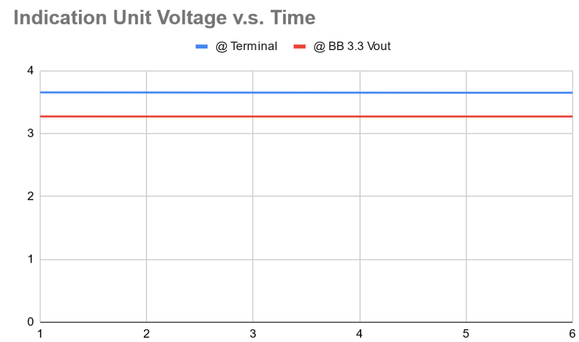

Figure 3.2.2: Indication Unit Power Measurements

- Realistic battery and power system testing
- Ran sensor and indication systems in busy location (to simulate traffic)
- Measured battery and power systems hourly up to expected limit
- Performed in a low humidity, room temperature environment
- Measured using a Fluke 117, last calibrated 12/05/2022

Overall, the chart shows that the sensor and indication units were able to operate reliably for six hours on a single charge. This is a positive result and suggests that our project is well-equipped for all kinds of cyclists, commuters and enthusiasts alike.

However, it is important to note that the test was conducted in a controlled environment with low humidity and room temperature. It is possible that the sensor unit may not perform the same way in real-world conditions, where it may be exposed to extreme temperatures and other environmental factors.

Verification

This experiment verified requirements 5, 6, and 7, regarding providing sustained independent system power via batteries, within the strict ±5% target. Our data strongly indicates that our system can outlast the six-hour requirement, all while maintaining the correct outputs.

3.3 General Verifications

3.3.1 LiDAR Sample Frequency Requirements

The LiDAR sample frequency requirement 4 was fully met. LiDAR latency testing took place during our software development and verification stages, where we were able to drive the unit to read up to 200 times a second. This is inline with the specification in its datasheet, and by the limits of the serial data protocol. There was a subtle loss in quality, though not beyond 3 centimeters in deviation.

3.3.2 LED Indication Requirements

The LED brightness and functionality requirements 1 and 9 were fully met, as the LED system has a linear scale of hazard level, and is clearly visible in daylight. These are observable in our video demo.

3.3.3 Buzzer Indication Requirements

The buzzer loudness and functionality requirements were fully met, as the buzzer system is audible, even in heavy traffic (~80dB), and switches between low and high frequencies at different hazard severity levels. These are observable in our video demo.

3.3.4 Enclosure Reliability Requirements

The enclosure requirements 11 and 12 were largely met. The current enclosure is built using junction boxes made out of 2mm thick ABS plastic, which are gasket sealed and relatively durable to impacts, and have minimal cutouts to expose sensors. While our team does not have the equipment to properly evaluate our enclosure with IP standards, we are relatively confident in its durability and ability to function under poor weather and physical conditions.

4. Cost and Schedule

4.1 Cost of Parts

Table 4.1: List of Parts and Components, including unused and development parts.

Order	Description	Manufacturer	Part #	Unit Cost	Qty	Cost
09/27/23	Garmin LiDAR Lite v4 LED	Garmin	010-02022-00	$59.99	1	$59.99
09/28/23	ESP32-WROOM-32E Devkit	Expressif Systems	ESP32-DEVKITC-32E/1965-ESP32-DEVKITC-32E-ND	$9.80	2	$19.60
10/09/23	RF TXRX MODULE BT PCB TRACE SMD	SCHTOETA ENGINEERING LIMITED	ESP32-S3-WROOM-1-N16/1965-ESP32-S3-WROOM-1-N16CT-ND	$3.48	2	$6.96
10/09/23	IC REG BUCK-BST ADJ 3.5A 14VSON	TEXAS INSTRUMENTS	TPS63020DSJR/296-36491-1-ND	$2.97	3	$8.91
10/09/23	FIXED IND 1.5UH 2.6A 0.06OHM SMD	MURATA ELECTRONICS	DFE252012P-1R5M=P2/490-10648-1-ND	$0.27	4	$1.08
10/09/23	TRANS NPN 25V 1.5A SOT23-3	COMCHIP TECHNOLOGY	SS8050-G/641-1790-1-ND	$0.29	3	$0.87
10/09/23	CONN HEADER VERT 2POS 2MM	JST SALES AMERICA INC	B2B-PH-K-S/455-1704-ND	$0.19	2	$0.38
11/09/23	RES SMD 1K OHM 1% 1/8W 0805	PANASONIC ELECTRONIC COMPONENTS	ERJ-6ENF1001V/P1.00KCCT-ND	$0.05	15	$0.78
11/09/23	RES SMD 180K OHM 1% 1/8W 0805	PANASONIC ELECTRONIC COMPONENTS	ERJ-6ENF1803V/P180KCCT-ND	$0.05	15	$0.78
11/09/23	RES SMD 100K OHM 1% 1/8W 0805	PANASONIC ELECTRONIC COMPONENTS	ERJ-6ENF1003V/P100KCCT-ND	$0.05	15	$0.78
11/09/23	RES SMD 10K OHM 1% 1/8W 0805	PANASONIC ELECTRONIC COMPONENTS	ERJ-6ENF1002V/P10.0KCCT-ND	$0.05	15	$0.78
11/09/23	RES SMD 200 OHM 1% 1/8W 0805	PANASONIC ELECTRONIC COMPONENTS	ERJ-6ENF2000V/P200CCT-ND	$0.05	15	$0.78
11/09/23	SWITCH SLIDE SPST 0.4VA 28V	NKK SWITCHES	AS11CP/360-2610-ND	$4.22	2	$8.44
11/09/23	RF TXRX MODULE BT PCB TRACE SMD	SCHTOETA ENGINEERING LIMITED	ESP32-S3-WROOM-1-N4/1965-ESP32-S3-WROOM-1-N4CT-ND	$2.95	2	$5.90
11/09/23	CAP CER 0.1UF 50V C0G/NP0 1206	MURATA ELECTRONICS	GRM31C5C1H104JA01K/490-8335-1-ND	$0.30	10	$2.95
11/09/23	25V 300MW 1.5A 100MHZ 500MV@800M	UTD SEMICONDUCTOR CO.,LTD	SS8050/4518-SS8050CT-ND	$0.21	5	$1.05
11/09/23	IC REG BUCK-BST ADJ 3.5A 14VSON	TEXAS INSTRUMENTS	TPS63020DSJR/296-36491-1-ND	$2.97	4	$11.88
11/09/23	FIXED IND 1.5UH 2.6A 0.06OHM SMD	MURATA ELECTRONICS	DFE252012P-1R5M=P2/490-10648-1-ND	$0.27	5	$1.35
11/09/23	RES SMD 1M OHM 1% 1/8W 0805	PANASONIC ELECTRONIC COMPONENTS	ERJ-6ENF1004V/P1.00MCCT-ND	$0.05	15	$0.78
11/09/23	CAP CER 1UF 25V X7R 1206	MURATA ELECTRONICS	GRM31MR71E105KA01L/490-5860-1-ND	$0.17	10	$1.68
11/03/23	CAP CER 100UF 10V X5R 1206	MURATA ELECTRONICS	GRM31CR61A107MEA8L/490-GRM31CR61A107MEA8LCT-ND	$0.28	10	$2.80
11/03/23	CAP CER 10UF 6.3V X5R 0402	MURATA ELECTRONICS	GRM155R60J106ME05D/490-GRM155R60J106ME05DCT-ND	$0.02	10	$0.18
11/03/23	CAP CER 22UF 4V X5R 0603	MURATA ELECTRONICS	GRM188R60G226MEA0D/490-5526-1-ND	$0.11	15	$1.61
11/03/23	RES SMD 1.6M OHM	PANASONIC	ERJ-6ENF1604V/P1.60	$0.05	10	$0.52

	1% 1/8W 0805	ELECTRONIC COMPONENTS	MCCT-ND			
11/03/23	RES SMD 100K OHM 1% 1/10W 0402	PANASONIC ELECTRONIC COMPONENTS	ERJ-2RKF1003X/P100K LCT-ND	$0.02	10	$0.24
11/03/23	RES SMD 1M OHM 1% 1/10W 0402	PANASONIC ELECTRONIC COMPONENTS	ERJ-2RKF1004X/P1.00 MLCT-ND	$0.02	10	$0.24
11/03/23	RES SMD 10K OHM 5% 1/10W 0402	PANASONIC ELECTRONIC COMPONENTS	ERJ-2GEJ103X/P10KJ CT-ND	$0.02	10	$0.21
11/03/23	CAP CER 0.1UF 6.3V X5R 0201	MURATA ELECTRONICS	GRM033R60J104KE19 D/490-3167-1-ND	$0.01	10	$0.12
11/03/23	RES SMD 1K OHM 5% 1/10W 0402	PANASONIC ELECTRONIC COMPONENTS	ERJ-2GEJ102X/P1.0KJ CT-ND	$0.02	10	$0.21
11/03/23	RES SMD 200 OHM 1% 1/10W 0402	PANASONIC ELECTRONIC COMPONENTS	ERJ-2RKF2000X/P200L CT-ND	$0.02	10	$0.24
11/03/23	RES SMD 180K OHM 5% 1/10W 0402	PANASONIC ELECTRONIC COMPONENTS	ERJ-2GEJ184X/P180KJ CT-ND	$0.02	10	$0.21
11/03/23	BUZZER PIEZO 3V 12.2MM TH	TDK CORPORATION	PS1240P02BT/445-252 5-1-ND	$0.60	2	$1.20
					Total	$143.50

4.2 Cost of Labor

According to data from the University of Illinois, the average electrical engineer will make $42 per hour and the average computer engineer will make $52 per hour [6]. With this in mind we can anticipate around $50 per hour for our time. The time spent designing, developing, and implementing our system was quite large, but as we expected. In some areas we had a great deal of experience while in others we had very little. There were many unexpected problems that needed to be solved as the testing and assembly process continued. Over the course of the semester we would guess around 80 hours per team member was spent to complete the project. This would bring the salary for each team member to $50/hr * 2.5 * 80hr = $10,000. With 3 members on the team the labor cost would total to ~$30,000.

4.3 Total Cost

As with many projects the labor costs are the main component in our detection system. Labor comes out around $30,000 while parts are much less as seen in Figure 4.1. Adding in a 20% upcharge on parts due to shipping costs we will see parts totaling to $172.20. In total we can expect this project to cost $30,172.20.

4.4 Schedule

Table 4.4: Work Schedule throughout Semester

Week	Task	Person
September 24th - September 30th	Pick out / research components	Everyone
	Order parts	Erik
	Design Document Due 9/28	Everyone
	Research physical design	Adam

October 1st - October 7th	Design Review with Prof. and TAs 10/2	Everyone
	Pick out remaining parts	Everyone
	Order remaining parts	Erik
	Finish prototyping systems for sensor unit	Erik & Adam
	Finish first PCB design for sensor unit	Erik and Adam
October 8th - October 14th	First Round PCBway Orders 10/10	Everyone
	Begin networking / communication code	Oz
	Finish prototyping systems for indication unit	Erik & Adam
	Finish first PCB design for indication unit	Erik & Adam
October 15th - October 21st	Second Round PCBway Orders 10/17	Everyone
	Continue networking / communication code	Oz
	Revise sensor unit PCB design	Erik & Adam
	Revise indication unit PCB design	Erik & Adam
October 22nd - October 28th	Third Round PCBway Orders 10/24	Everyone
	Continue networking / communication code	Oz
	Final revision for sensor unit PCB design	Erik & Adam
	Final revision for indication unit PCB design	Erik & Adam
October 29th - November 4th	Fourth Round PCBway Orders 10/31	Everyone
	Order resistors / capacitors	Erik
	Continue networking / communication code	Oz
	Logistics + TA Meeting	Adam
	Develop plan of attack for next couple weeks	Everyone
	Plan enclosure design	Everyone
November 5th - November 11th	Continue networking / communication code	Oz
	Custom enclosure design	Oz
	Bake board with ESP32, Buck-Boost,Inductors	Erik
	Start sensor unit PCB assembly	Erik & Adam
	Order new parts (physical size was wrong)	Erik & Adam
	Research / attempt 5 V Buck-Boost fix	Adam
November 12th - November 18th	Finish networking / communication code	Erik & Oz
	I2C code	Erik
	Attempt another 5 V Buck-Boost fix	Adam
	Restart sensor unit assembly	Erik & Adam
	Attempt many download mode fixes	Erik & Adam
	Mock Demo	Everyone
	Documentation	Adam
	Lab day debugging PCB issues	Erik & Adam
November 19th - November 25th	Assemble indication unit PCB	Erik & Adam
	Testing of system (home and lab)	Erik & Adam
	Continue custom enclosure design	Oz
	Build / modify testing enclosure	Adam
	Testing / bugs found	Adam
	Finalize entire system	Erik & Adam
November 26th - December 2nd	Final Demo	Everyone
December 3rd - December 7th	Final Presentation	Everyone

5. Conclusion

To wrap up our discussion we will speak on our accomplishments throughout the semester, some lacking results, and consideration regarding our design and potential future work.

5.1 Accomplishments

This entire semester has been a learning experience for all of us on the team. More than just the project at hand we believe a major accomplishment is the teamwork we have shown along the way. From troubleshooting problems together on the circuit or PCB design to debugging the assembly of both units to hurdling problems that arose making the enclosures, we have banded together as a group to have a successful project. On the project side of things, we have many successes to show for our efforts. The LiDAR sensor equipped with our sensor unit could accurately detect hazards in its expectant range of 6 m while being accurate within +/- 5 cm as shown in section 3.1. In the demonstration for the Professor and TAs, we were able to show that the indication unit alerts the rider prominently. The LEDs could be seen from many tens of feet down the hallway while the buzzer was audible even with the movement and noise of 8 to 10 people. The buzzer also had the ability to change tone depending on the severity of the hazard which was shown working in the demo too. The last couple of functionality pieces deal with the power system. As shown in section 3.2 the battery pack supply does not vary much over the given 6-hour time period and can provide both 3.3 V and 5 V the entire time. This means both on-board power systems can function independently for more than 6 hours before needing to charge.

5.2 Uncertainties

The single unsatisfied requirement is the onboard 5 V power system in the sensor unit. As briefly mentioned in the hardware design section, we were never able to supply 5 V with the TPS63020 chip on the PCB itself. During the first failure, the system was outputting around 2.3 V which was nowhere near the needed 5 V. As the input voltage was stepped from the lowest battery voltage of 3.2 V to the highest battery voltage of 4.2 V, the output voltage also moved from around 1.2 V up to 3.1 V. This behavior was frightening as we debugged the system because the buck-boost we implemented was supposed to keep the output voltage stable. For example, when the input voltage was stepped in the same fashion and we measured the 3.3 V side we saw about 3.3 V no matter what the input was. This is the behavior we expected so we ran countless more tests on the 5 V side before deciding to resolder that portion of the power system. Over the course of the next few days, we tried 3 or 4 more entire configurations of the 5 V system knowing it was most likely a soldering problem. On all the boards except one the systems failed immediately. We saw some hope on a single system for about 30 seconds before we started running diagnostic testing and fried this board as well. In that short time period, we were outputting a solid 5.02 V which is exactly what we wanted to see. To patch our problem we were able to use a tiny boost converter chip that worked in the exact same way as our failed implementation. The only downside was we had to deal with an external chip connected to the PCB now. In the grand scheme of things this fix we implemented didn't hurt the functionality of our system at all. We were excited to find a fix even though it was not exactly what we had in store. In the end, we technically had one little portion of our PCB not working, but the system was mended to have full functionality.

5.3 Ethical considerations

With the design and implementation of our hazard detection system we didn't have and don't expect many ethical concerns to present themselves. The system was designed and tested solely by us and didn't make use of any unlawful activities along the way. One minor concern one might bring to the table is the property damage when such a system is installed. According to statement II.9 in the IEEE Code of Ethics, no injury should be caused to people or property by ill intent [7]. With an aftermarket detection system being installed on a bike, there is the possibility of some incidental scratching and/or wear on the bicycle. However, this will not be intentional and kept to the absolute minimum. Potential damage will be inevitable with the number of hours spent testing and using these machines not to mention installation. The user will be aware of this from the very beginning and if some damage is caused, all parties will act accordingly to take care of the situation. In terms of people, no person should be harmed by the detection system. The LED indicators and buzzer will be used in a way to visually and audibly notify the rider but will be tested and configured to ensure light and sound will not impair or impede anyone.

The entire point of the hazard system is to make traveling safer for the user. This goes hand in hand with statement I.1 in the IEEE Code of Ethics which states, "to hold paramount the safety, health, and welfare of the public" [7]. As a group, we saw a huge area where a breach in safety can easily lead to fatal situations. Keeping safety at the forefront of our system will be vital to upholding this statement and ensuring the success of our product. During the progression of our project, we will revisit these statements to provide motivation as well as structure in our development. This also goes hand in hand with risk mitigation. Frequently testing to fix bugs and distributing solutions to users will be the best way to make sure our system is not putting cyclists in more danger than normal. A lot of this mitigation will be done by us using the system in the field before broadcasting it to the public. This should allow most concerns to surface and be addressed promptly prior to release.

5.4 Future Work

While there are a multitude of ideas for improvement we will highlight a few of the most effective ones here. The first is upgrading our LiDAR sensor. According to the datasheet the sensor we have is effective out to 10 m, but from testing, we found the effective range is actually closer to 6 m. Different types of LiDAR sensors are sold which include mechanical scanning and solid-state sensors. Both of these types have good coverage and would provide an extended range compared to the flash LiDAR sensor we are currently using from Garmin.

However, these sensors come with higher costs and more complex integration which steered us away from them.

Another improvement is adopting other sensors and doing sensor fusion in our system. This could be using other sensors completely like ultrasonic, radar, or a camera as well as adding another LiDAR sensor. Any of these ideas would add more coverage to our sensor unit, increasing the overall effectiveness of the hazard detection system. One downside to our current configuration is the small field of view of the sensor leading to a small detection area. During testing, this didn't affect the results as much as we thought, but with long-term use in the field, this is definitely one area we need to upgrade.

The last modification we wanted to highlight is the need for a sleeker enclosure design. The enclosures for testing as seen in the demo and on the bike in pictures work really well, but are bulky and take up unneeded space. These designs are perfect for testing as they allow for modifications on the fly, but long term smaller custom enclosures would decrease the footprint of our system leading to increased safety and ergonomics while keeping the functionality. These are just a few of the many improvements we could implement to continue our project and have a better user experience in the future.

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Appendix A Requirements and Verifications Table

Table A System Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
1. The LED array on the handlebar must be clearly visible under varying light conditions, from bright daylight to nighttime. (Research suggests that daytime use of LEDs requires at least 500 lumens whereas nighttime use of LEDs only needs 200 lumens to be completely visible.)	1. Test the visibility of the LEDs under controlled lighting conditions that simulate daylight, twilight, and nighttime. 2. Validate that the LEDs are consistently visible. 3. Use a protractor or specialized tools to measure the LED's beam angle to ensure consistent visibility from different angles. 4. Operate the LED continuously for a specified powered period and periodically measure brightness to ensure it remains within the specified ranges for day and night.	Y
2. The LiDAR must accurately detect objects approaching from the rear within a range of up to 20 ft (6 meters).	5. Place the bicycle in a controlled environment such that there is no obstruction at the start state. 6. Have vehicles approach from the rear at varying speeds and distances. 7. Compare the LiDAR's output with the actual vehicle positions. 8. Test under different weather conditions, ensuring accuracy isn't compromised. 9. Recheck if the LiDAR subsystem doesn't see any lingering objects once you remove the test obstacles.	Y
3. The LiDAR subsystem must determine the distance of the unit from any source, within a tolerance of ±5% of the distance value.	10. Place the bicycle in a controlled environment such that there is no obstruction at the start state. 11. Have vehicles approach from the rear at varying speeds and distances, and record these values to ensure that the accuracy of distance doesn't get reduced within its cone of sensing.	Y
4. Must process LiDAR data in real time and determine the severity of the potential hazard. The processing latency should not exceed 500ms.	12. Simulate diverse hazard scenarios and input them into the microcontroller. 13. Measure the time taken to process and provide an output. 14. Ensure that under heavy data inflow, processing speed doesn't diminish. 15. Confirm that the outputs match the expected results for each simulated scenario.	Y
5. Must provide consistent power to all components	16. Conduct a full-battery test, observing the time taken to reach low power.	Y

and has a battery life of at least 6 hours on a single charge.	17. Monitor voltage stability under different loads. 18. Test the charging speed and ensure it's consistent with design specifications. 19. Simulate a scenario of continuous high-load usage to test battery durability.	
6. The power subsystem must output 3.3V continuously and must not deviate more than ±5% from this value after regulation.	20. Use a calibrated digital multimeter to measure the output voltage under no-load conditions and ensure it reads 3.3V. 21. Connect the power subsystem to a variable load and monitor the output voltage. The voltage should stay within the range of 3.135V to 3.465V (representing a ±5% deviation from 3.3V). 22. Run the power subsystem for a specified duration, frequently measuring and recording the voltage output to ascertain that it consistently remains within the acceptable deviation range. 23. Subject the power subsystem to sudden changes in load and measure how quickly it stabilizes back to its nominal output. The deviations during these transient states should not exceed the ±5% limit. 24. Expose the subsystem to various environmental conditions (like temperature fluctuations) that might affect its performance. Monitor the voltage output to ensure it remains within the stipulated range, even under these conditions. 25. Integrate the power subsystem with the overall system and observe if any external factors or interactions cause deviations beyond the acceptable range.	Y
7. The power subsystem must output 5V continuously and must not deviate more than ±5% from this value after regulation.	26. Use a calibrated digital multimeter to measure the output voltage under no-load conditions and ensure it reads 5V. 27. Connect the power subsystem to a variable load and monitor the output voltage. The voltage should stay within the range of 4.75V to 5.25V (representing a ±5% deviation from 5V). 28. Run the power subsystem for a specified duration, frequently measuring and recording the voltage output to ascertain that it consistently remains within the acceptable deviation range. 29. Subject the power subsystem to sudden changes in load and measure how quickly it stabilizes back to its nominal output. The	Y (technically)

	deviations during these transient states should not exceed the ±5% limit. 30. Expose the subsystem to various environmental conditions (like temperature fluctuations) that might affect its performance. Monitor the voltage output to ensure it remains within the stipulated range, even under these conditions. 31. Integrate the power subsystem with the overall system and observe if any external factors or interactions cause deviations beyond the acceptable range.	
8. The buzzer should have a minimum volume of 80 decibels to ensure audibility in typical outdoor conditions.	32. Using a decibel meter, test the loudness of the buzzer in various outdoor settings, confirming it consistently achieves the minimum volume	Y (audible enough to hear, not measured)
9. LEDs must indicate the proximity and severity of an approaching hazard by lighting the LEDs: the more LEDs are the more imminent danger, and faster LEDs turning on means a hazard is approaching quickly	33. Design specific scenarios simulating various levels of threats. 34. Observe the LED response to each scenario. 35. Ensure brightness and colors are clearly distinguishable in daylight and night.	Y
10. The buzzer must sound a certain lower tone for caution and a continuous higher tone for high-risk scenarios.	36. Confirm auditory alerts are synchronous with LED alerts during high-risk scenarios.	Y
11. All devices must withstand vibrations and shocks typical of urban and off-road cycling.	37. Subject the system to vibration and shock tests, simulating typical riding scenarios, and ensure no component detaches or malfunctions.	Y (survived riding on roads)
12. Devices should be weather-proof, dust-tight, and protected against debris from all directions. (Originally IP65 rated)	38. Expose the devices to weather, dust, and debris, validating that they remain functional and undamaged afterward.	Y + N (enclosures are tight fitting, not completely airtight however)

Appendix B Sensor Unit Schematics

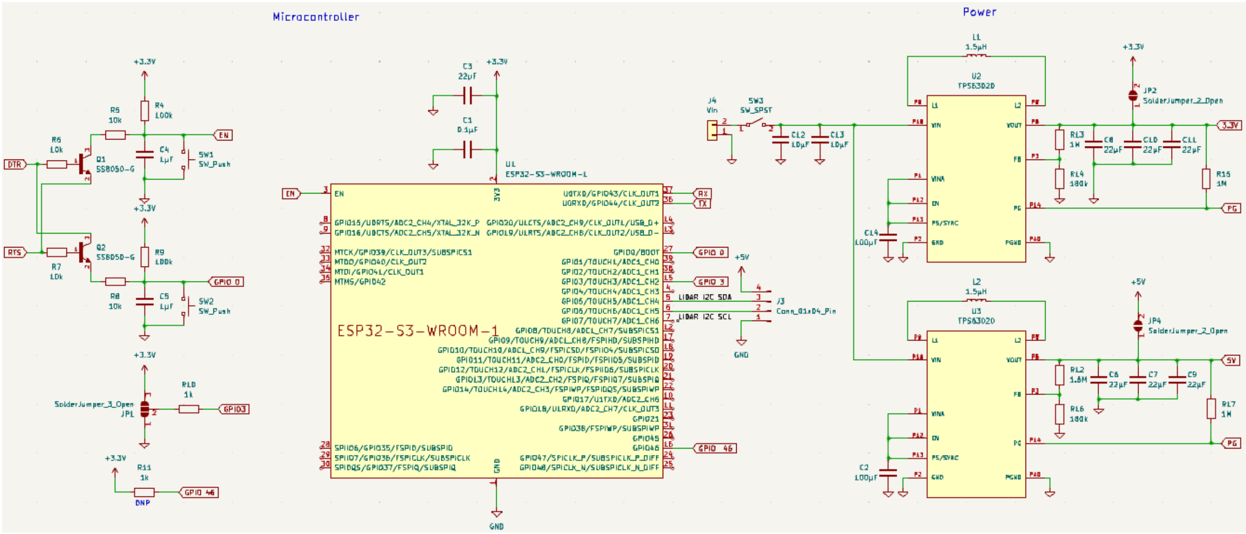

Figure B.1: Full Schematic for Sensor Unit

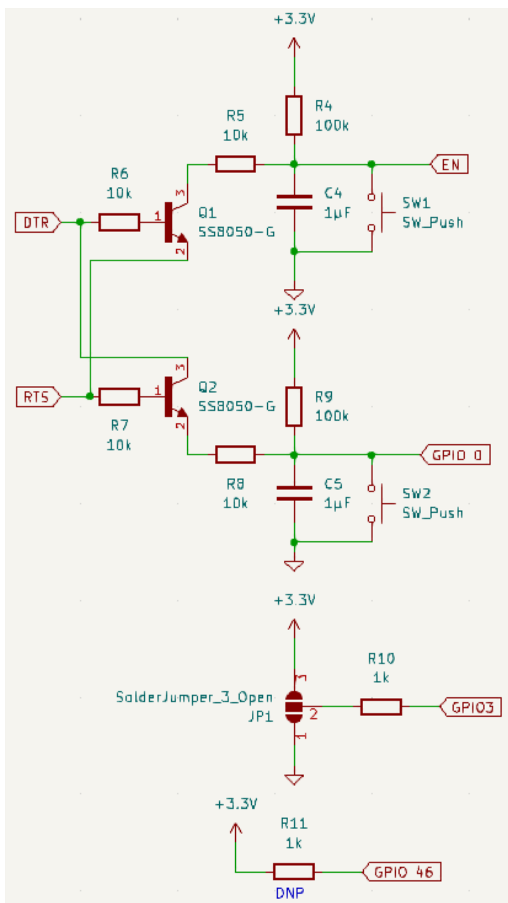

Figure B.2: Programming Circuit for Sensor Unit

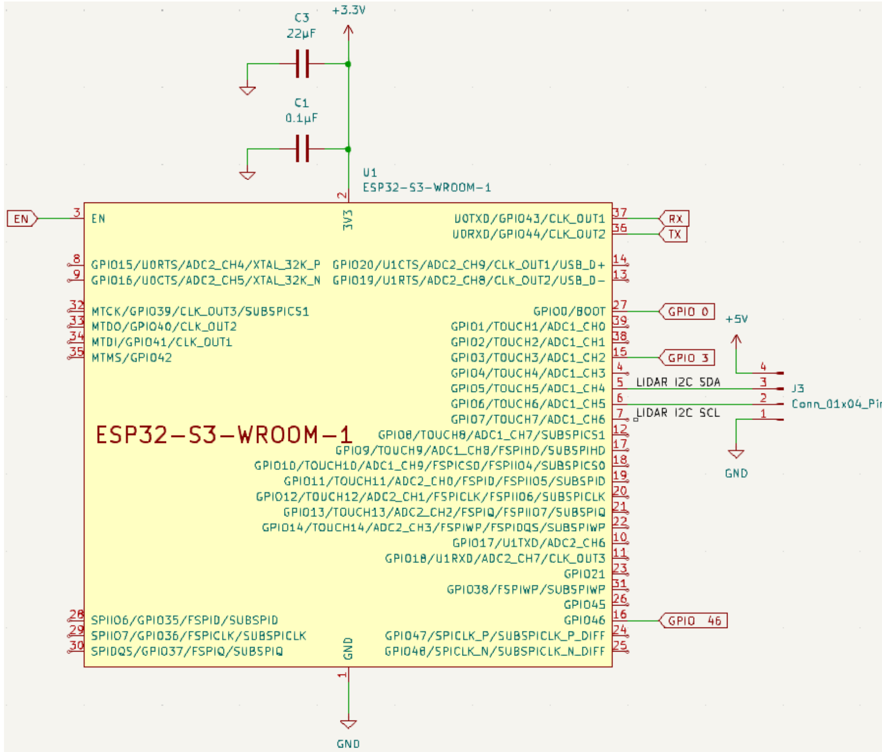

Figure B.3: Microcontroller with LiDAR Header for Sensor Unit

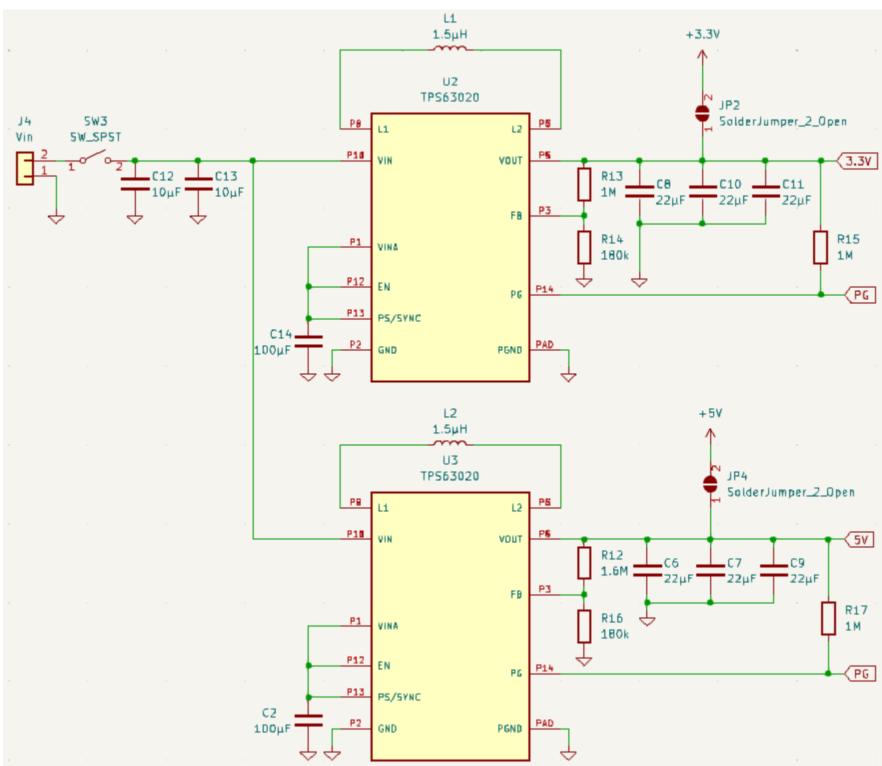

Figure B.4: Power System for Sensor Unit

Appendix C Indication Unit Schematics

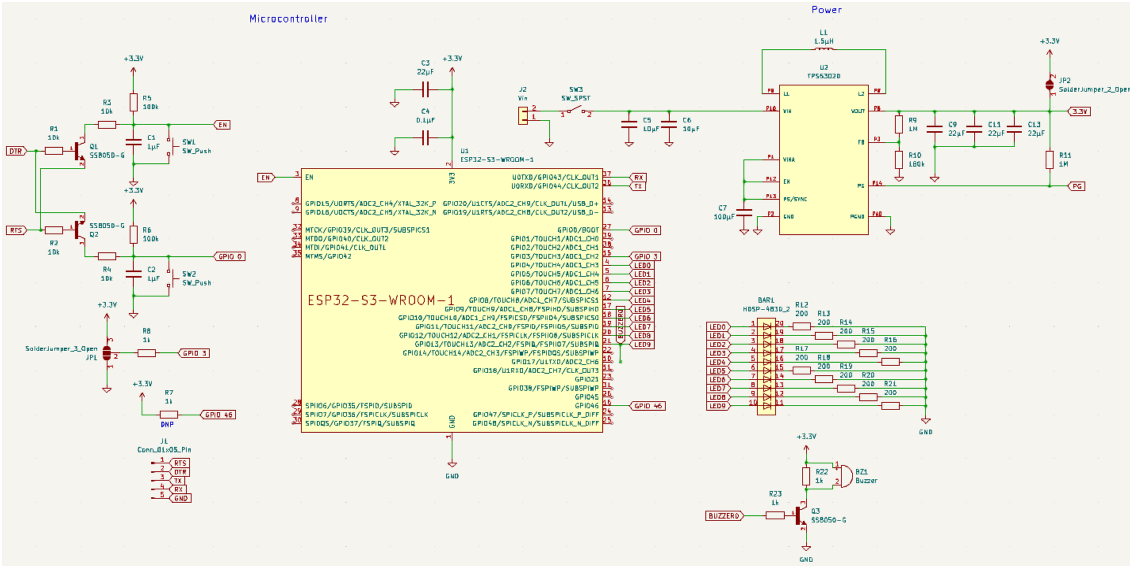

Figure C.1: Full Schematic for Indication Unit

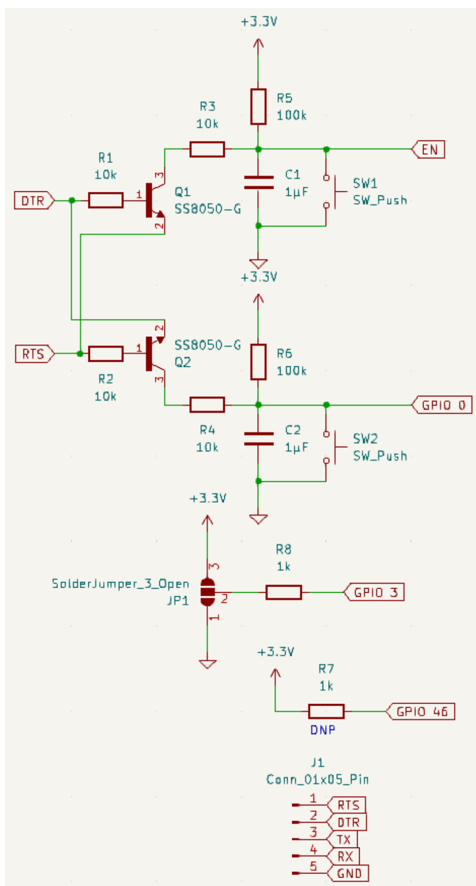

Figure C.2: Programming Circuitry for Indication Unit

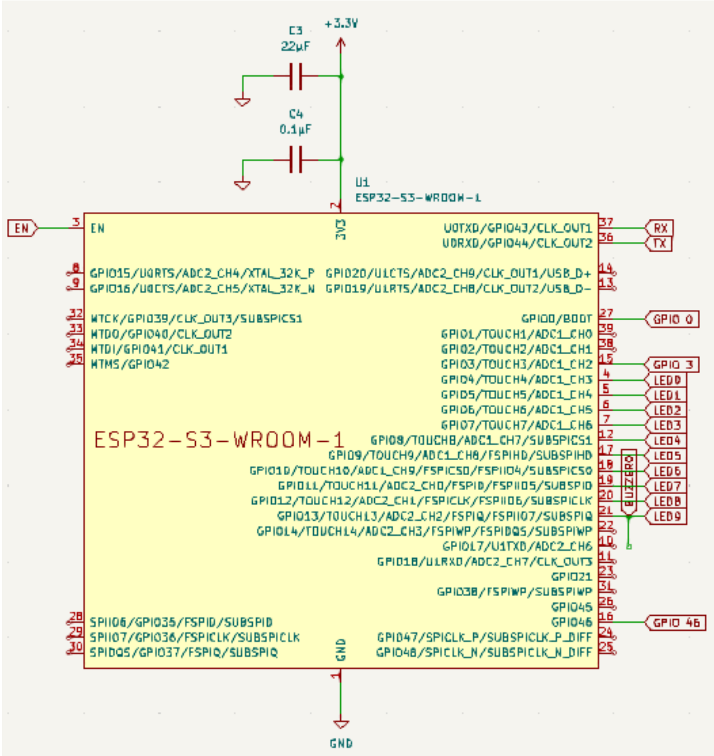

Figure C.3: Microcontroller with LED Array Outputs and Buzzer Output for Indication Unit

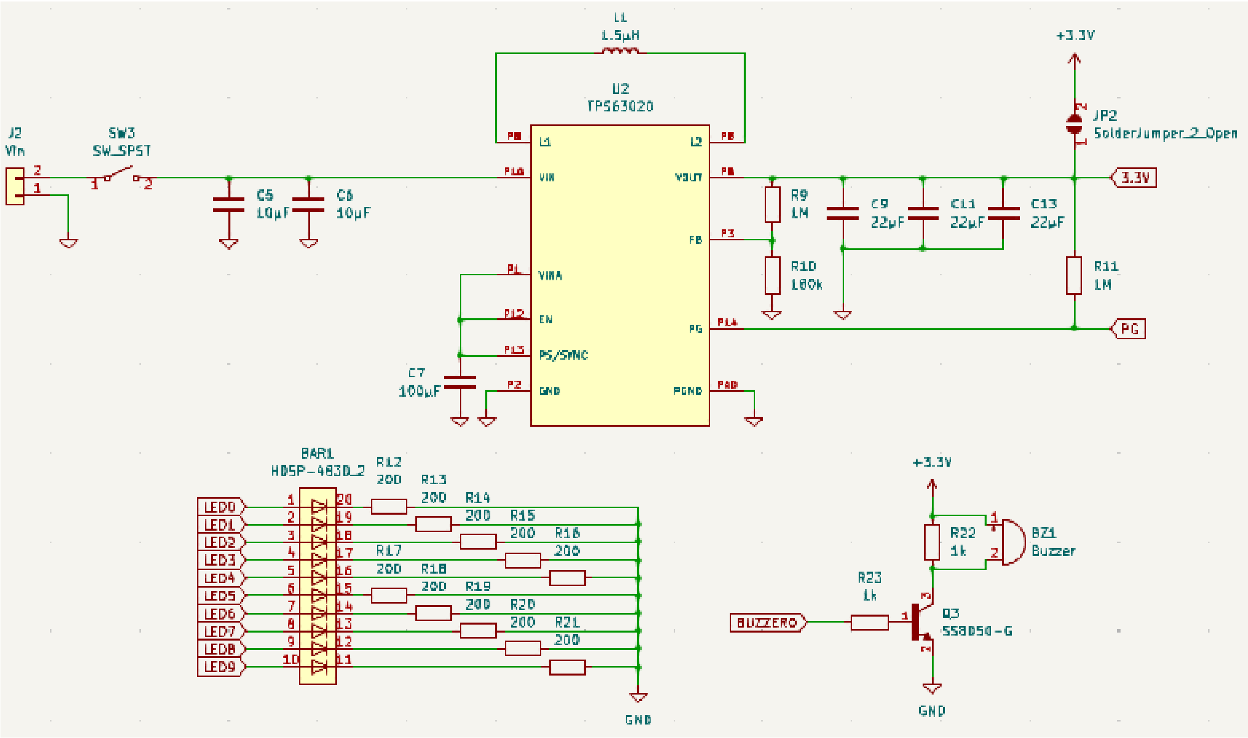

Figure C.4: Power System, LED Array, and Buzzer for Indication Unit