Aftermarket Hazard Detection for Cyclists

ECE 445 Project Proposal - Fall 2023

Team 19
Erik Ji, Adam Snedden, Ozgur Tufekci

Professor: Arne Fliflet
TA: Tianxiang Zheng

Contents

1 Introduction

1.1 Problem

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 are on the rise, preventing an estimated 50,000 accidents [2]; the same can't be said for cyclists. As urban cyclists, we've experienced situations where hazard detection could 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.

1.2 Solution

To address this problem, we are proposing to develop and implement 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 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 comfortability and usability are paramount to the success of our project.

1.3 Visual Aid

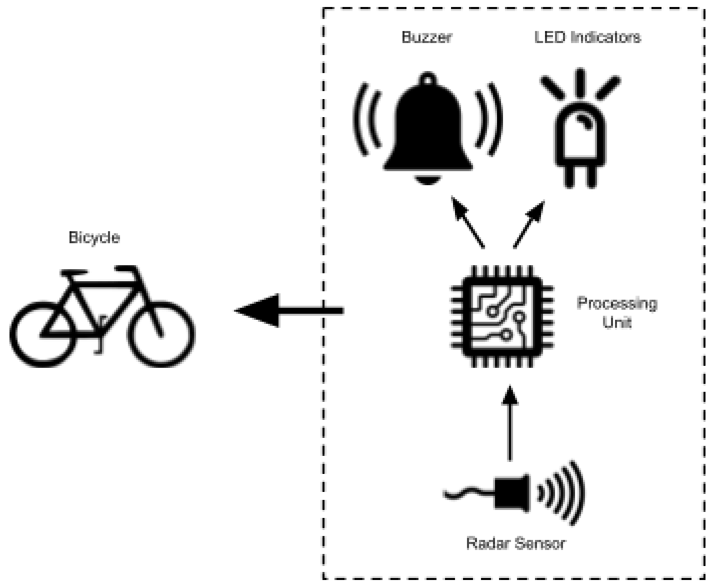

Figure 1.3.1: Hazard detection integrated on bicycle.

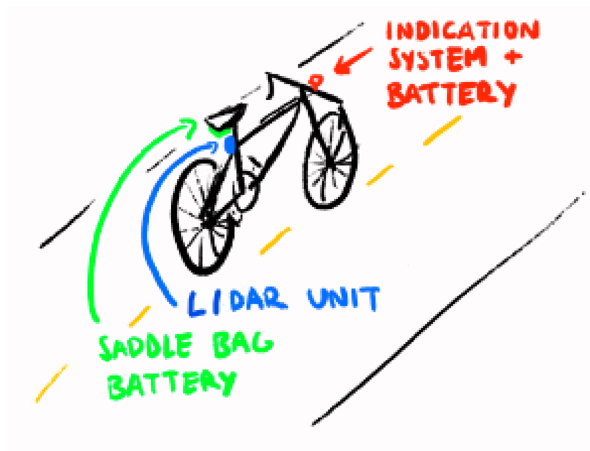

Figure 1.3.2: Mounting diagram.

The LIDAR sensor will send data to the MCU which will do processing and signal the LEDs and buzzer. This setup will be installed on various positions of the bike. The LIDAR sensor, power system, and one LED will be underneath the seat in some fashion towards the back of the bike. Another LED and buzzer will be placed on the handle bars with power to provide adequate alerts to the rider. Some of this setup can be seen in Figure 1.3.2 above and 1.3.3 below.

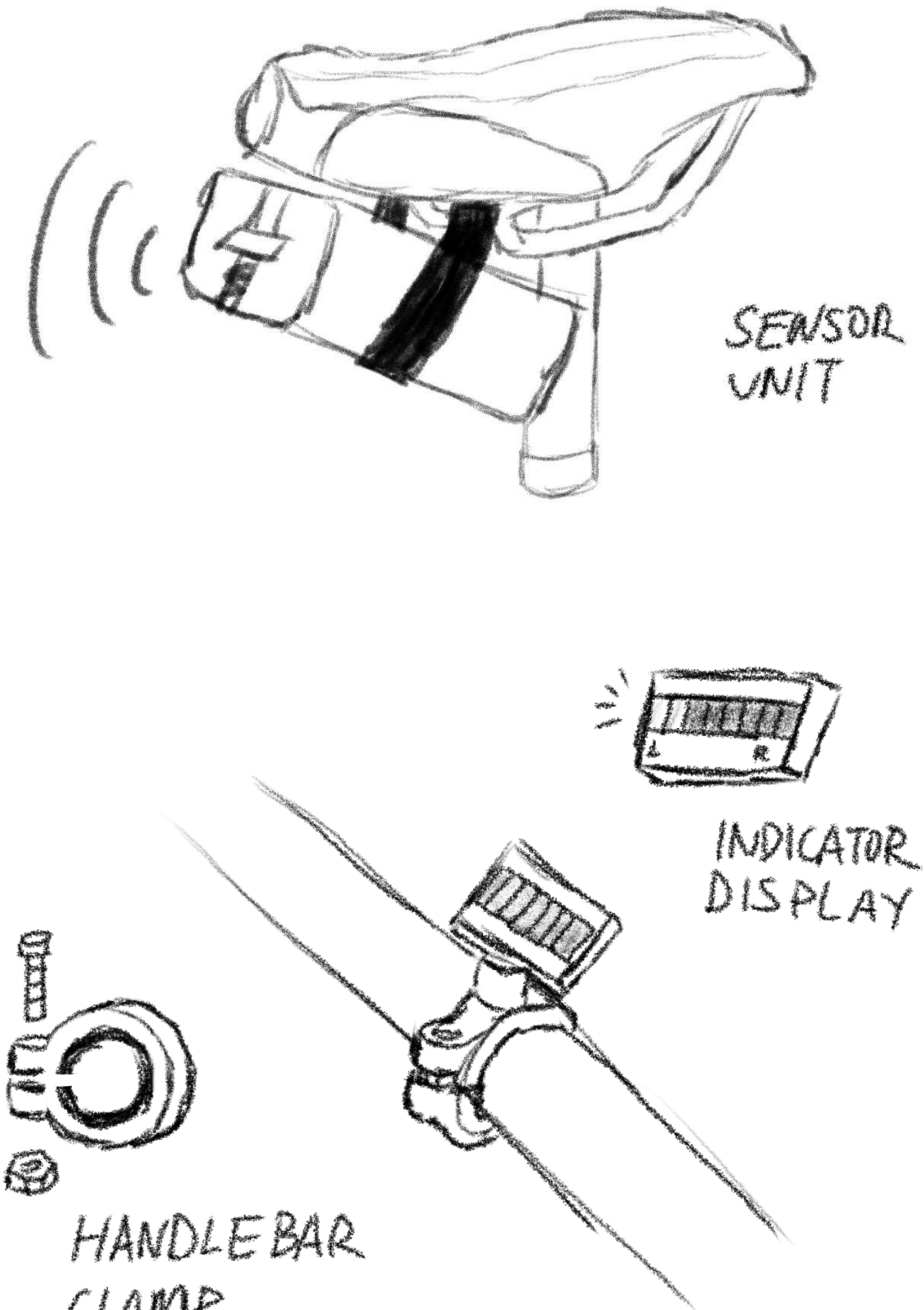

Figure 1.3.3: Pictorial representation of system.

1.4 High-Level Requirements

- The hazard detection system will detect and continuously track any potential hazards in its operational environment of 10 meters; when hazards are detected their proximity will be determined within +/- 5 cm.

- The indication system of LEDs and a buzzer alerts the rider when hazards are in the range set forth in the first requirement. The LEDs are bright enough to see clearly and as hazards become more imminent (within 3 meters), the buzzer intensity will adjust to correlate.

- The entire system functions on a battery pack that can supply 5 V +/- 10 % with it regulated down to 3.3 V +/- 5 %. The battery duration should last around 6 hours for average cycling trips; when the system is installed complete bicycle functionality is maintained.

2 Design

2.1 Block Diagram

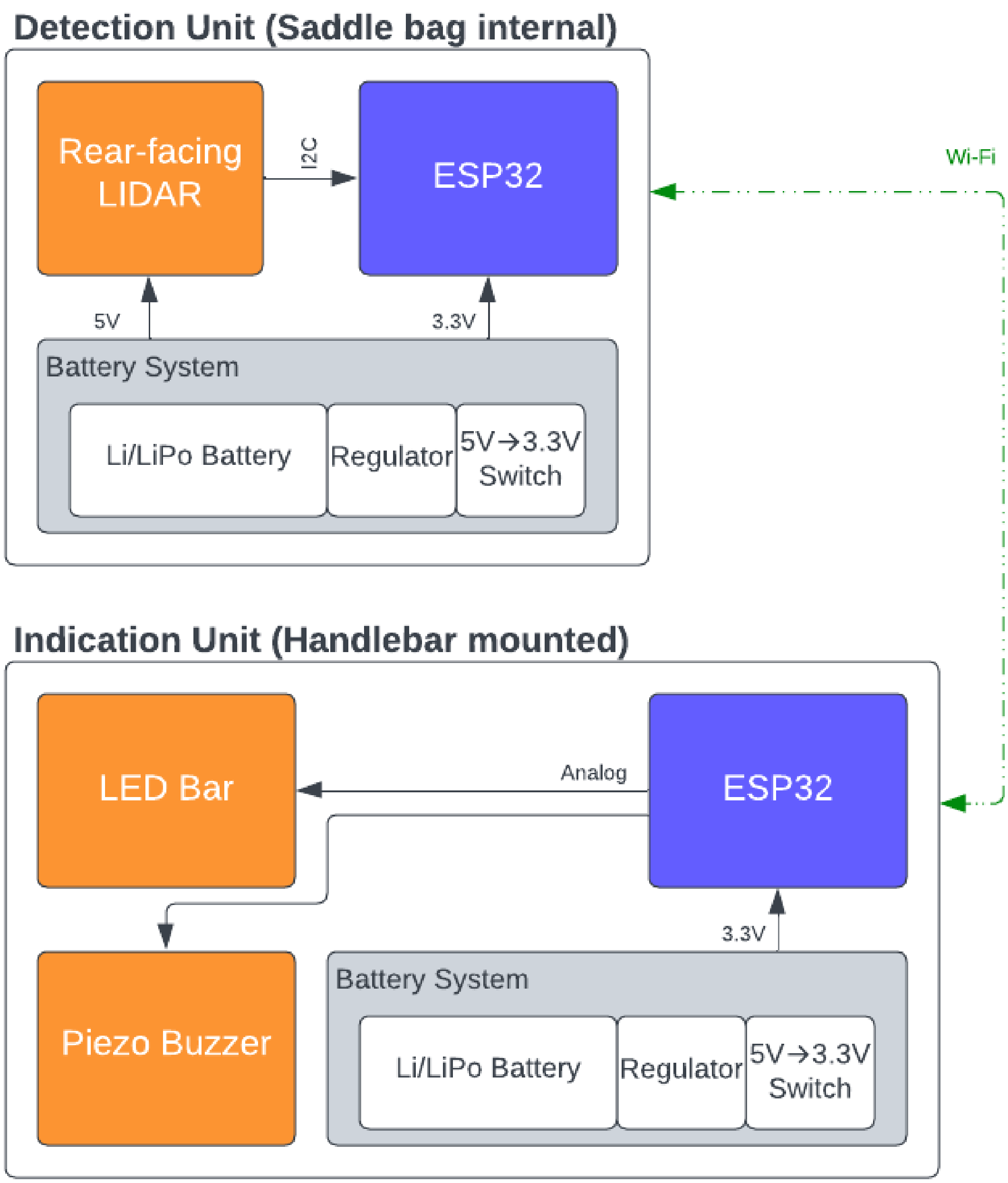

Figure 2.1.1: Block diagram of subsystems.

2.2 Subsystem Overview

The detection unit will be placed under the seat of the bicycle attached via a saddle bag. It will house the LIDAR unit which will sense approaching vehicles from the rear. The ESP32 microcontroller in the detection unit will process sensor data from the LIDAR unit and provide information to the indication unit on how to proceed. The microcontrollers will talk via wifi that is built into the ESP32 chips. The detection unit will be powered by a 5 V battery pack which will allow the system to run continuously for the duration of a cyclist's ride.

The indication unit will consist of the alert system that will notify the rider of potential hazards. An LED array will give the rider a visual cue on proximity of the threat. A buzzer will also be included to audibly alert the rider of imminent threats in case the visual cue was not seen. This unit will also use a ESP32 microcontroller to receive information transmitted by the detection unit. The indication system will be powered by a 5 V battery pack as well providing power during the duration of the trip.

2.3 Subsystem Requirements

2.3.1 LIDAR Sensor Subsystem

The LIDAR Sensor Subsystem, an integral component of our cyclist safety initiative, epitomizes the confluence of sophistication and functionality. Utilizing state-of-the-art LIDAR technology, this subsystem perpetually monitors the environment immediately rearward of the cyclist. Its primary function is not merely passive observation but an active and discerning analysis of potential hazards — detecting vehicles and other threats that might otherwise go unnoticed, even when they remain at a significant distance.

One of its most commendable features is its consistent performance across diverse meteorological conditions. Whether subjected to torrential downpours, dense fog, or the glaring sun, its accuracy and reliability remain uncompromised. This ensures that irrespective of external variables, the cyclist is always privy to a robust and precise dataset. The data, once collected, is relayed systematically to the overarching system, providing an indispensable foundation for our safety protocols. In summation, the LIDAR Sensor Subsystem should not be perceived merely as a component within the safety architecture; rather, it functions as a quintessential cornerstone, underpinning the robustness and efficacy of our overarching cyclist protection methodology.

Table 1: LIDAR Sensor Subsystem – Requirements & Verification

Requirements	Verification
• The LIDAR must accurately detect objects approaching from the rear within a range of up to 10 meters.	• Place the bicycle in a controlled environment such that there is no obstruction at the start state. • Have vehicles approach from the rear at varying speeds and distances. • Compare the LIDAR's output with the actual vehicle positions. • Test under different weather conditions, ensuring accuracy isn't compromised. • Recheck if the LIDAR subsystem doesn’t see any lingering objects once you remove the test obstacles.
• The LIDAR subsystem must determine the distance and angle of the unit from any source, within a tolerance of ±5% of the distance value.	• Place the bicycle in a controlled environment such that there is no obstruction at the start state. • Have vehicles approach from the rear at varying speeds and distances, and record these values against the angle from the central to ensure that the accuracy of distance doesn’t get reduced within its cone of sensing.

2.3.2 Microcontroller Subsystem

At the heart of this advanced safety apparatus, the Microcontroller Subsystem stands as the epitome of cutting-edge engineering and foresight. Not only does it operate with unprecedented efficiency, but its adaptability ensures it is ever-ready for the unpredictable nature of road conditions. Drawing on an extensive library of patterns and behaviors, the subsystem refines its decision-making prowess with each passing moment. As it parses through the data from the LIDAR Sensor, it employs intricate filtering mechanisms, separating the mundane from the essential, ensuring that no critical detail is overlooked.

Beyond its primary function of threat assessment, the Microcontroller Subsystem is also equipped to learn from its environment. Over time, it can recognize recurrent patterns, making its responses even more timely and accurate. This element of adaptability, paired with its meticulous data analysis, offers a dual shield of protection for the cyclist. Once it has made its assessments, the system communicates seamlessly with the Indication System, translating complex data into clear, actionable alerts. This synergistic operation not only heightens the safety quotient for the cyclist but also paves the way for a future where human-machine collaboration makes road navigation an effortless endeavor.

Table 2: Microcontroller Subsystem – Requirements & Verification

Requirements	Verification
• Must process LIDAR data in real-time and determine the severity of the potential hazard. The processing latency should not exceed 500ms.	• Simulate diverse hazard scenarios and input them into the microcontroller. • Measure the time taken to process and provide an output. • Ensure that under heavy data inflow, processing speed doesn't diminish. • Confirm that the outputs match the expected results for each simulated scenario.
• Sensor MCU is able to recognize sensor failure and inform cyclists.	• Read sensor data and design ability differentiate bad sensor responses ○ Inform indication MCU and trigger warning response

2.3.3 Power Subsystem

Within the framework of complex systems, the role of a reliable energy provision mechanism is fundamental. The Power System acts as a critical nexus, ensuring that all dependent subsystems receive the necessary energy to function at their highest potential. Utilizing the latest advancements in battery technology, its design is predicated on providing sustained energy over extended periods, while maintaining consistent performance metrics.

The architecture of the Power System goes beyond mere energy storage and distribution. It incorporates sophisticated algorithms that continuously monitor and adjust power consumption based on system demands. This real-time monitoring and adjustment capability is essential for efficiently managing varying operational requirements. Additionally, the system's integrated charging techniques not only allow for efficient energy restoration but also play a role in prolonging the overall battery lifespan, an essential consideration for long-term system utility.

Furthermore, the Power System's advanced energy management strategies, which are informed by predictive data analysis, are designed to anticipate and mitigate potential energy constraints. This forward-thinking approach ensures a continuous operational state, preventing the cyclist from experiencing energy-related interruptions, especially during extended use.

Table 4: Power Subsystem – Requirements & Verification

Requirements	Verification
• Must provide consistent power to all components and have a battery life of at least 6 hours on a single charge.	• Conduct a full-battery test, observing the time taken to reach low power. • Monitor voltage stability under different loads. • Test the charging speed and ensure it's consistent with design specifications. • Simulate a scenario of continuous high-load usage to test battery durability.
• The power subsystem must output	• Use a calibrated digital multimeter

3.3V continuously and must not deviate more than ±5% from this value after regulation.	to measure the output voltage under no-load conditions and ensure it reads 3.3V. ● 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). ● 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. ● 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. ● 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. ● Integrate the power subsystem with the overall system and observe if any external factors or interactions cause deviations beyond the acceptable range.

2.3.4 Handlebar Indication Subsystem

Within the context of human-machine interfaces, the Handlebar Indication Subsystem occupies a critical position in the cyclist's perceptual field. Its primary function is to convey essential alerts in an efficient and digestible manner, facilitating real-time decision-making. By employing a synthesis of LED indicators and an auditory buzzer, it offers a multimodal approach to threat notification. This subsystem's strategic positioning is a testament to ergonomic considerations, ensuring that cyclists receive timely alerts without diverting their focus from the immediate roadway environment.

The Indication System serves as a pivotal intermediary, translating machine-derived insights into actionable human responses. It is equipped with a comprehensive LED matrix and a distinct auditory signaling mechanism, both of which process and present the data relayed from the microcontroller. The chosen chromatic and auditory representations have been methodically designed, bearing in mind cognitive load principles, to guarantee rapid and unambiguous comprehension by the cyclist. Such clear delineations facilitate prompt and appropriate decision-making, bolstering the overall safety paradigm for cyclists in potentially hazardous scenarios.

Table 5: Handlebar Indication Subsystem – Requirements & Verification

Requirements	Verification
• 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.	• Test the visibility of the LEDs under controlled lighting conditions that simulate daylight, twilight, and nighttime. • Using a calibrated lux meter, measure the LED's emitted brightness under simulated daylight conditions. • Ensure the readings fall within the 500 to 1,000 lumens range. • Measure the LED's emitted brightness in a dark environment using the lux meter. • Confirm that the brightness is at least 200 lumens. • Validate that the LEDs are consistently visible. • Use a protractor or specialized tools to measure the LED's beam angle to ensure consistent visibility from different angles. • Operate the LED continuously for a specified period (e.g., 24 hours) and periodically measure brightness to ensure it remains within the specified ranges for day and night.

• The buzzer should have a minimum volume of 80 decibels to ensure audibility in typical outdoor conditions.	• Using a decibel meter, test the loudness of the buzzer in various outdoor settings, confirming it consistently achieves the minimum volume
• LEDs must indicate the proximity and speed of an approaching hazard using color codes: green for safe, yellow for caution, and red for immediate danger.	• Design specific scenarios simulating various levels of threats. • Observe the LED response to each scenario. • Ensure brightness and colors are clearly distinguishable in daylight and night.
• The buzzer must sound a short beep for caution and a continuous beep for high-risk scenarios.	• Confirm auditory alerts are synchronous with LED alerts during high-risk scenarios.

2.3.5 Installation & Integration Design Features

Within the broader schema of system design, robustness, and endurance are paramount, complementing the intrinsic technological capabilities. The Installation and Integration Design Features is tasked with ensuring the secure affixation and synergy of each constituent component, preparing them to endure the inherent challenges posed by routine cycling environments. Through a meticulous evaluation of variables such as vibrational forces, abrupt impacts, and environmental exposures, this subsystem plays a cardinal role in enhancing both the lifespan and the unwavering functionality of the overarching hazard detection apparatus.

Table 6: Installation & Integration Design Features – Requirements & Verification

Requirements	Verification
• All devices must withstand vibrations and shocks typical of urban and off-road cycling.	• Subject the system to vibration and shock tests, simulating typical riding scenarios, and ensure no component detaches or malfunctions.

Devices should have an IP65 rating, making them dust-tight and protected against water jets from any direction.	Expose the devices to dust and water jet tests, validating that they remain functional and undamaged afterward confirming adherence to IP65 standards.

2.4 Tolerance Analysis

2.4.1 Linear Regulator Thermal Analysis

The microcontroller we decided to use is in the ESP32 series, specifically the ESP32-WROOM-32E. We plan to use its wireless capabilities to send information to our indication system which is housed near the handlebars of the bicycle. We are running the system off a stand alone battery pack which can provide 3.7 V to our system. The ESP32-WROOM-32E chip has an operating voltage of 3.0 - 3.6 V with ideally 3.3 V being supplied to it. This means we will need to step our voltage down from 3.7 V to around 3.3 V. This will be done using a linear regulator. We decided on a linear regulator since this is a small system and we wanted a simple, cheap component with high reliability. After some research we think an AZ1117 Linear Regulator will work for our circuit as we only expect to need a fixed 3.3 volt output. Going from 3.7 V down to 3.3 should be sufficiently done by a regulator of this nature.

One concern using a linear regulator is overheating due to high power dissipation. This analysis will run through worse case scenarios to determine whether or not this regulator is fit for the needs of the system. In the end, our hope is that the max operating temperature of the regulator is well above what we determine as the worst case temperature it can reach. To start we will need to look at power dissipated in the regulator. In simple terms this can be given as:

$$V_{regulator} = V_{in} - V_{out}$$

$$P_{dissipated} = i_{regulator} * v_{regulator}$$

$$P_{dissipated} = i_{regulator} * (v_{in} - v_{out})$$

According to the document "Linear Regulators" on the ECE 445 wiki page, "A linear regulator is usually lumped into two pieces: junction-to-case and case-to-ambient" [3] There is a simple circuit from the document shown below to demonstrate this concept.

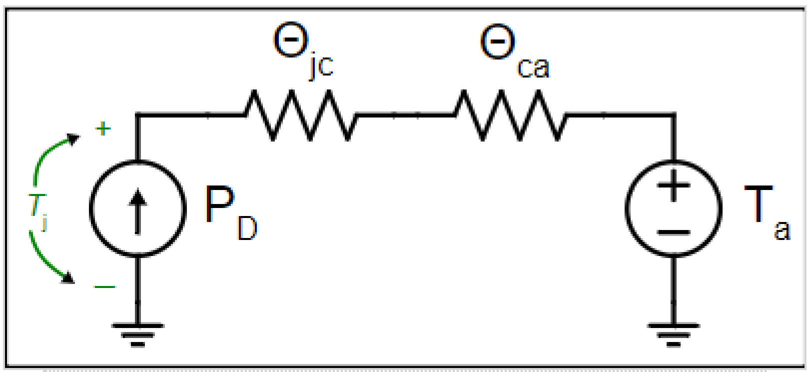

Figure 2.9-1: Diagram of a Simple Thermal Circuit

Θ_{jc} and Θ_{ca} are the thermal resistances from junction-to-case and case-to-ambient. These can be found in the data sheets. T_j and T_a are the junction temperature and the ambient temperature. To determine whether or not this regulator is suitable, we want to compare the junction temperature, T_j, to the max operating temperature. P_D in this circuit is the $P_{dissipated}$ we found earlier. Analyzing this circuit using common techniques we can find that:

$$I = V / R$$

In terms of our variables:

$$P_D = (T_j - T_a) / (\Theta_{jc} + \Theta_{ca})$$

$$P_D * (\Theta_{jc} + \Theta_{ca}) = T_j - T_a$$

$$T_j = P_D * (\Theta_{jc} + \Theta_{ca}) + T_a$$

$$T_j = i_{regulator} * (v_{in} - v_{out}) * (\Theta_{jc} + \Theta_{ca}) + T_a$$

Part	**Max Current Draw when Operating**	**Notes**
Processor	379 mA	Peak current drawn while transmitting ESP32-WROOM-32E
LIDAR Unit	85 mA	Peak current drawn while operating LIDAR Unit 010-02022-00
Buzzer	7 mA	Based on SBZ-204 buzzer spec
Total	471 mA	

Figure 2.9.1-1: Max Current for Components

Variable	**Value**	**Notes**
T_j max	150 °C	Max operating temperature from AZ1117C-3.3 datasheet
$i_{regulator}$	471 mA	Max current draw by components
v_{in}	4.2 V	Max voltage of battery source
v_{out}	3.3 V	Regulator operating level
Θ_{jc}	10 °C/W	Thermal resistance, j-to-c from AZ1117C-3.3 datasheet (TO252 series)
Θ_{ca}	90 °C/W	Thermal resistance, c-to-a from AZ117C-3.3 datasheet (TO252 series)
T_a	40.5 °C	Max temperature seen in IL throughout the year.

Figure 2.9.1-2: Values of Each Component in Temperature Calculation

$$T_j = .471 * (4.2 - 3.3) * (10 + 90) + 40.5$$

$$T_j = 82.89\ °C$$

This temperature is well below the max operating temperature of 150°C so we shouldn't have a problem with overheating. We have a moderate margin for temperature to move in case changes are made down the road. We had talked about adding a rear facing LED to this system if we have time. If this is wanted, the system should handle the addition fine as a small LED doesn't require much power to operate. If we get any closer to the max operating temperature, we can always think about adding a heat sink as well. This would reduce the overall thermal resistance from junction to ambient allowing for a lower junction temperature or more current draw for the same junction temperature. Looking at the datasheet, the total thermal resistance would drop from 100 °C/W to about 70 °C/W which would drastically pull down the junction temperature leading to certain safety. This would be a rather simple upgrade if for some reason we find ourselves approaching the overheating territory.

3 Ethics

With the design and implementation of our hazard detection system we don't expect many ethical concerns to present themselves. The system will be designed and tested solely by us and should not make use of any unlawful activities along the way. One minor concern one might bring to the table is the damaging of property 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 [3]. 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" [3]. 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.

4 Safety

While none pose an immediate threat to ourselves or the user, there are a few safety concerns with the detection system. To remove common risks, all components and wiring will be low voltage (5V or less) and low current barring design changes in the future. Before testing, whether it be in the lab or in the field, all circuit elements will be checked visually for damage and to ensure connection stability. Mechanically our design will not impede the maneuverability of the bike with any wiring and devices firmly attached.

The biggest concern comes with the use of a battery pack to supply power to the system. On the battery safety guideline document it mentions covering terminals and providing a circuit to ensure no overcharging or over discharging along with other regulations [6]. The setup we hope to use is a stand alone battery pack (bank) with most safety features already built in to prevent over charging, over discharging, etc. This will provide an extra layer of safety as common consumer battery packs are highly tested for any level of consumption. The exact pack hasn't been chosen yet, so these regulations will be revisited at that time, but we don't foresee the pack we choose to cause any safety concerns. To minimize the risk of injury or damage to property we decided a pack of this nature was important. Designing our own pack would lend itself to unneeded safety risks as the pack isn't the main concern of our project. The pack will be stored in isolation with no devices connected to help meet the storage requirement and prevent any extraordinary circumstances. The pack will also be examined before each use to ensure there is no visible damage or alteration.

The last thing to mention is the magnitude of the alert system. While LED lights and a buzzer will be used to inform of hazards, the intensity of both will be set to ensure the rider is not impaired. Our system should never distract or impede the cyclist as these would both lead to other safety concerns or harm.

References

[1] S. Zhu, “Blind spot warning technology contributes to a 23 percent reduction in lane change injury crashes,” Real-world benefits of car safety technology, 2019.

[2] J. B. Cicchino, “Effects of blind spot monitoring systems on police-reported lane-change crashes,” *Traffic injury prevention vol. 19,6*, 2018.

[3] *IEEE Code of Ethics*, IEEE, 2020.

[4] *Safe Practice for Lead Acid and Lithium Batteries*, Spring 2016 Course Staff, 2016.

[5] Espressif Systems, *ESP32-WROOM-32E Datasheet*, (2003). Accessed: Sept. 28, 2023. https://www.espressif.com/sites/default/files/documentation/esp32-wroom-32e_esp32-wroom-32ue_datasheet_en.pdf.

[6] Diodes Incorporated, *Low Dropout Linear Regulators AZ1117C*, (Sept. 2022). https://www.diodes.com/assets/Datasheets/AZ1117C.pdf.