UNIVERSITY OF ILLINOIS AT
URBANA-CHAMPAIGN

ECE 445 : Bike Assist

FINAL REPORT

Jason Yang **Justin Young** **Kush Gupta**

Teaching Assistant: Shuai Tang

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1 Introduction

Our project, *Bike Assist*, focuses on generating a solution to the standing issue of biker safety. Our main goal and motivation comes from the obscenely high rates of fatality each year, and we look to solve the issue by providing warning signals to the users while others in cars and bicycles may be on a collision course with our users. From our feedback from the design review, we have focused on extending our solution to incorporate not only an audio signal, but also a visual signal, and we've also doubled the threshold of distance for our proximity detection units.

1.1 Problem Statement

Currently, cyclists and motorcycle riders face many difficulties while traveling on the road. Statistics show that currently, approximately 14 million Americans ride their bike over twice a week, with over 100 million cyclists per year [9]. However, the number of reported accidents is staggering. These accidents can stem from anywhere such as the daily commute or a leisurely night-time ride. In fact the NHTSA reports that each year there are approximately 55,000 accidents, with an average of 857 fatalities [1]. In California alone, there were 12,000 per year on average between 2007 and 2013 [4].

For decades people have tried to improve road safety, from the introduction of seat belts in 1968 to bike helmets in 1975. As of recent companies like Argoverse and nuScenes have taken this a step further by creating data sets as a foundation for autonomous driving research, which many believe will prevent autonomous accidents entirely. Until technology is capable of fully automated transportation however, the issue of road safety still persists. More importantly, modern solutions to road safety have been largely focused on the perspective of someone driving an automobile, while bikers have limited and archaic options to mitigate risk on the road. Things like bike helmets, reflector vests, and bike lights are still the most common form of biker safety, all of which have been around for decades. Therefore, we wanted to develop a modern solution for bikers who want to take their safety into their own hands.

While there are a number of archaic solutions that work to improve the safety of those who use alternative transportation on the road by working to improve visibility/other facets of biker safety, none of these solutions focus on the users ability to be conscious about their blind spots without directly observing their surroundings. For example, this poses a problem due to the fact that it prevents the user from keeping their eyes on the road ahead of them, where the highest risk of an accident exists. Furthermore, bikers may also misjudge the amount of leeway they have while attempting to turn, and others who are not paying attention to the roads in front of them or do not notice cars/other objects in their immediate vicinity are in danger of being in an accident. Each of these scenarios presents an opportunity for an accident to take place. Our goal and focus of this project is to reduce the number of accidents by bicyclists down to zero by providing a medium of increased awareness to their surroundings.

1.2 Solution Overview

Our goal of increased biker awareness will be achieved by our product in two fronts: a proximity detection unit that alerts bikers when other objects or people are in their immediate vicinity, and a turn signaling unit that provides allows for bikers to display their intentions. These units will be bundled into a single attachment that will be able to sit on an adult or adolescent bicycle and provide signals and indicators when objects are coming too close to the user. By alerting the biker when there is imminent danger, **our product allows them enough time and speed to react and avoid the danger**.

This information will come to the user through two mediums: one form includes loud beeps that speed up as objects move within a distance threshold, and the other form includes a flashing light signal that increases its frequency as objects become closer. The system includes a Proximity Detection Unit, comprised of ultrasonic sensors and micro-controllers that detect the distance between others on the road. The audio cues will come from our Speaker Subsystem mounted on the bicycle, while the visual cues will come from the LED Array Subsystem that will sit on the handlebar. The *Bike Assist* accessory will further house two directional-lights, also part of the LED Array Subsystem, that activate upon button press of the Turn Indicator Control Subsystem, and allow for the users to signal to others when they will turn left or right, and the buttons will sit one on each handlebar. These accessories are further combined; when a user activates a turn signal, the proximity detection kicks in, allowing heightened awareness while the user is turning, one of the more dangerous components of bicycling.

Our project will interest users through its simplicity and its ability to function without user input. Our original solution, Project Safe-Tee, provided an intuitive gesturing system to the cyclist, allowing them to display turning intentions to other members on the road by lifting their arms. **The main difference between our current project and previous solution to the question of bicycle safety lies in the flow of information.** The previous project brought information from the user to other users, while *Bike Assist* provides information to the user regarding the surroundings. Furthermore, at this point in time, there do not exist any similar products that exist as *accessories*. Our project solution is an accessory that can be attached to any bicycle, and it provides a quick and reliable method of alerting cyclists without requiring the user to interact with the product, inducing a seamless integration with the normal cyclist.

1.3 High Level Requirements

- Our ultrasonic sensors must be able to determine whether or not an object is within a threshold of 8 feet, report the actual distance with a granularity of at least 1 foot, and the reported value should be accurate to within .5 feet of the real value, in at most 0.1 seconds.
- When an object or person is registered within the threshold of distance near the user, the speaker system will begin to beep within 0.1 seconds at a volume

audible to the user. As the distance decreases down to 3 feet, the beeps from the speaker system will slide up linearly at a rate of 0.5 Hz up to 5 Hz.

- When the user presses the appropriate buttons (left, right turn) the corresponding turn LEDs will light up within 0.3 seconds and must be visible in clear night-time conditions at least 50 feet away facing the front or back of the bike.

1.4 Visual Aid

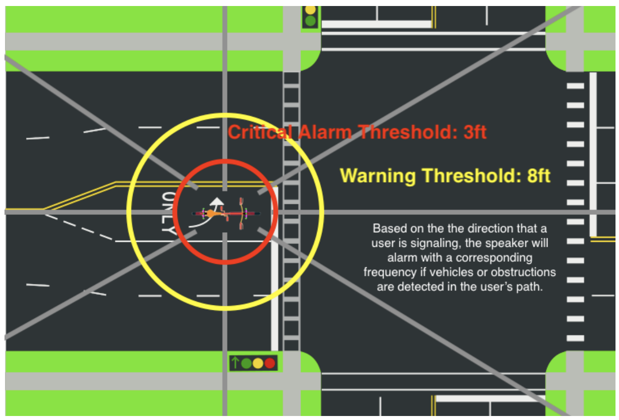

Figure 1: Diagram showing the regions that each ultrasonic sensor will cover as well as the conditions under which varying alarm tones will be made.

1.5 Physical Design

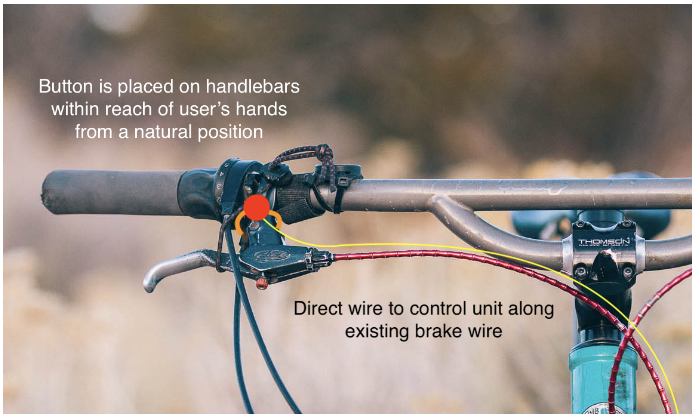

Figure 2: Diagram showing how a turn signal button will be mounted on a bike's handlebars so that a user can activate the turn signals.

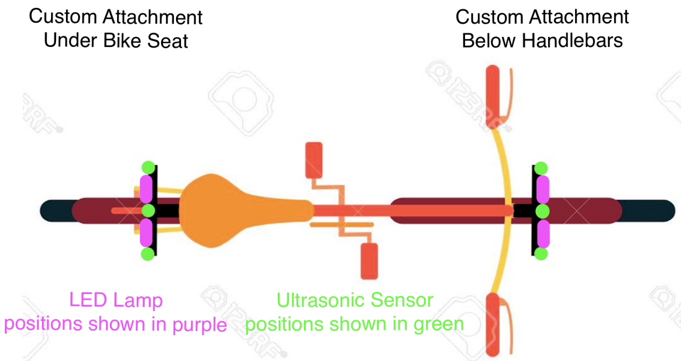

Figure 3: Diagram showing the physical placement of the ultrasonic sensors and turns signals on the bike, with our custom hardware attached to a bike.

1.6 Block Diagram

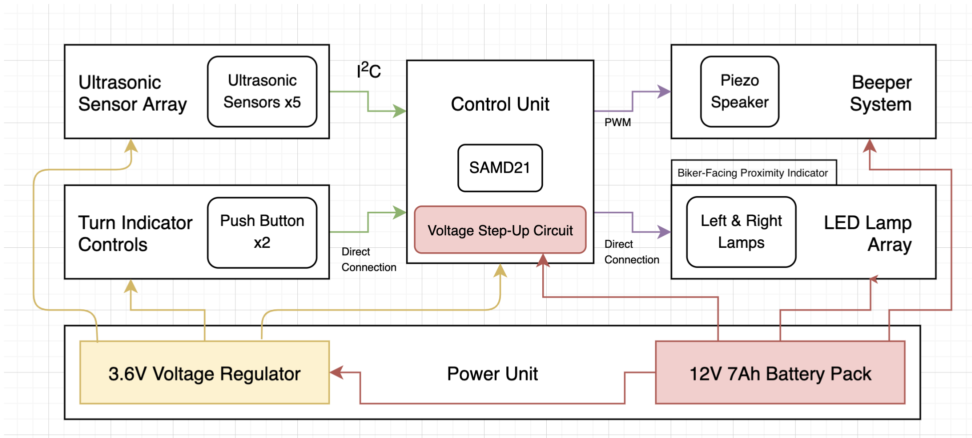

Figure 4: Block Diagram model outlining the interconnections between the subsystems in our design. Note that the red connections denote power lines operating at 12V while the yellow connections denote power lines operating at 3.6V. The purple and green lines denote protocol lines operating at 12V and 3.6V respectively.

The block diagram outlined here shows how we intend to build the proposed product. It shows the modules and interconnections necessary to make the feature-set we imagined possible and to fulfill the high level requirements stated above.

It is composed of 3 overall groups: inputs/sensors, control, and outputs. The sensors are the ultrasonic array and the turn signal buttons used by the user to indicate their actions and for the device to determine if there are any hazards to the user on the road. That data is then used by the control unit to generate a set of outputs to indicate to the user that an obstacle or vehicle is dangerously close through the speakers and biker-facing indicator LED, and to show on the left and right LED lamps that the user intends to go in a particular direction. Together, these modules can be used to build a product that will help improve biker safety.

2 Implementation

2.1 Implementation Details & Introduction

In this section, we will explore our proposed system in depth and verify that it is indeed a viable design. Since we do not have the physical sensors or components necessary to implement the design for real, we have produced a software simulation that shows how the design will function to help the user, and have also outlined at a high level the circuit that could be used to implement this design in hardware.

2.1.1 Simulation

To build upon the tolerance analysis completed in our previous report, we wanted to show that our design could function in real world conditions and successfully avert a collision between a biker and another vehicle or obstacle on the road.

Implementing this without any physical components meant that we must simulate the various parts of the system – most importantly the biker, a driver, and the sensing + warning system we designed. In our simulation, we account for varying driver and biker speeds plus orientations, and also adjust our findings based on the known frequency of our ultrasonic sensor readings (20ms) and a typical human reaction time of 250ms [6], which we increased to 300ms to offer a worst-case scenario for the simulation.

A single run of the simulation works by randomly selecting starting locations for the biker and vehicle on the road, as well as initial velocities for each. These are chosen to be between $15-45$mph for the vehicle, and $10-20$mph for the biker, based on our research about typical biking conditions on large, busy roads where our prototype will have the greatest effect.

The simulation then calculates the movement of both the biker and the driver and reevaluates whether they have collided. For simplicity, we have defined both objects as spheres that 'collide' when their radii intersect. The selected radii for the biker and the driver are 3ft and 5ft, based on our research about typical vehicle and bicycle dimensions [2].

Additionally, at the provided ultrasonic sensor frequency (20ms), we also attempt to take a 'reading' at a configurable distance, varied between 8ft and 24ft. The simulation also accounts for the ultrasonic sensor's accuracy by potentially reporting a dangerous false negative (since false positives in this design do not affect the base safety guarantees being made). For our tests, we have set the ultrasonic sensor accuracy to 80%, implying an accurate detection that percentage of the time, which should be substantially higher than the value obtainable in practice with the use of many sensors and software filtering.

If the ultrasonic sensor triggers an event successfully, the simulation then plays out a user's physical response to the speaker after the designated response time of 300ms. At this point, the simulation is considered complete and the final positions of the biker and vehicle are noted and displayed. At any point, if the two objects collide the simulation is ended and marked as a failure. The presence of a ultrasonic detection during the run is also saved, as is the final distance (excluding the object radii) between the bike and vehicle.

The results of the simulation are then displayable on a graph like the one shown below in Figure 5. This depicts a near-crash using an ultrasonic sensing maximum distance of 8ft. Specifically, the yellow circle shows the ultrasonic sensing range at the moment when it detected the vehicle (shown as a blue circle at that time), at which point both the vehicle and biker move for the full length of the biker's response time of 300ms. their final positions and object radii are then shown in red (biker) and green (vehicle). In Figure 5, it is clear that while a collision was narrowly avoided, the final distance between the objects after the user is alerted to the vehicle's presence is very small (< 1ft), and therefore unsafe. Based on our research, if the objects are greater than 6ft, or a bicycle-length, away from each other when the biker needs to respond to the event and change course to avert a collision, they will have a high likelihood of avoiding a crash. Conversely, even if an outright collision is avoided, if the vehicle and biker are less than 6ft from one other when the biker is able to react, they will likely still incur some kind of personal injury when attempting to avoid the crash (caused by rolling over, light contact with the vehicle, etc).

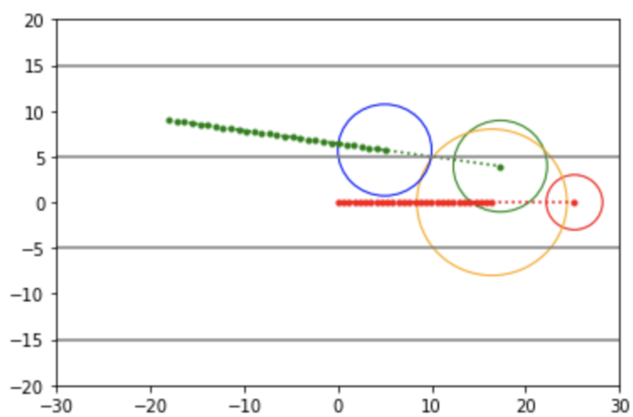

Figure 5: Near crash simulation run, with the bicycle path shown in red, vehicle path in green, detection radius against the vehicle shown in yellow and blue respectively, and then the final object positions shown as circles once again in red and green.

Below is another example simulation run, this time where the vehicle was detected, but before the biker had a chance to respond they were part of a crash. this is shown by the final position green and red circles intersecting.

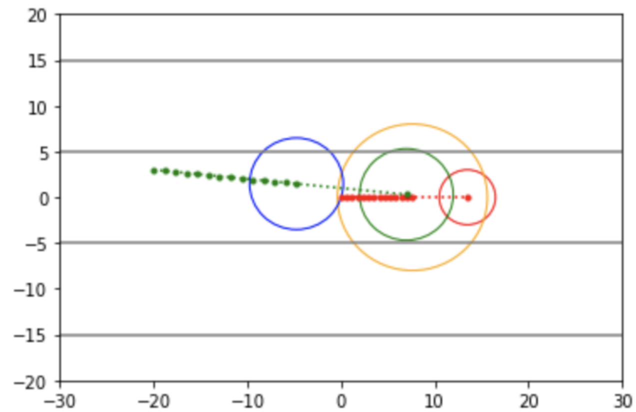

Figure 6: Simulation run showing a crash before the biker had a chance to respond to the alert. Ultrasonic maximum range is 8ft.

In order to reason about the performance of our device under arbitrary circumstances, we repeated this simulation $10,000$ times using different parameters, and recorded the collision rate, detection rate, and the final distance between the two objects.

Ultrasonic Max Range	Collision Rate	Detection Rate	Median Final Distance
8ft	11.6%	98.3%	1.87ft
12ft	6.3%	99.4%	4.24ft
16ft	2.1%	99.9%	7.47ft
20ft	2.0%	99.9%	11.12ft
24ft	2.0%	99.9%	15.44ft

Table 1: Table showing the aggregate collision and detection rates, as well as the final distance between the biker and vehicle after they have had a chance to respond to the alert provided by the system. Simulation runs in this test used an arbitrary vehicle position directional velocity and an initial speed of $15-45$mph, and a fixed biker speed of 20mph, for a worst case test scenario. The ultrasonic sensor accuracy is fixed at 80%, and the reaction time used was 300ms. This was repeated a total of $10,000$ times per test case.

From this, it is clear that increasing the range of the ultrasonic sensor dramatically improves the performance of our design and allows us to better guarantee a biker's safety on the road. As mentioned above, the threshold for preventing injuries in most cases is to avert the outright collision and have a final distance after reaction time of $>$ 6ft. Based on our trials an ultrasonic max range of $\geq$ 16ft meets these requirements.

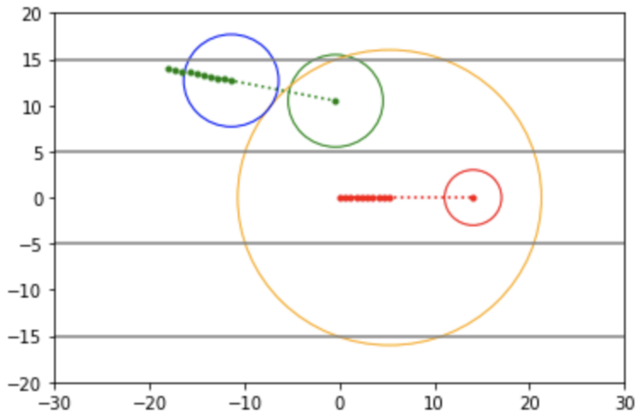

Figure 7: Sample simulation run showing a crash that was successfully averted using an ultrasonic sensor distance of 16ft.

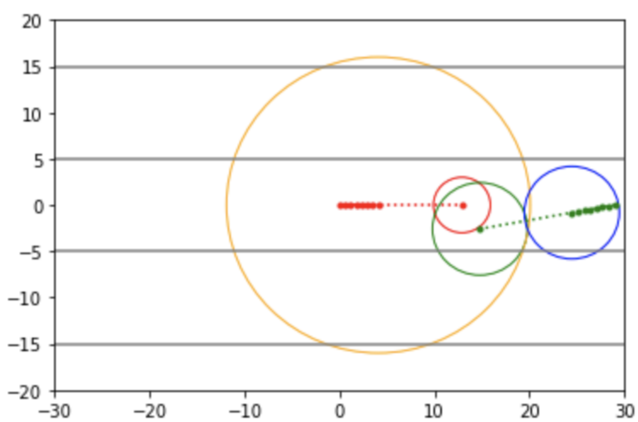

Figure 8: Simulation run showing a crash that is not possible to avert, regardless of ultrasonic sensor range.

It is interesting to note however, that the collision rate for all of these cases stayed about the same at $\approx 2\%$, and the final distance began to increase linearly with the range, rather than doubling from the previous measurement. This is likely because there are certain scenarios where a crash is unavoidable without significant advance alerting, such as in a head-on collision, but all other situations are successfully averted when using a sensor with a suitably large range. Because of this, we have concluded that a 16ft ultrasonic sensor maximum range actually provides the best specification for our design, since it effectively prevents injury to the biker in the majority of cases, but also provides less false positives and will probably also be less expensive to source capable sensor hardware for.

Based on this, we have adjusted the high level requirement that we had originally defined to 16 feet, in order to provide users with ample space and time to react to events as they occur and avoid collisions. To match this, we have also found a new ultrasonic sensor that is capable of meeting the updated requirement and allowing us to certify that our design could successfully prevent an accident in the vast majority of cases.

2.1.2 Circuit Design

Here we will describe at a high level a potential circuit that could be used to develop a prototype for our design. Because we did not have access to a circuit analysis or schematic building program, we will describe the components necessary and how the interconnections would be laid out regarding the microcontroller and its inputs/outputs.

Our design makes use of a SAMD21 microcontroller, similar to our first proposed design, once again because of its ease of use, low power consumption, and community of resources available for aiding development on the platform. One important resource that it has is a large number of IO pins which will be used to control the output signals such as the lights and speaker, as well as read inputs from the ultrasonic sensors and buttons. However, our design calls for a total of 19 IOs which is greater than the number of available pins. To manage this, we plan to include a set of multiplexers on the IOs to handle taking inputs from a series of ultrasonic sensors and buttons in turn, and then writing the outputs one at a time.

In the circuit schematic shown below (which is a modified version of our previously proposed schematic), we plan to use pins D1-11 for the purpose of providing multiplexed IOs to the components that will be used at different times. Specifically we can read from 3 of the ultrasonic sensors at once and then switch to reading the opposite set of 3 every 10ms to meet our overall sampling rate per sensor of once every 20ms. The turn indicators can also be multiplexed similarly, since a user will only be able to indicate a turn in a single direction at once. These kinds of simplifications will help make our design easier to implement in real life and possible to control using a single chip.

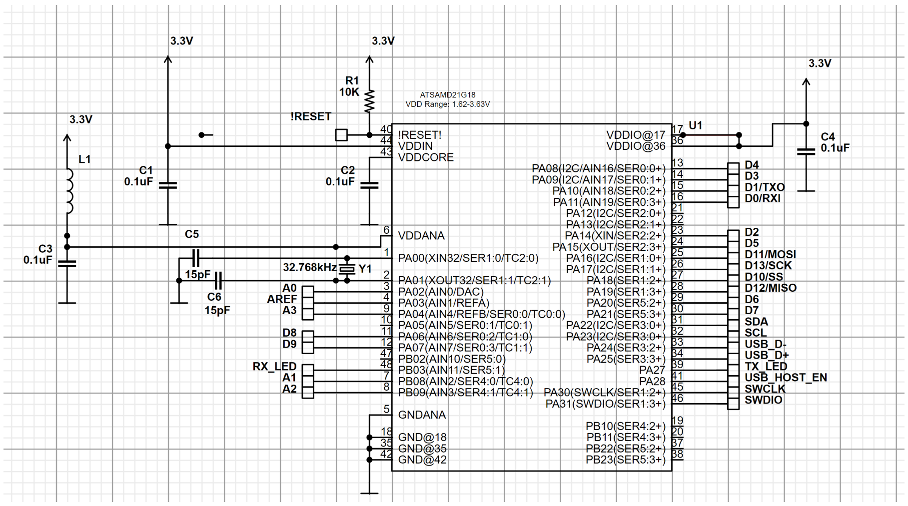

Figure 9: Draft circuit schematic based upon the datasheet with respect to typical usage.

2.2 Tolerance Modeling & Analysis

To validate that our design will be successful, we will analyze its core operating component – the ultrasonic sensing unit. This unit is composed of the sensors itself, as well as the control unit that will perform the real-time sensor fusion to produce meaningful and usable inputs to the internal state machine.

Our approach will focus upon the usage and ability of a single ultrasonic sensor, which can be extrapolated to determine the usability of the series of six ultrasonic sensors in our system.

Consider a single ultrasonic sensor. Based on the datasheet for the ultrasonic sensors that we intend to use, HC-SR04, with some added improvements, we can note that the recommended measurement cycle is approximately 20ms. This provides a refresh rate, variable *RR* of $1s/20ms = 50$ Hz. We need to be able to support the identifying the presence of objects at least of *D* ft away. From our high level requirements, we have determined and justified the distance $\mathbf{D} = \mathbf{16}$ ft. We look to prove that our approach satisfies any reasonable user situations by determining which situations our product would be unable to catch. We will determine our system to be successful if we are able to detect other bikers at a rate of at least 99%.

We now consider the case in which a collision for the user would occur. If a collision has occurred, this must mean that the Ultrasonic Sensor does NOT detect an incoming object with enough time to allow the user to react.

We will look to define a probabilistic model to determine the percentage chance we are able to avoid a crash between the user and another object. We will look to define certain constants that we will use in order to create this model. We will also define an input to the model to be the relative velocity of the crashing Object in question, defined as variable Y. Other constants we will use:

$$\begin{aligned} R_t \text{ (Reaction Time)} &= 300\text{ms} \\ D \text{ (Distance Threshold of Sensor)} &= 16\text{ft} \\ RR \text{ (Refresh Rate) } &= 50\text{Hz} \\ \alpha \text{ (Accuracy of Sensor) } &= 80\% \end{aligned}$$

To do these calculations, we will make an assumption regarding the accuracy of our ultrasonic sensors. Under normal circumstances, we would test this accuracy in real-life experiments. However, for the purpose of this analysis, we will assume an accuracy α that is much lower than what it should be, $\alpha = 80\%$. We will define accuracy to mean that 80% of the time, the measurement provided will be correct, and 20% of the time it will be a trash value.

In order for this reaction time to be satisfied, we note that we can use the input Y with relation to the reaction time to determine how much of the 16 feet will be covered by the incoming object while the user is reacting, and define it as variable L.

$$L = velocity * time = distance$$

$$L = Y * RR = Y * 0.300 \text{ s}$$

We can see here that this now implies that the value of $D - L$ provides the number of feet within the threshold D that the ultrasonic sensor can use to be able to detect the incoming object. As a result, we can now apply our previous tolerance to the new distance. We look to use the refresh rate of the Ultrasonic sensor as the input speed to determine this.

We will do this by finding the amount of time (variable T) that the ultrasonic sensor has, by using the distance and velocities, and apply the refresh rate to see the number N readings that we will be able to achieve.

$$\text{Time} = \frac{\text{distance}}{\text{velocity}}$$

$$T = \frac{D - L}{Y}$$

$$\text{Number of Readings} = \left\lfloor \frac{\text{Time}}{\text{Refresh Rate}} \right\rfloor$$

$$N = \left\lfloor \frac{T}{RR} \right\rfloor$$

We can see here how simply with the input of the the objects velocity, we are able to determine a linear relation to the the amount of time that the object will take to cover the distance of the threshold in which it is acceptable for the ultrasonic sensor to read off a value. Using the amount of time, we are able to determine the number of readings by taking the floor of the readings divided by the refresh rate.

Given a value of N, and that each individual measurement should follow the memoryless property of probability, we can apply a geometric distribution to determine the chance of detection. Let's define a function $F(Y)$ that encompasses the entire model and outputs the final probability of capturing an object given its speed, while taking the Y as an input. We will then expand the equation.

Geometric Distribution:

$$F(Y) = 1 - (1-\alpha)^N$$

$$N = \left\lfloor \frac{T}{RR} \right\rfloor$$

$$N = \left\lfloor \frac{\frac{D-L}{Y}}{RR} \right\rfloor$$

$$N = \left\lfloor \frac{\frac{D-Y*R_t}{Y}}{RR} \right\rfloor$$

$$F(Y) = 1 - (1-\alpha)^{\left\lfloor \frac{\frac{D-Y*R_t}{Y}}{RR} \right\rfloor}$$

With this model, we can apply the model to the two major cases, the case of a biker, as well as the case of a nearby car. Remembering our end goals, we will be able to generate a probability that a collision will occur. Lets apply this to the case of a bicyclist. From research the average speed of a bicyclist is approximately 13.5 mph. This means that $Y = 13.5$ mph $= 19.8$ ft/s:

$$N = \left\lfloor \frac{\frac{16-19.8*0.3}{19.8}}{0.02} \right\rfloor = 25$$

$$F(Y) = 1 - (1-0.8)^{25} \approx 1$$

This shows that we can with near 100% accuracy be able to capture another biker within this threshold. However, when applying this model for drivers on the road, we can see a different story. Let's use an average speed of 30 miles an hour, which is reasonable for most roads a biker would take. We can apply $Y = 30$ mph $= 44$ ft/s:

$$N = \left\lfloor \frac{\frac{16-44*0.3}{44}}{0.02} \right\rfloor = 3$$

$$F(Y) = 1 - (1-0.8)^3 = 99.2\%$$

We can see easily how even with this poor assumption regarding the accuracy of the ultrasonic sensor, that we are easily able to surpass our value of a 99% accuracy when detecting cars and bikers. Realistically, the accuracy of the sensor should be much higher, which would only strengthen our result. As a result, we can confidently say that from our mathematical analysis, our system has a high probability of detecting objects within the threshold.

3 Second Project Conclusions

From our implementation, we are able to come to a number of conclusions regarding the viability of our product. We further note the further needs that we would need to address as well as various parts that we would need to test. Through our extensive work, we also can now conclude what our project might need to maintain a high level of ethics and safety, as well as various improvements that we would look to make if we had unlimited time and resources.

3.1 Implementation Summary

In our implementation of this design, we were able to verify that the overall design was sound by simulating its operation in a wide range of scenarios, modeling the response of both the sensors and users, and additionally outlined how the corresponding circuit could be built. In the context of our original problem statement, this means that our prototype successfully implements a design that will substantially improve the safety of bikers on the road.

The simulation allowed us to re-evaluate our high-level requirements and adjust + verify them based on real world constraints. This was the primary feedback from our original proposal, and the simulation has allowed us to show clearly that in a worst case scenario, ultrasonic sensors with a range of at least 16ft would be successful in the vast majority of cases. Additionally, we reworked our prior tolerance analysis using this data, and were able to further show that a design that meets our requirements and specification would be able to help bikers stay safe on the road.

Through the course of numerous scenarios that we modeled, both mathematically and programmatically, we found that our simple design should be successful even in the face of worst-case ultrasonic sensor accuracy, high vehicle and bicycle speed situations, and even when accounting for upper-bound response times from users. This led us to conclude that the design we have proposed over the past weeks should be successful when built for real.

To that end, we also explained how to build a circuit to support the functions that we proposed. Since we did not have access to circuit schematic building tools or the lab, we found it difficult to articulate each of these elements exactly. However, we have taken this into consideration when creating our design so that many of the components have simple interconnections, such as PWM signals or direct connection. As such, we were able to describe how the microcontroller could be connected to the other components and expect that building this design from the specification that we were able to provide here would be possible. In general, we found that simplifying our design was a way to make it more robust and would likely also lead to it being more successful in practice.

Overall, the implementation of our design has shown that the concept proposed here is viable and could be implemented physically given more time and resources. We believe that in terms of preventing injuries and fatalities to bikers sharing the roadway with other vehicles, our device would be able to perform successfully when built for real.

When working on this project, all teammates worked together on each of the components collaboratively and we made it a point to work together during meetings to ensure that each member had a strong working knowledge about each of the implementation and other aspects of the project.

3.2 Unknowns, Uncertainties, Testing Needed

Due to the challenges posed by the emergence of COVID-19, there are a variety of uncertainties and unknowns in the implementation of our project. Having no access to the lab prevents us from being able to design and order our PCB, which is fundamental to the core design of our project. Not having access to lab equipment also prevents us from unit testing our individual parts, like capacitors, resistors, etc. If we were required to do these things, we would either need to buy lab equipment like and oscilloscope and buy CAD software in order to design the PCB.

In addition to not being able to access the lab, being unable to order parts also prevents us from analyzing data from our ultra sonic sensors in any way. This is crucial because without real data, it would be difficult to understand how to extrapolate the relevant data and write software around it. A work around for this would be to try and find example data outputs from the same sensor we were thinking of buying, and try to make sense of the data presented. Lastly, without the ability to order parts, we simply cannot build our project. We could order parts, but the delay caused due to the corona virus makes it unpredictable when we would receive our shipment.

3.3 Discussion of Ethics and Safety

In the effort to create a product that is meant to save lives, it is important to consider the safety and ethical components of not only the creation of this project, but also the usage of it by the populus. While building the project, as we are working with electrical components, we run the risk of harm to ourselves and those around us. Our utmost concern will be laboratory training and safety with regards to the Division of Research Safety training [5].

Furthermore, when considering the production of our product, we must adhere strictly to Rule 3 of the IEEE Code of Ethics, which states that we must be “honest and realistic” with our claims with respect to available data [3]. Our plan of development includes extensive experimentation that allows for the easiest and most intuitive usage of Project Safe-Tee. The jacket must always light up when the user brings up his arm, as there is an even greater risk when the user thinks that others on the road can see his turning indicator when in fact they do not. Our project further must follow Rule 9 of the code of ethics, to ensure that our product will neither indirectly cause harm due to missing indicators nor directly cause harm due to malfunctions [3].

We are cognizant that there are multiple concerns that stem from the creation of the project that may directly cause harm to a user. One of the most obvious is short-circuits, as our device is an electrical one that is meant to be used outdoors. As a result, we will ensure that the internal components of our project will be dry while submerged up to 1 meter of water, adherent to the IP67 guidelines [7]. Finally, the LiPo battery is well known for its inherent safety risks, as it is not difficult to start a fire or even an explosion under certain circumstances. To combat this, we will ensure that the charger prevents overcharging outside of the 3.7V range, and we will tell the users basic safety tips, such as to wait for it to cool before charging it after usage, as well as to never leave the battery unattended while charging [8].

In order for our project to meet the criteria we've established, we plan to implement certain safety measures to mitigate risk to the user when the product is both in use and during charging. Firstly, in order to prevent the battery from overcharging, we plan to use a voltage regulator to limit the output of our power source. To prevent the worst case scenario of thermal runaway, which would lead to the battery potentially exploding, we plan to encase the battery in a durable heat resistant material such as leather or mineral wool. Secondly, we decided to use LED's that are assembled in parallel as opposed to LED's assembled in series, so that one failed LED does not compromise the reliability of the product. This makes it so that unless every single diode fails simultaneously, the turn signal indicator will always light up when the button is corresponding button is pressed, given that the rest of the components are functional.

Additionally, if the micro controller handling the LED's recognizes that it is unable to communicate with the control unit, or that the data it is receiving is corrupted, the LED's will blink red to indicate to the user that the product is no longer operational. Similarly, if the control unit recognizes that the ultrasonic sensor array is failing to deliver reliable data, the LED's will blink yellow to indicate that the sensor array is in need of repair. Lastly, in order to clarify to the user how to properly use the product, we could include a brief safety pamphlet to inform the user about the various risks and how to mitigate them.

While the safety risks of assembling this product are minimal, we recognize that there is some form of danger when handling and building electronic components. In order to prevent any injury or harm when assembling this product, we have decided to use electricity resistant gloves.

3.4 Project Improvements

One possible improvement we could have implemented given more time is to use IR cameras and machine learning to identify potential threats, instead of ultrasonic sensors. Similar to object detection systems on self driving cars, our system would be able to identify threats more accurately and at greater distances, without blind spots. The potential of ultrasonic sensors are limited by their accuracy at varying distances and response time, both of which can be greatly improved by using an IR camera/software.

Another improvement we could have made was to the sound component of the system. While in theory our speaker is loud enough so that the user can hear it even in traffic, there can be times where there are unexpected noises that could make it difficult to discern whether our speaker is beeping or not. Therefore, we could either mount custom speakers near the ears on a bike helmet, or allow wireless earphones to communicate with our system via Bluetooth as an alternative speaker.

Lastly, given more time we could have made the battery that supports the system be rechargeable via the energy produced through peddling, which will extend the battery life indefinitely. This will eliminate the worst case scenario of the system losing power and being unable to function, which could be dangerous if the user is not aware of the situation.

4 Appendix

4.1 Requirements and Verification

4.1.1 Sensors

Ultrasonic Sensors

Requirements	Verification
Each ultrasonic sensor should report distance data at a rate of at least once every 60ms in order to detect objects and obstructions within their field of view.	We will directly obtain the values reported by an ultrasonic sensor driven by a trigger once every 60ms over a fixed time interval of 10 seconds and confirm that at least 166 samples are recorded.
The ultrasonic sensor measurement granularity should be smaller than 1 foot. This will allow us to discern that an object or obstacle has moved relative to the biker.	We will take a series of ultrasonic sensor measurements and move the sensor base until we can register a consistent difference in the reported value that can then be replicated over at least 10 trials. The physical length of this adjustment represents the granularity of the ultrasonic sensor measurement.
The sensors should be able to meet the above requirements when tested where the objects are placed an angle of at least 10° away from the sensor face's normal direction. Thus, the field of view over which accuracy is maintained should be at least 10°.	We will repeat the testing steps described above where the obstructions are placed at an angle of 10° away from the sensor normal. The sensor is expected to be able to satisfy the provided constraints under these conditions.

Turn Buttons

Requirements	Verification
Each button should trigger an interrupt on the SAMD-21 microcontroller when a user holds the key down for at more than 0.2s. A short press is considered 0.5s, but a shorter activation period will ensure greater safety for the user.	We will write s simple program for the SAMD-21 that fires an interrupt when the button input signal is pulled low to test this, by counting the number of interrupts fired over the course of execution and comparing that to the number of times the button was pressed. These numbers should always match up for 'full' button presses that last at least 0.2s.

Control Unit Software

Requirements	Verification
A program running on the SAMD-21 must be able to generate a trigger input for the ultrasonic sensors once every 60ms. This will be used to drive the sensors and request values at that rate.	We will write a test program to generate this trigger signal for the ultrasonic and verify that the output satisfies the constraints of the physical ultrasonic sensors. This will be tested in conjunction with the first Requirement & Verification entry for the ultrasonic sensors.
The generation of output signals for the LED lamps and speaker must be completed within 40ms of when the inputs are originally derived from the ultrasonic sensors. This will ensure delivery of outputs to the user within 0.1s overall.	We will write a test program to take a set of arbitrary sensor inputs and generate the necessary output signals to power the LEDs and speaker, once every 200ms. These generated signals can then be verified using an oscilloscope to ensure that they are accurate and meet the timing constraints provided.
Software will move through a simple finite state machine between an idling state, right turn state with no potential dangers, left turn state with no potential dangers, right turn state with potential dangers, and left turn state with potential dangers.	We will compare the expected output state to the actual output state based on a series of pre-defined inputs.
The software should be capable of communicating its internal state information between micro controllers (such as object detection, between the LED controller and the ultrasonic sensor controller) via a simple serial connection.	We will verify that data was successfully transmitted via serial connection through the micro controller by checking the output signals to see if there was any data loss.

4.1.2 LEDs

Requirements	Verification
LEDs should produce at least 50 lumens of light energy when fully powered on and set to the color white.	We will use a Lux meter to verify this requirement directly.
LED indicators should be visible to others both in front and behind the user at a distance of 50 feet in ideal nighttime conditions, up to 25 feet in ideal daylight conditions, and up to 10 feet in severe weather conditions.	After the LEDs have been mounted on the bike, we will verify this requirement by observing the visibility of the LED's at various distances under various weather conditions.

4.1.3 Power

Requirements	Verification
The lithium iron phosphate battery, with the assistance of the voltage regulator circuit should be capable of providing a constant 3.6V of power, as well as 12V directly.	We will directly inspect the power output from our power system over an extended period of time and under different usage constraints.
The battery should power the hardware components and microcontroller for a minimum of 4 hours.	We will leave the system on and time how long the battery lasts.
The system should have an ON/OFF switch enabling the user to save battery when not in use.	We will analyze and confirm the power to each of the on-board components when the switch is in the OFF and ON positions.

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