Bike to the Future
Final Project Report

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LIDAR (Light Detection and Ranging): A detection system using the light from a laser and measuring the time for the reflected light to return to the receiver.
Ultrasonic: Vibrations of frequencies greater than about 20 kilohertz, i.e. greater than the audible range for humans.
Tactical Feedback: A physical response on a device such as high vibration patterns and waves used to transmit information to the user.
Ergonomics: The relationship between people and their working environment.
APS (Accessible Pedestrian Signals): Devices at crosswalks that communicate information in non-visual formats.
Sensor Scan Rate: Indicates the speed with which data can be collected.
Anthropometrics: Science of measuring the human individual.
Piezoelectric: Electric charge in response to applied mechanical stress.
Hardcoding: Fixing parameters in a program in a way that they cannot be altered without changing the code.

Executive Summary

Brian Higgins is a veteran with retinitis pigmentosa who enjoys biking. The motivation for this project was to design and manufacture a refined prototype of a bike attachment to assist Brian in safely biking to and from work. The customer needs, problem definition, background, design development, final design, testing, costs and recommendations are provided in this report.

The solution for this project, as layed out in the design development section, was to design an assembly that would detect objects in the biker's path and relay that information to them. The design incorporated a dashboard to conceal components within, protect them from weather and keep the user's handlebar area clear from clutter. The final design of the project was altered from the initial iteration due to additions to the sensor package. More information on these specifics can be seen in the product realization section which covers the major changes made to the design.

Upon testing, the sensor package was examined to determine if the combination of LIDAR and ultrasonic sensor met the defined design requirements. The output from the speaker cone was also tested to determine if the audio level was detectable. Three variations to the audio feedback were made based on pitch, delay and a combination of both. All versions were demonstrated to the customer who showed preference for the combined option.

The timeline of this project was estimated at approximately 7 months to complete. The budget was set to $1,000 but $762.89 was used to purchase and ship materials. Manufacturing items such as the 3D printed speaker cone, laser cutting the platform and cutting holes on the dashboard were not included in the cost estimate.

Introduction

Prevalence of eye disorders affecting vision is significant, affecting approximately 2.4% of US citizens, even among those in the cycling community [1][2]. These types of disorders can make it unsafe or even impossible for the individuals affected to bike on their own. The customer for this project, Brian Higgins, bikes to work every day, but due to his diminishing vision, requires a method for identifying obstacles which may present themselves during a typical bike commute.

The purpose of this project was to improve Higgin's current bike so that it could identify and notify him of obstacles in his path, ensuring his daily commute to work remains safe. These obstacles include static objects such as posts and fences as well as moving objects such as other pedestrians, cars, and animals. The use of sensors allows for the detection of objects in the path of the customer. The detected objects are relayed back to the customer through auditory and tactile feedback which allow him to expect these obstacles then change course. Furthermore, Higgins needs to rely on this prototype regardless of the environment, so it is durable enough to withstand daily use through rain, wind, or sun.

Through the course of this project, the top priority was making sure that Higgins' needs were met. Additionally, Higgins' commute will be enhanced through the implementation of new hand grips, and keeping the overall weight of his bike low. Finally, the solution maintains a high degree of longevity such that Higgins will be able to continue biking safely. In theory, the final product can be used to aid anyone experiencing limited vision.

This project was managed by assigning specific roles to each of the four members. These roles include a point of contact with the customer, an investigator to look into valid ideas and concepts, an implementer to fully realize these conceptual ideas, and a team manager responsible for guiding the team through objectives and milestones.

In order to manage and maintain progress for this project, the team used the Gantt chart attached in Appendix T to keep track of major milestones and make sure all tasks are completed within a set timeframe. These milestones were created based on the map showing the flow of the design process in Appendix C. The chart breaks down key steps of the project by showing the tasks needed to be accomplished at each stage of the process along with their deadlines.

Background

From observing current technologies, it seems that the ability to detect objects will depend heavily on the type of sensor used. Many options exist and are used in a variety of fields, however the two most prevalent types of sensors are LIDAR and ultrasonic based. LIDAR, or "Light Detection and Ranging" is a common method for detecting distances which sends out a pulse of light and measures the time it takes for the light to bounce off of an object and return to the sensor–often referred to as "time of flight" or ToF. This is then used to calculate a distance between the sensor and the object [3]. Ultrasonic sensors operate in a similar manner but emit pulses of high frequency sound waves instead of light and use the speed of sound in conjunction with the measured ToF to calculate distances [4]. LIDAR can typically measure at a higher measurement frequency than ultrasonic sensors as the speed of light is much higher than the speed of sound, allowing for more data to be collected over a given time period. However, LIDAR sensors often provide less accurate readings than ultrasonic sensors as the pulse of light used by the LIDAR system can be dampened by heavy fog or rain and masked in bright sunlight [5].

A previous iteration of this project produced promising results through use of a 360° LIDAR based sensor, the RPLIDAR A1 as seen in figure 1. The students working on this project mounted this sensor to the front of Higgins' bike and attached a case to house the batteries and related electronics. Additionally, they included both audio and tactile feedback through a 3D printed housing they attached to the handlebars as seen in figure 2. While this iteration of the project produced promising results in a laboratory setting, their design proved unsuccessful during use in the daytime as the RPLIDAR A1 could not produce a powerful enough pulse to work effectively in bright conditions. This does provide a useful starting point for this project however as RPLIDAR's new sensor, the A3, produces a more powerful pulse and as such is rated for use in the daytime [6]. Authors of the previous iteration indicated however that they believed multiple fixed sensors or using different types of sensors would work more reliably than a single rotating LIDAR sensor due to the high cost of LIDAR and its inherent limitations in bright light.

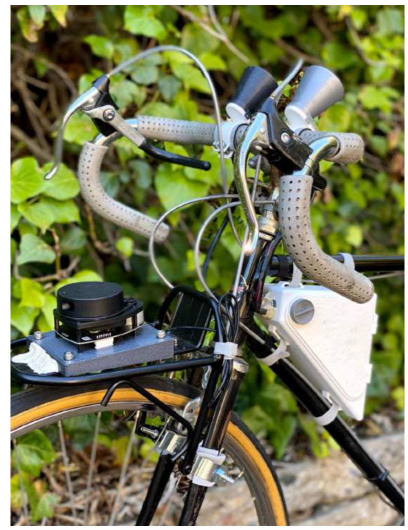
Figure 1. Previous iteration of project with LIDAR


Figure 2 Previous iteration of audio and tactile feedback

There are currently no acceptable solutions on the market that address all of Higgins' needs and few that even come close. The closest applicable solution we have found comes from a company called Ultracane through their product, the Ultrabike. The Ultrabike is described on their website as a "kit" that can be attached to any bike and uses two ultrasonic distance sensors accompanied by vibrating buttons for tactile feedback [7]. This design is very reminiscent of the previous iteration of this project due to the manner in which the sensors and tactile vibrators are mounted

as seen in figure 3. Through the use of ultrasonic sensors, the Ultrabike would not experience the same issues in the daytime that the authors of the previous iteration experienced. Ultracane maintains however that this product is only to be used on a closed course with constant supervision and is currently not for sale, all of which makes it of little use to Higgins [7].

Figure 3. Ultrabike "kit" mounted underneath handlebars of a bike

Other companies offer products that use LIDAR sensors such as the Calamus One from Calamus Bikes [8]. The Calamus One is an electric bicycle equipped with LIDAR sensors capable of detecting objects in the rider's blind spot and provides tactile feedback through vibrating handlebars [8]. This product, seen in figure 4 , does not provide any feedback for objects and other obstacles in front of the rider therefore would not be helpful for a rider with limited vision [7]. While this product will not effectively meet the customer's needs, considering vehicles approaching from the rear may be a useful feature to include in this project as well.

Figure 4. Calamus One Bicycle

Objectives

The project goal is to create a secondary, refined prototype of a bicycle attachment to allow for the rider to safely bike to and from work daily. This prototype should be able to identify objects in the bike's path, such as pedestrians, pets, fire hydrants, mailboxes, etc. (appendix A), in a variety of climates. *Table 1* shows the formal engineering requirements that were derived from initial conversations with the customer and following customer feedback from the project requirement document.

Based on his previous experiences and his own "smart bike" prototypes, he would like for the sensors to alert for objects in his path when they are approximately 7m away. This distance allows enough time for him to change directions and move his path away from the object. Higgins requests both audio and tactile feedback when objects are detected in order to adequately recognize and prepare for confronting objects in his path. He also mentioned how the weight of the prototype was not something that needed extensive focus. Currently, the customer has a laminated sign that identifies that he is blind. This sign alerts pedestrians and vehicles around him to the fact that he has limited sight and that others should be cautious.

The project will involve replacing this sign to incorporate it better with another of Higgins' recommendations, a dashboard. This dashboard would act as a console to attach all of the components of our product to. It would make installation and maintenance easier as well as make the product easily scalable if in the future, it could be used for a variety of customers. In addition, Higgins is having difficulty gripping his bike handles because the handlebar space is currently occupied by dashboard components. At this time, he is holding onto the brackets containing those components rather than the actual handlebars. The customer provided the team with hand grip measurements in a concept sketch, as seen in appendix D. Using these given values, the team will define hand grip length and implement hand grips for ergonomic and safety purposes.

The risk column of the table below refers to the risk of meeting each of the targets that were set. The possible values are High (H), Medium (M), and Low (L) and were decided on for each requirement through customer consultation and team discussion.

The compliance column in *Table 1* refers to how the specification will be met. An “A” indicates the specification will be met through analysis including calculations or computer models. A “T” indicates the specification will have to be tested in a laboratory setting. An “I” indicates that the specification can be met through simple inspection which may include measuring distances or weights of components.

Table 1: Formal Engineering Requirements

Spec. #	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Sensor Range	9 (m)	MIN	H	T
2	Sensor Notification Range	7 (m)	+-1 (m)	H	T
3	Audio Feedback	70 (dB)	+- 10 (dB)	H	T
4	Tactile Feedback	0.5 (G)	+- 0.1 (G)	M	T
5	Sensor Scan Rate	4.2 (hz)	MIN	H	T
6	Weight	10 (kg)	MAX	L	I
7	Dashboard Size	5 x 25 (cm)	+- 5 (cm)	M	I
8	Blind ID Sign Size	21 x 28 (cm)	+- 5 (cm)	H	I
9	Detectable Object Size	40 x 61 (cm)	MIN	H	T
10	Electrical Housing Size	64 (cm^2)	MIN	M	I
11	Dashboard to Person Distance	51 (cm)	+- 8 (cm)	M	I
13	Battery Lifespan	2 (years)	MIN	L	A
12	Sensor Lifespan	10 (years)	MIN	L	A
14	Battery Length	10 (hours)	MIN	H	T

15	Hand Grip Length	10 (cm)	+- 0.5 (cm)	L	I
16	Impact Force for Collision	500 (N)	+- 400 (N)	L	A

The first engineering requirement, sensor range, is based on the customer's notification distance of 9m with an added meter to account for the time needed to send a notification to the rider. This target is a minimum because the prototype will be notifying the rider at 9m but the total sensor range could be any value greater than 9m. The sensor notification range specification is the distance that the rider needs to be notified of an obstacle in order to be able to change course and avoid a collision. This distance of 7m will give the rider ample time to make a decision and move around the obstacle. A small tolerance of +-1 m is allowed because the rider should still have time to change their path in this case.

The targets for audio and tactile feedback were determined through comparison to common objects. The audio feedback target was set to 70 dB with a 10 dB tolerance because a typical fire alarm sounds within the 65-120 dB range, with most homes being around 85 dB [9]. The team chose to stay on the lower end of that scale to be loud enough to be heard with the sound of traffic but not so loud to be dangerous to the rider. Another consideration taken when deciding on this value was comparison to crosswalk APS (Accessible Pedestrian Signals). These crowwalk sounds take into account road sounds but also measure for what can be heard from the middle of the cross walk. Their maximum output is 100 dB for noisy areas with high traffic but this is to be heard from a distance [9]. Since the end user of the prototype will be in close proximity to the speaker, our level of 70 dB is still reasonably loud for times of high background noise.

The tactile feedback provided should be a force of approximately 0.5 G, however deviations from this of up to 0.1 G will be acceptable as well. This amplitude of vibration, while relatively small, is well within the detectable range for human hands without being too large as to become uncomfortable for the customer [10]. Further, this requirement will pose a medium risk to this project; while providing feedback for incoming obstacles is important, there will be multiple feedback systems for the customer to rely on.

For sensor scan rate, the requirement was determined by looking into the scan rate on sensors mentioned to by the sponsor as well as other comparables on the market. Many advanced sensors have a scan rate of 5-10 hz so a minimum requirement of 6 hz was decided on. This specification is in place because the sensor will need to be able to quickly detect changes in the environment to relay data back to the rider quickly. A faster scan rate will send feedback to the rider more quickly and give more reaction time.

The customer's bike without attachments is approximately 1 kg and the average bike weighs closer to 9 kg [11]. A maximum weight for the prototype was set at 10 kg so his final bike would not be much heavier than the average.

For the seventh specification, dashboard size, the 5 x 25 cm target came from the customer. This dashboard will hold all of the components of the prototype so the size is important to be able to be easily attached to the bicycle and be out of the way of major functioning parts. Here, a tolerance of 5 cm is included to make sure that all components can be accommodated easily but the prototype still fits well on the customer's bike.

It was noted above that there is currently a laminated sign in place identifying the rider as blind. If it is decided that the current sign should be replaced to better fit the prototype, the same size of 21 x 28 cm should be kept so it is large enough to be seen easily by others on the road. Again, a tolerance of +-5 cm is included in the case that it better fits the design because a slight change in size will not affect the sign's overall purpose.

Higgins sent us a list of objects that our sensor should be able to detect which can be seen in appendix A. As mentioned before, this list includes items such as trash cans, pedestrians, fire hydrants, pets, mail boxes and more. These objects are commonly seen on his commute and would likely be something he would need to be warned of. The smallest of these objects was a fire hydrant 41cm x 61cm so that is our minimum requirement.

All of the electrical components for the bike will be stored within a housing. In order to prevent this housing from interfering with the rider's ability to bike, we chose a housing size of 64 cm^2. This size was chosen because it is large enough to store a raspberry pi, batteries, wires, and any other electrical components but not so large that it would get in the way.

Dashboard to person distance is used to ensure that the dashboard is of a comfortable distance from the user. The use of anthropometrics was chosen so that the prototype could be used by a variety of end users. This would help the product become scalable in the future. From a book of anthropometric measures, the forward functional reach for the 50th percentile of people is 65 cm whereas the elbow to fit length, the distance between a bent elbow and palm, is on average 37 cm [12]. Since a biker usually has arms slightly bent, we chose a value in between these at 51 cm with a tolerance of 8 cm that stems from the average difference from the 50th to the 95th percentile [12].

The lifespan of the sensor should be a minimum of 10 years to ensure that the customer will be able to rely on this product for a long period of time. A standard solid-state lidar sensor is rated for 100,000 operating hours which–assuming Higgins bikes 10 hours a day–should last well over

25 years [13]. As the requirement for this project is well below the standard threshold, this is a low risk requirement.

The standard lifespan of a lithium-ion battery is approximately 2-3 years so the formal requirement for this project will be a minimum of 2 years [14]. Lithium-ion batteries are relatively low cost and can be easily swapped in and out. For that reason, this requirement is relatively low risk.

Engineering specification number 14 is battery length. It can be assumed that the customer will require a long enough battery length to get to and from work as well as any other small trip they may need to make on a daily basis before charging overnight. As they will rely on this product for their safety, it is important that it can operate for extended periods of time between charges. For this reason, this requirement is considered high risk. A standard lidar sensor draws roughly 100 mAh and a 6600mAh battery would be well within the price range of this project, therefore the final product of this project should be capable of powering multiple sensors for a minimum of 10 hours, plenty of time to accommodate commuting to and from work as well as any miscellaneous trips the customer may want to take in a given day [15].

The hand grip length requirement is based on the values that were shown in the customer's concept sketch, as seen in appendix D. This hand grip length requirement of 10 centimeters is horizontal distance from the center of the bike. Since the customer provided a value of 4 inches and we converted units to centimeters, we decided on a tolerance of +-0.5 centimeters to account for the significant figures lost in the nominal value.

The final engineering specification is the impact force of collision that the bike should withstand. Assuming mostly small collisions, such as the bike tilting over or lightly hitting an object, the team decided on a force of 500 N. This value was calculated using the weight specification mentioned, the speed of gravity for dropping, and a distance of one meter (the maximum height of the bike in relation to the ground). The average force calculated was approximately 500 N with a maximum force of approximately 900 N [16]. The tolerance for impact force (+-400N) is large because there are many different objects that the bike could be colliding with, so the impact force will differ greatly depending on object size, material, geometry, and other parameters.

Design Development

Initial ideas were generated using a combination of functional decomposition and a morph chart located in appendix E in order to quickly generate a wide variety of ideas. Many of the functions and ideas were implemented in a series of Pugh matrices found in appendix F. These Pugh matrices were employed in order to generate ideas and compare them against each other, resulting in important takeaways. Concepts such as ultrasonic and LIDAR sensors, feedback in the form of vibrating and auditory components, and the use of clamps to mount objects to the bike were some of the key components that stood out from the initial brainstorming.

Inspired by these takeaways, a series of holistic sketches were created in order to provide different models for potential final products. Based on the requirements of the customer and the concepts generated from the morph chart and pugh matrix, the top three concepts focused on three primary components: the sensor, the dashboard and a blind ID sign. These components can be seen in figure 5 which shows the two blind ID signs placed on the front and back of the bike, the dashboard which is mounted on the head of the bike, and the sensor placed near the dashboard. Additionally, Mr. Higgins mentioned how strenuous the handlebar placement was to his back so we incorporated an additional handlebar mounted at the stem of the front to help alleviate the strain. This added component will also be used to relay information from the sensor through tactile feedback. The following three concepts were the top candidates for this project.

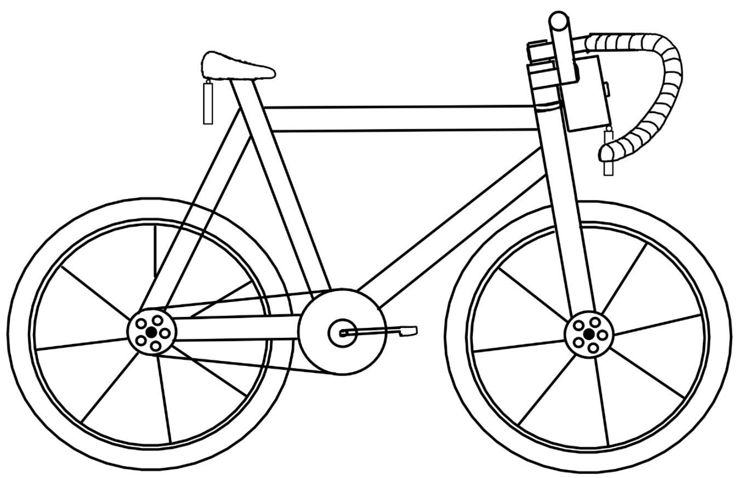

Figure 5. General layout of the Project

Concept 1: Rotating LIDAR Sensor

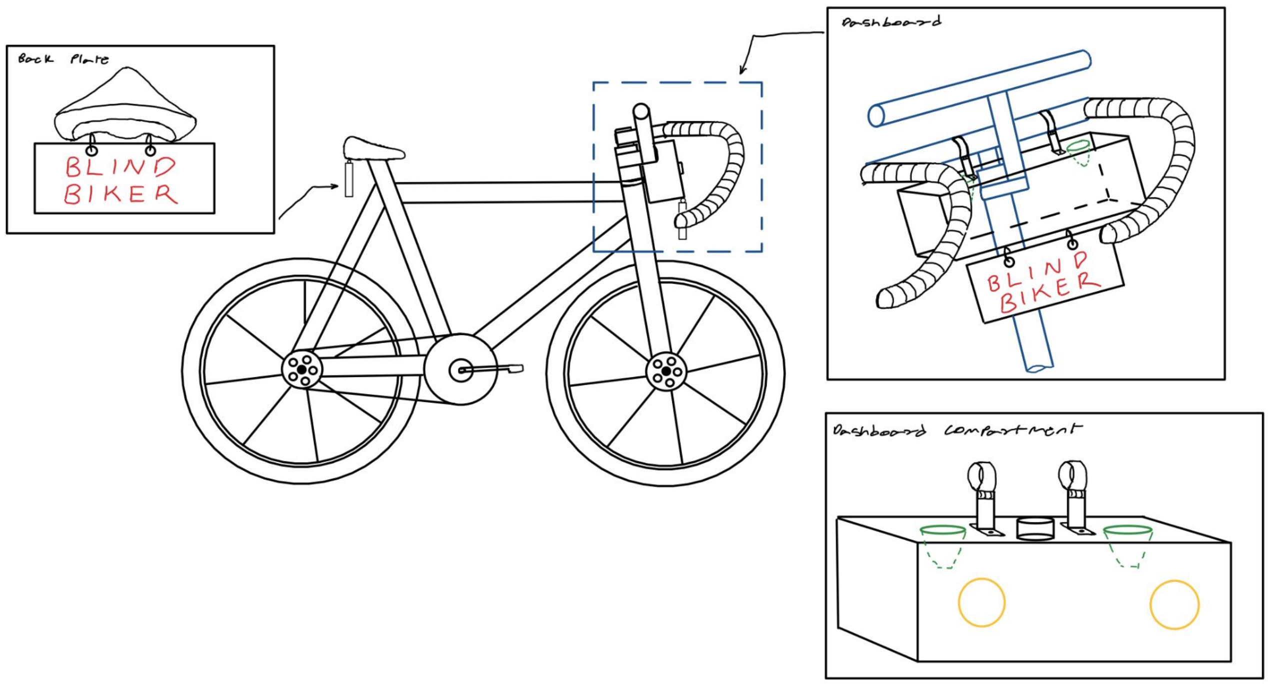

Figure 6. Sketch of Concept 1

The first concept, seen in figure 6, is similar to the existing prototype, except there is one rotating LIDAR sensor instead of two. Higgins expressed concerns with the previous iteration of this project regarding his ability to quickly react to an obstacle directly in front of him. Therefore, it was decided that placing one LIDAR sensor located at the center front of the bike was more ideal than placing two sensors on each side. This concept prioritizes detecting obstacles straight ahead rather than detecting objects within a peripheral range.

The LIDAR sensor will be secured on top of the dashboard and have a 15º horizontal range of rotation in front of Higgins. This concept also kept the directional feedback feature from the existing prototype, which includes: tactile feedback on the left and right handlebars from the two lily pads and audio feedback from two speakers.

In the previous iteration, there was a lack of handlebar space and organization of components due to several brackets being attached to the handlebars. This concept addresses that issue by incorporating a box-shaped dashboard that organizes all of the bike components. To ensure a strong, removable attachment of the dashboard, it will be mounted underneath the handlebars using clamps. Attachments will be made at two points from the top as well as the back of the dashboard compartment to ensure the part is secure and is constrained at all degrees of freedom.

Lastly, one of the main features of this concept is utilizing reflective signs to alert others of Higgins' condition. To efficiently alert people of his condition during the day and nighttime, reflective signs will be placed in front of the dashboard and at the back of the bike. Two bike lights could be placed behind the reflective sign, with holes cut out of the sign, to allow light shining through while maximizing space.

Concept 2: Single Ultrasonic Sensor

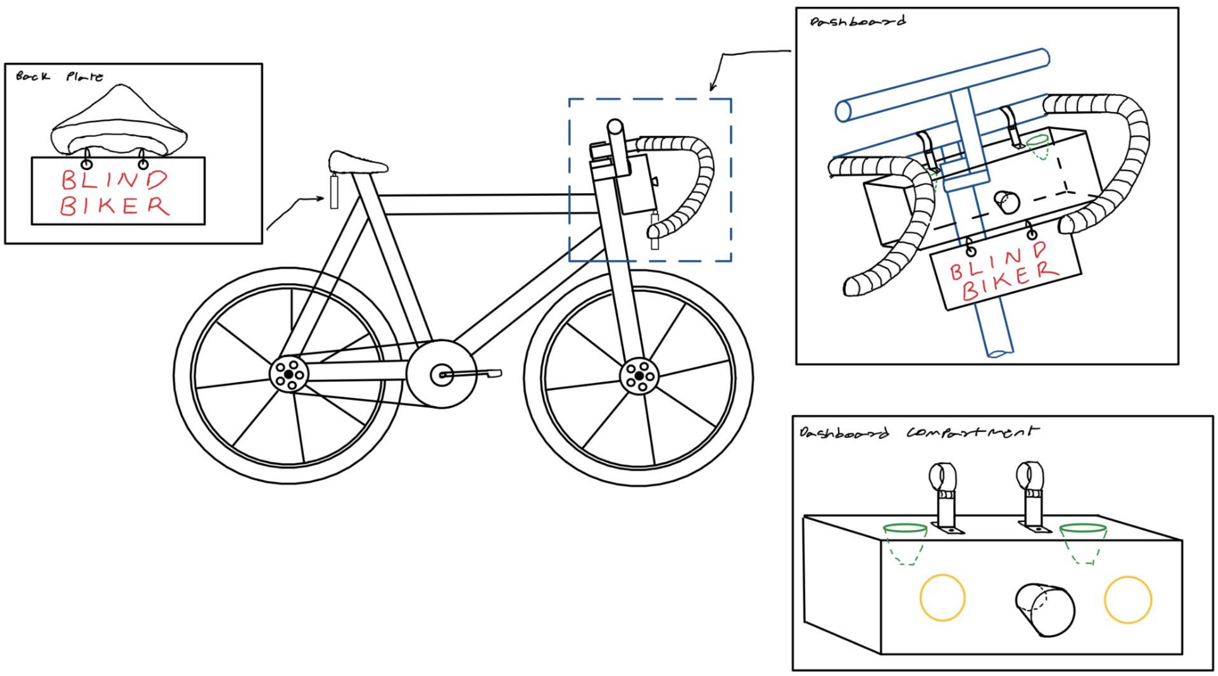

Figure 7. Sketch of Concept 2

Unlike the previous iteration of this project, this concept would employ a single ultrasonic sensor fixed such that it measures directly in front of the bike rather than rotating as seen in figure 7. While this concept would not account for objects in the peripheral field of view of the bike, this would simplify the acquisition of obstacles directly in the user's path as well as simplifying the feedback being relayed to the user.

A concern with the previous iteration is that by providing "directional feedback" (providing feedback in the right buzzers for obstacles detected on the right side and vice versa), the user may become confused or the on board processing of the information may be too slow to provide timely feedback to the user. For this concept, the sensor would only detect obstacles in front of the user and therefore would not need a complicated "directional feedback" system, instead providing simple feedback only when an obstacle was detected in close proximity to the user. This would be both audio and tactile feedback mounted in an additional set of hand grips above the existing handlebars and within the dashboard itself.

Ultrasonic sensors inherently detect objects within a "cone" emanating from the sensor as shown in figure 8 [17]. Therefore, by positioning the ultrasonic sensor directly in front of the user, this design would be able to detect obstacles within a few degrees to either side of the user.

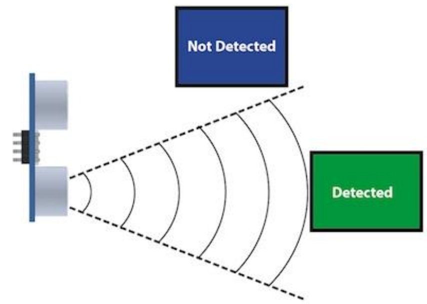

Figure 8. Ultrasonic "cone"

This concept would still require a dashboard to hold the microcontroller, batteries, and wiring, however due to the simplified design, this compartment could be relatively small. Additionally, LED "Blind Biker" signs mounted on the front and rear of the bike would provide other motorists and pedestrians with clear information regarding the user's condition.

Concept 3: Helmet

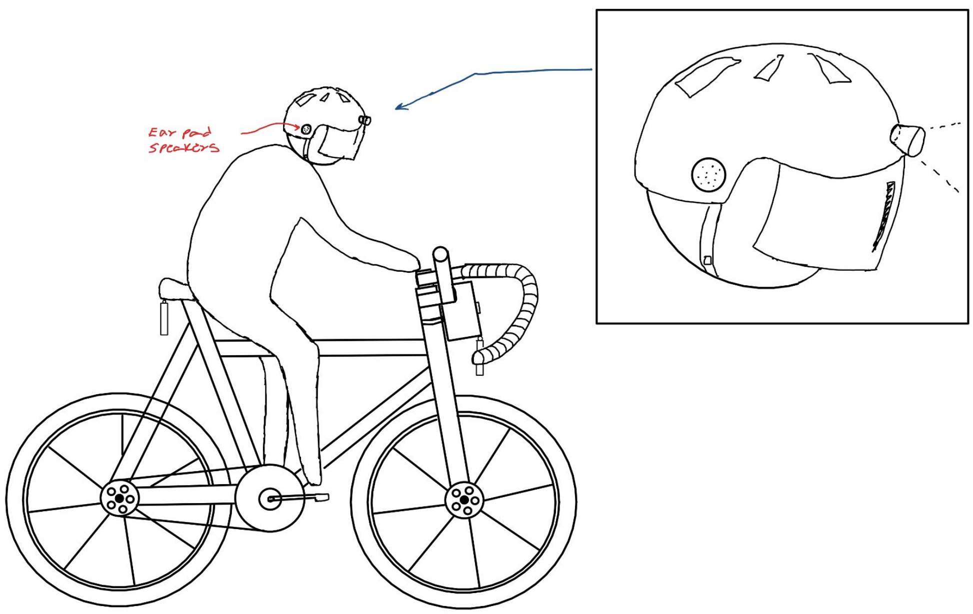

Figure 9. Sketch of Concept 3

The third and final concept to examine is the use of a helmet, instead of the original bike-mounted prototype design. This concept would have a sensor mounted on the helmet as well as speakers placed in the helmet's ear pads that would provide audio feedback. See figure 9 for placement. Other aspects that are included in previous designs, such as bike lights and handlebars, would not be included in this design and would be attached to the bike separately.

Figure 10. Helmet Bluetooth Headset

The sensor mounted on the helmet would be a LIDAR sensor that is stationary as it would move with the helmet as the rider turned their head. The speakers, as seen in Figure 10 [18], were chosen based on Smith bluetooth speakers that are made for ski helmets. They fit into the ear pads on a helmet and provide audio to the person wearing the helmet. For this concept, the level of this audio could be changed easily to fit the user. These headsets are designed to be used when doing a sport so they are not extremely noise-canceling in that they would distract the user from their surroundings. For this design, tactile feedback would not be included because audio feedback would be sufficient.

This design was selected because it was a drastically different design that the other two discussed above. In this design, nothing would need to be mounted to the bike so ease of charging would be greater. The product would also be more portable and potentially easier to maintain.

Selection Process:

From these three designs, Concept 2 is the most promising as it will be simpler and less expensive to build than the other concepts, will likely be more reliable and easier to use for the customer, and will not sacrifice any of the design requirements.

Concept 1 which was based largely off of the previous iteration of this project would require using the RPLIDAR A3 rotating LIDAR sensor as it is compatible for use in daylight [6]. With a cost of $600 however, this product would be an unreasonable expense, especially considering that the final product only needs to sense objects within a 10-15° field of view. This field of view could reasonably be covered by one or two ultrasonic sensors at a fraction of the price of the A3 [19].

While Concept 3 could allow the user to direct the field of view precisely in the direction they were interested in, safety concerns make this concept less desirable. If the user turned their head away from the direction of travel for any reason, they would not be notified if an obstacle suddenly blocked their path. Additionally, the audio feedback built into the helmet may muffle ambient noise, posing a safety risk on busy streets.

Concept 2 does not suffer from these safety concerns and due to its simplicity relative to the previous iteration and Concept 1, should be less expensive to produce. Further, the simplified feedback system will be easier for the user to interpret than the more complicated “directional feedback” system inherent to the other two concepts. With these factors in mind, Concept 2 meets all of the project requirements and is the most promising candidate for future prototyping.

Final Design Concept:

The final design concept would use a single stationary ultrasonic sensor rather than a rotating LIDAR sensor as the previous iteration employed. As seen in figure 11, the product will begin sensing using the ultrasonic sensor and will continue to do so until an object has been detected within a specified range. Assuming the customer may travel at approximately 7 meters per second (~16 mph) and allowing for a one second reaction time, this provides an object detection distance of 7 meters. This calculation can be found in appendix G. When an object is detected within this range, the vibrating feedback system will be triggered followed rapidly by the audio feedback system. The product will then repeat this process.

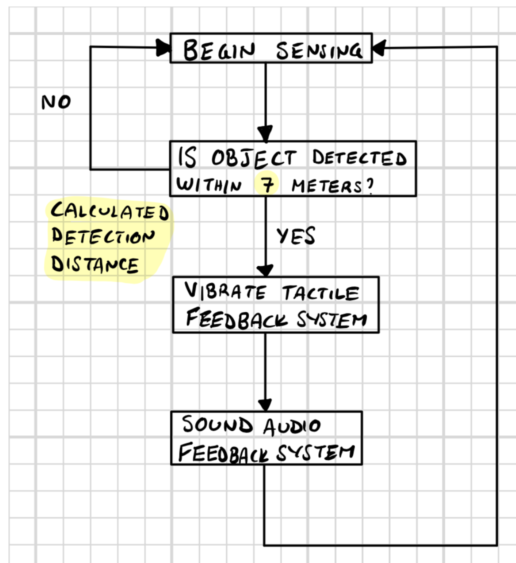

Figure 11. Concept Flowchart

The ultrasonic sensor required for this concept would be significantly less expensive than a rotating LIDAR sensor and would also be physically smaller. Due to these two factors, if the user desired a larger field of view in order to detect objects in the peripherals, a second ultrasonic sensor could be added to increase this field of view. In doing so, the final product would still be less expensive and come in a smaller form factor than a concept using a rotating LIDAR sensor. Additionally, ultrasonic sensors draw less power than rotating LIDAR sensors, allowing for the use of a smaller battery, and ultrasonic sensors have no moving parts that may be more prone to breaking or wearing down over time [19].

This concept will still use two vibrating components such as the vibrating Lilypad breakout boards used in the previous iteration as well as two auditory components such as piezo speakers. Unlike the previous iteration however, using two of each will only provide redundancy, rather than providing a “directional feedback” system as described previously. This redundancy will reduce the probability that a faulty component would result in failure for the customer to be alerted of approaching obstacles.

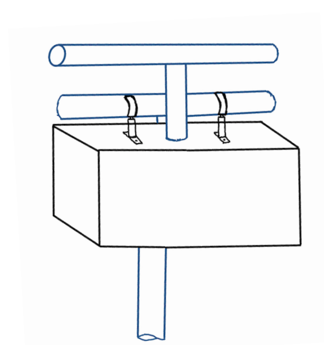
Figure 12. Additional Hand Grips Mounted within Dashboard

The vibrating components will be housed within a set of hand grips that will be mounted on top of the existing handlebars and a dashboard as seen in figure 12. These hand grips will serve a dual purpose; they will allow the user to assume a more comfortable “upright” sitting position while maintaining control of the bicycle as well as providing a location for the vibrating components to be housed securely in a location the user will physically be in contact with.

Due to the simplified feedback system and sensor, this concept would not require any high level processing for the ranging data and thus a smaller and slower microcontroller could be used such as an Arduino Nano or similar product. The smaller microcontroller, battery, auditory feedback components, and sensor could all be housed in a small dashboard mounted between the handlebars as seen in figure 13. This dashboard would keep all of the electronics protected from weather and would allow for firm mounting of each of the components such that they would not be jostled loose when riding over rough terrain. In order to prevent this dashboard from shifting during use, it will be mounted to the handlebars using strong clamps at multiple points of contact.

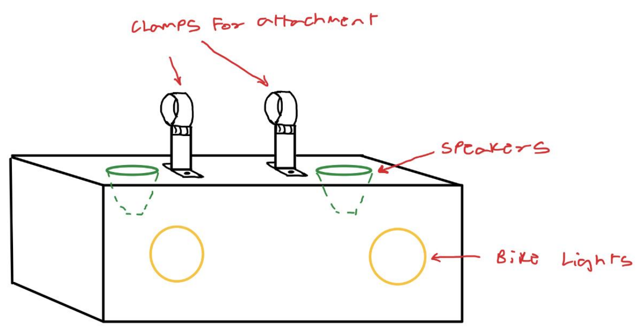

Figure 13. Dashboard Compartment for Housing Electronics

Finally, this concept will incorporate two signs on the front and rear of the bike to indicate to pedestrians and drivers that the user is blind. These signs will incorporate either LED lights or a reflective material so that they are clearly visible in all conditions. The signs should be large enough to be visible, so printing “Blind Biker” on 8.5”x11” signs will be adequate.

Comparison of Design Concept to Project Requirements

The final chosen concept satisfies and exceeds the following project requirements: safety, organization, ergonomics, and functionality.

Incorporating an ultrasonic sensor will ensure the customer’s safety because of its ability to detect objects in the daytime and nighttime. In addition to the single sensor, there will be audio and tactile feedback features to alert the customer of detected objects. The final concept includes two vibrating components and two speakers that will serve as tactile feedback and audio feedback respectively. Currently, the customer has a LIDAR sensor that only works in the night time, which jeopardizes his safety in the daylight. He mainly uses his bike to travel to work during the day, and having a reliable ultrasonic sensor that works when he needs it most satisfies the safety requirement.

Another safety factor incorporated into our design is the LED or reflective signs that display "Blind Biker". These signs are designed to communicate the customer's condition to surrounding people. The customer has been using a laminated sign that says "Blind Biker" attached to his backpack. The final design features of the LED or reflective signs exceeds and satisfies the safety requirement because the sign could be seen at night, and having one in the front and one in the back allows people from both sides to be notified of his condition. These visual indications will ensure his safety because people can be more aware of their surroundings and avoid potential collisions.

The next requirement, organization, is satisfied by the dashboard feature that will organize the bike components. At this time, the customer is struggling to grip his handlebars because there are so many brackets on his bike. These brackets were used to attach his bike components in the previous iteration of this project. Our design concept includes the dashboard, which will organize bike components, such as the sensor batteries or speaker cones, into prospective compartments. As we mentioned before, the dashboard will be secured to the bike using clamps at several points of contact with the bike to ensure a strong but removable attachment.

Another requirement that our final design concept satisfies is ergonomics. Although the dashboard feature will make the bike less cluttered and unorganized, the customer has been struggling to grip onto his handlebars and feels extreme discomfort while biking. Therefore, our idea of incorporating another set of handlebars with hand grips will ensure a more comfortable and enjoyable biking experience. These handlebars will be connected to lilypads for the tactile feedback, and will be more ergonomic-friendly so our customer can sit upright without straining his back.

The last project requirement, functionality, is satisfied by the dashboard feature that provides housing for the bike components. The customer expressed needs to weatherize and protect his bike components, and this need is addressed by using the dashboard to shield the components from water and other harsh weather. Since the dashboard provides more protection, this concept could help the components last longer over time against wear and weather.

Safety Considerations

The first safety consideration for the final design concept is how ultrasonic sensors might work in varying temperatures. Ultrasonic sensors work most accurately when environmental factors are eliminated, in controlled lab environments or fixed conditions [20]. At higher temperatures, sound waves travel at a faster speed, which means objects will be detected by the sensor and the customer will be notified of this at a faster rate. Therefore, he will have the misconception that the object is closer than it appears. Since air temperature will change throughout the day and throughout different seasons of the year, ultrasonic sensors may detect objects at inconsistent rates. This issue makes the design concept lack in usability and functionality because the inconsistency will confuse the customer and cause him to react to obstacles that may be further or closer than expected.

To address this potential safety consideration, we plan to conduct several lab tests and field tests to determine if the ultrasonic sensor is the best choice. We will pay close attention to the accuracy of the ultrasonic sensor and find ways to test the ultrasonic sensor's performance in varying temperatures. If we find that the ultrasonic sensors are not satisfying our requirements or expectations, we can look into the LIDAR A3 sensor, which was mentioned in one of the top three design concepts.

The second safety consideration is ensuring that the dashboard stays securely attached to the bike. The final design concept utilizes clamps as a strong but removable attachment. However, there may be lots of bumps or rough bike paths that jostle the dashboard around and possibly disconnect the electronic wires. To address the possible risk regarding the security of the dashboard and its components, we plan to heat shrink wires and secure the dashboard to the bike at several different points of contact. Heat shrinking the wires together could help keep the wires together and organize the electronics stored in the dashboard. In addition, we will attach the dashboard to the bike at several different points to ensure that the dashboard stays relatively static throughout rigorous movement. We may also conduct static analysis to minimize movement in all axes. In addition, the security of the dashboard will be tested in the lab and field, so we can determine if clamps are the best choices for attachment. If we decide to change the method of attachment, we can consider other ideas such as velcro, which was generated during concept ideation.

Description of Final Design

Note that aspects of the final design changed during the manufacturing process. All updates can be found in the Product Realization section below.

Design Description

Our final design includes a dashboard concept that will house several bike components for the sensor feedback system including the following: ultrasonic sensor, Piezo speaker, speaker cone, portable battery, Arduino Leonardo microcontroller, battery charging port, and other hardware parts such as screws and spacers (which will be discussed in further detail later in this report). This dashboard will be attached to the bike using handlebar risers that are clamped to the original handlebars as shown in Figure 14. This component will be secured to the risers with four screws placed on the back side of the box.

Figure 14: CAD Model of Attachment Method

The figure below is a snapshot of our dashboard CAD model in isometric front view with the bike components labeled.

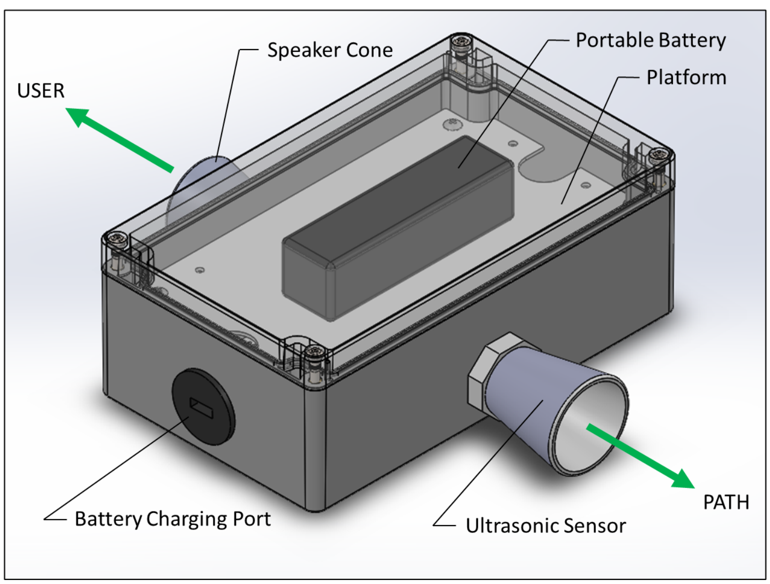

Figure 15. Dashboard Assembly Isometric Front View

As seen in the figure above, a waterproof polycarbonate enclosure will be slightly altered and manufactured to fit our organizational and attachment needs. Since we have several components that need to fit in this dashboard, we designed to have two levels to properly store each component by separating them with an acrylic platform. The ultrasonic sensor will point towards the path in front of the bike to detect objects, while the speaker and speaker cone will point towards the user to provide audio feedback. Electronic components will be powered by a portable battery, and the sensors and feedback system will be controlled using an Arduino Leonardo. The portable battery will be connected to the battery charging port through an extension cable. This will ensure ease of usability, since the power bank can be recharged without the need to remove the cover and cover screws. To secure the portable battery to the dashboard and prevent it from being jostled around during a bike ride, we will adhere it to the platform using velcro. The usage of velcro allows the user to remove the portable battery if needed. In addition, we chose to place the portable battery at the top level instead of other components to provide easier access to it and to prevent cable bending. Once the power bank has reached the end of its life cycle, the user can easily replace it by unscrewing the cover and unplugging it from the battery charging port.

The sensors and feedback system work by providing slightly different feedback as a detected object approaches closer and closer. The ultrasonic sensor will determine the distance between the bike and obstacle, and in return, the frequency of beeps will increase the closer the object gets. The distance range selection process and more detailed descriptions of this sensor and feedback system is provided later in the report.

More detailed information on electronics, assembly hardware components, and manufacturing will be provided later in this report. Since only a few of the bike components could be seen in the figure above, more views will be provided and discussed below for clarity. It is important to note that the Lilypad components that provide tactile feedback in our detect-and-alert system are not displayed in the dashboard CAD models because they will be attached to the user's handlebars.

The figure below showcases the dashboard components at the bottom level.

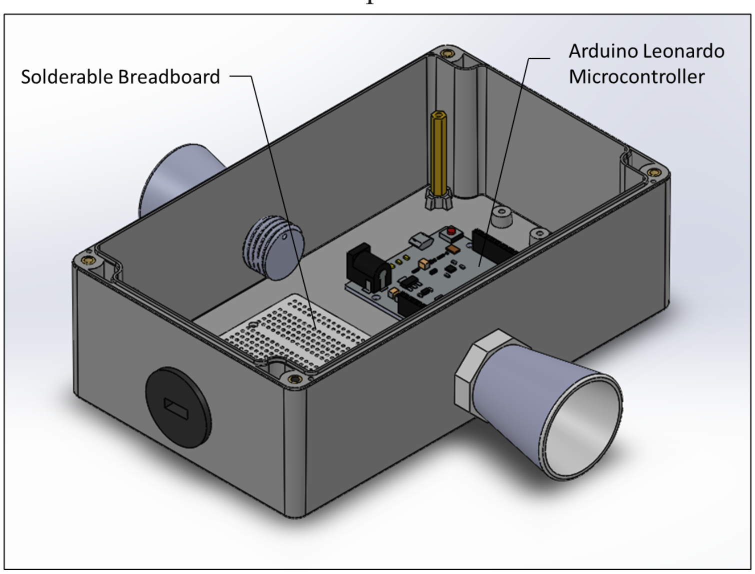

Figure 16. Dashboard Assembly Isometric Front View - Bottom Level

The snapshot above shows an isometric front view of the dashboard's bottom level with the other parts hidden. We will be using a solderable breadboard to ensure our wire connections do not become undone. The Arduino Leonardo will be used to control our detect-and-alert system by being connected to: the portable battery for power, the ultrasonic sensor for object detection, the Lily Pads for tactile feedback, and the speakers for audio feedback. The breadboard and Arduino microcontroller components were placed in the bottom level because they should not need to be accessed. However, using the platform and standoff spacers and screws setup will allow access to these components if needed. More information about the platform setup and manufacturing process will be discussed later in the report.

The figure below shows a back view of the dashboard, normal to the speaker and speaker cone setup.

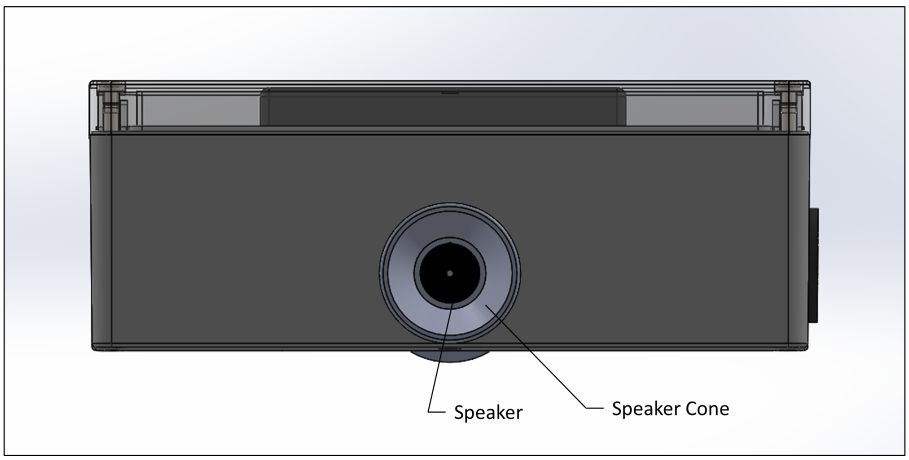

Figure 17. Dashboard Assembly Back View

As seen in the screenshot above, the Piezo speaker will be placed and secured within the 3-D printed speaker cone. The purpose of the speaker cone is to amplify the audio feedback towards the user. More information about component selection and speaker cone manufacturing will be provided later in the report.

The figure below shows the dashboard assembly model without bike components.

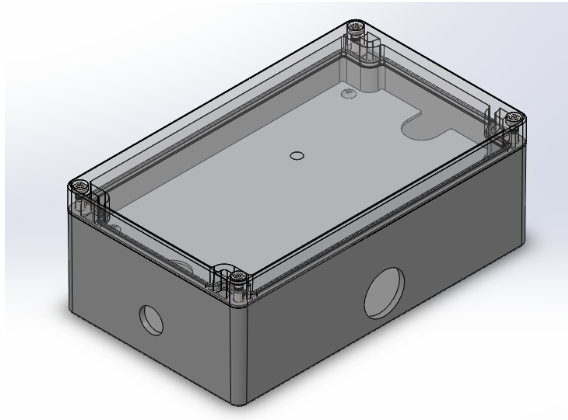

Figure 18. Dashboard Assembly Model without Bike Components

The dashboard assembly is made of several parts to ensure its functionality and usability. Below, we will briefly discuss each hardware component of the assembly.

The figure below shows an exploded view of our dashboard assembly without the bike components and provides a clearer understanding of how the dashboard will be assembled. To view the detailed drawing of this assembly, see Appendix H.

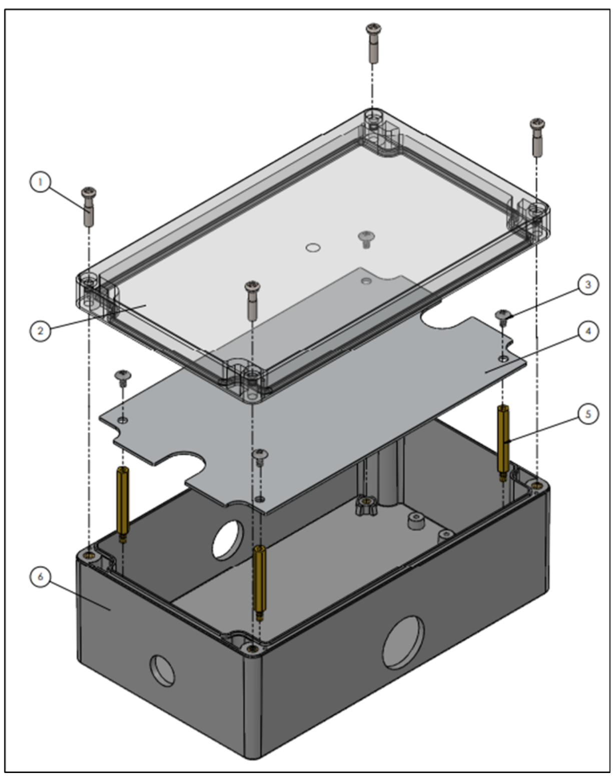

Figure 19. Exploded View of Dashboard Assembly without Bike Components

As seen in Figure 19 above, this design consists of several physical components. The first component we will be discussing is the set of four cover screws (Item No. 1 in Figure 19) that were provided with the purchase of the Polycase enclosure. The M4 X 0.7 mm stainless steel screws have an overall length of 20 mm according to the product specifications found on the manufacturer's website. These screws are user-friendly because they can easily be tightened or loosened using a phillips screwdriver. They are important to the assembly because the enclosure must be waterproof and securely house components inside. These screws ensure that the clear cover does not budge while the user is on a bike ride. The next mechanical component that will be discussed is the set of four standoff spacers.

The standoff spacers (Item No. 5 in Figure 19) provide clearance between the platform and enclosure base, serving as hardware parts to offset the platform that divides the enclosure into two levels. (For more information on the platform and how it will be manufactured, please view the Manufacturing Plan section of this report.) The enclosure came with four mounting bosses with brass inserts at each corner of the box's base, which we will be using to screw in four male-to-female hexagonal standoff spacers. Through 3D-CAD modeling on SolidWorks, we determined that a minimum of 34 mm clearance is required between the bottom of the platform and the enclosure base. According to the drawing specifications of the Polycase enclosure, M3 X 0.5 mm screws fit in the brass inserts at the base. Therefore, we decided on using four M3 X 35 mm brass standoff spacers. The male-to-female feature of this part allows us to simply secure the spacers to the base of the box while providing a tapped hole for screws that will fix the platform on top. The next hardware component that will be discussed is the set of four screws that will be inserted into the hexagonal standoff spacers.

The last hardware part is the set of four screws (Item No. 3 in Figure 19) that will attach the platform to the standoff spacer. To ensure the security of this platform, we chose to go with M3 x 0.5 mm Extra-Wide Truss Head screws. We wanted to simplify the assembly process of the dashboard by choosing a relatively large diameter screw head rather than adding nuts or washers. However, we are aware that the dashboard may undergo lots of turbulence from a bike ride. Therefore, we plan on making improvements to our design if needed after further testing, such as incorporating vibration isolation washers or other hardware parts. In general, we plan on doing more testing in a lab and field environment and conduct force analysis to make sure all of the hardware components will satisfy our design requirements.

The Polycase enclosure will also house several electrical components necessary to the function of the final product. These components include a microcontroller, one to two vibration motors, a piezo speaker, and a battery to provide power for all of the components. Analysis indicates that the microcontroller and battery should be capable of driving the motors and the speakers, however additional components such as MOSFETS or external motor drivers may be required if testing indicates that the components are not receiving adequate power.

All components will share a common ground, while the battery should provide 5 volts to the microcontroller which will in turn provide power to each of the components as seen in Figure 20. Further detail for each of these components can be found below in the Component Selection section.

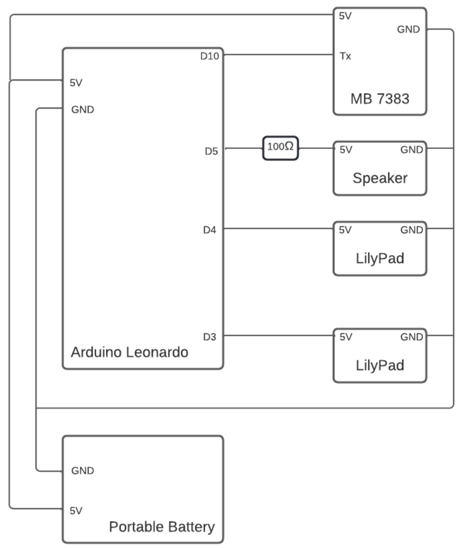

Figure 20. Electrical Component Diagram

The microcontroller will communicate with these peripheral components through software. As seen in Figure 21, this software will oscillate between two distinct states. In state zero, the ultrasonic sensor will be used to obtain a distance measurement. After a distance has been measured, onboard processing will determine if any detected object is within a predetermined range. Current analysis indicates that this range should be 9 meters to account for processing time and user reaction time. If there are no objects detected within range, another distance measurement will be taken.

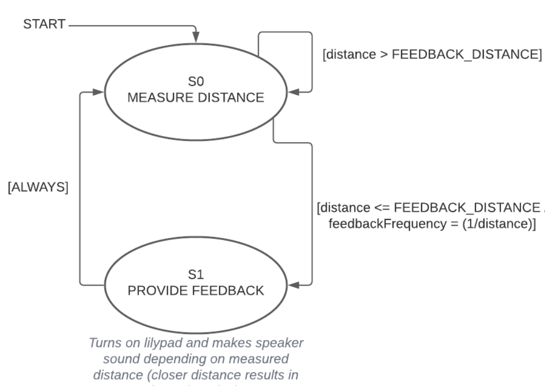

Figure 21. Software Flowchart

If however an object is detected within range, the code will proceed to state one where feedback will be provided to the user. This feedback will take two forms, vibration from the Lilypad Vibe Boards and audible beeps from the piezo speakers. The vibrations will either be "on" or "off" depending on whether an object is within the specified range, however the audible beeps will occur more frequently as the measured distance decreases.

After feedback has been provided, the code will return to state zero to obtain another distance measurement. These oscillations between states will occur at a frequency of 6 hertz in order to provide an adequate response time for the user.

Analysis Results

Analysis was conducted to determine the required measurement distance, sensor range, battery capacity, and minimum battery current output. Assuming a processing time of one second and an additional user reaction time of one second, it was determined that the minimum range for the sensor is 9 meters with a minimum measurement frequency of 4.2 hertz. It should be noted that both of these assumptions are somewhat conservative and additional testing will be required to achieve more accurate results.

In order to determine the minimum required battery capacity, it was assumed that each component would draw its maximum rated current for the entirety of the 10 hour engineering requirement stated earlier. Real world conditions would likely result in significantly lower current draw from the battery, extending the charge life significantly. With these assumptions, analysis indicates that a 4860 mAh battery capable of outputting 0.486 amps will be sufficient, however more testing could likely lower these requirements significantly. For more details, see Appendix L.

Cost Breakdown

The cost for our final design can be seen below in Table 2. Including all critical components, the prototype costs approximately $314.01. There are still minor components, such as screws and 3-D printed components that will add to the final cost of the prototype. We estimate the cost of these additional materials to be under $50, keeping the final prototype at a cost of approximately $365. This leaves $135 of our budget for any necessary adjustments in the testing phase of development.

In the future, our prototype could be developed further as an application for other visually impared bikers. For mass manufacturing, many of the costs could be reduced. The sensor company offers price reduction on mass orders bringing the cost of the sensor down to about

$88. Polycase, the manufacturer of the enclosure, also offers cost reductions in bulk bringing that cost down to $19.28 per unit. The mosfet we are using ships in lots of ten. Currently, we are not using the other nine but in mass manufacturing, all of the pieces would be used bringing the cost of that item down ten fold. For the remaining components, mass manufacturing would reduce shipping costs and may be able to get further price reductions with the vendors.

Table 2: Bill of Materials with Cost Breakdown

Item Name	**Vendor (with hyperlink)**	**# Units**	**Unit Cost ($)**	**Shipping Cost ($)**	**Total Cost ($)**	**Order Date**	**Delivery Date**
MB7383, HRXL-MaxSonar-WRLST	MaxBotix	1	131.95	12.56	144.51	01/25/22	01/31/22
AT-1750 Speaker	Digi-Key	2	1.42	7.45	10.29	01/26/22	02/01/22
Lilypad Vibe Board	SparkFun	2	7.50	10.59	25.59	01/26/22	01/29/22
WC-34 Clear Case Box	Polycase	1	29.45	18.12	47.57	01/26/22	02/01/22
Tc4428 Mosfet	AliExpress	1	2.90	1.79	4.69	01/26/22	02/15/22
Arduino Leonardo without Headers	Arduino	1	18.40	3.95	22.35	01/26/22	02/02/22
Adafruit Breadboard (3 pack)	Amazon	1	17.65	0.00	17.65	01/26/22	01/30/22
Miady 2 Pack Portable Charger	Amazon	1	16.99	0.00	16.99	01/26/22	01/30/22
Marine Heat Shrink Tubing	Amazon	1	14.57	0.00	14.57	01/26/22	01/30/22
Sugru Adhesive Putty	Amazon	1	9.78	0.00	9.78	01/26/22	01/30/22
Total Prototype Cost					**314.01**		

Materials and Geometry

Material selection was critical for components such as the dashboard, speaker cone, Ultrasonic sensor, and Foam Lining. The primary consideration for most components was to have weather resistance which was satisfied by the dashboard, ultrasonic sensor housing and Lily pad. For the items that were not weather proofed such as the electronics and wiring, we will enclose the items within the dashboard and use marine shrink tubing for additional sealed protection of the wires. The dashboard itself is made from Polycarbonate, a material that is UV stabilized, impact resistant and durable. This material will not only limit the amount of damage that can result from being dropped, but the UV resistance allows for heat from extreme high temperatures to be dispersed at low levels. This effect will keep our electronic components from heating up while in use. The speaker cone will be made out of the same material and therefore have a similar effect as it will be exposed to the outside. The ultrasonic sensor is made out of PVC housing and meets the water intrusion standard common in standard PVC pipe fittings. Lastly, we may install a foam core lining around the inside surface of the dashboard to dampen vibrations from the bike and ensure items don't jostle around and break.

In addition to selecting appropriate materials, the physical geometry of the components is an important consideration as well. The dashboard is one of the major components that required geometry consideration. The geometry of the dashboard was chosen because this geometry is the most optimal in terms of the amount of space provided to store multiple components. Additionally, a cube proved to be the easiest shape to attach to the bike compared to other shapes. After receiving feedback from our customer, we also constrained the dimensions of this component since all of the components stored within the enclosure will not take too much space therefore a larger enclosure would take up space on the handlebars for no reason. Within the dashboard, is the platform that sits on the spacers and holds the battery. In order to allow the platform to easily slide into the dashboard, we designed the outer boundary of the platform to match the wall design to account for the fileted edges. As for the components store within the dashboard, since we purchased each item from another source, no geometry considerations were required. Lately, the speaker cone geometry was based off of the previous Smart Bike product since our customer was satisfied with the quality of the previous design. A detailed drawing of this component can be found in Appendix M.

Component Selection

a) *Polycase WC-34*

This case, seen in Figure 22, was selected because it is relatively compact while still having room for all of the electrical components as well as the battery, negating the need for two separate housings. Further, the polycarbonate material is UV resistant and seals such that it is water tight, allowing the user to commute in a variety of weather conditions. Finally, the clear lid to the enclosure ensures that the user can view the state of charge of the battery as it charges or discharges without having to remove the lid.

Figure 22. Polycase WC-34

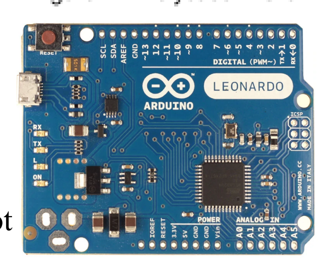

Figure 23. Arduino Leonardo

b) *Arduino Leonardo*

This microcontroller, seen in Figure 23, while not particularly "top of the line" is more than adequate for this project. Due to the relative simplicity of the software, the speed or processing power of the microcontroller used is not a concern. Additionally, the customer's familiarity with Arduino microcontrollers and software offer additional peace of mind moving forward. Ideally, the customer should never need to access or change the code on the controller, however through the use of familiar components, the customer may make changes in the future if he deems it necessary or if his needs change.

c) *Maxbotix 7383*

This ultrasonic sensor, seen in Figure 24, has a maximum range of 10 meters with a measurement frequency of 6 hertz (6 measurements per second). Both of these criteria surpass the calculated requirements of a 9 meter maximum range and a 4.2 hertz measurement frequency. Additionally, this sensor–unlike competing LIDAR sensors such as the RPLIDAR range–works well in daylight conditions and has no moving parts. This, coupled with UV and water resistance, make this sensor durable enough to withstand any perceivable weather conditions and any vibration or impact experienced through the customer's daily bike commute.


Figure 24. Maxbotix 7383

d) *AT-1750 Piezo Speaker*

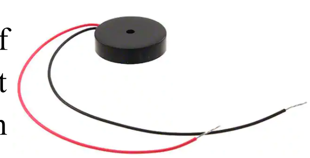
Figure 25. AT-1750 Piezo Speaker

This speaker, seen in Figure 25, has a maximum rated output of 80dB and an input voltage of up to 10 volts. This output exceeds the required minimum output of 70dB. The maximum input voltage of 10 volts means that the microcontroller selected will be able to power the speaker at 5 volts, however will not be able to achieve the maximum rated sound output of the speaker. Initial testing with sound amplification devices such as speaker cones have been promising, however further testing is required to determine whether a booster board such as the Tc4428, seen in Figure 26, will be required.

Figure 26. Tc4428 Board

e) *LilyPad Vibe Board*

These compact vibration motors, seen in Figure 27, have a rated vibration amplitude of 0.8 G with an input of 3 volts. This is above the target amplitude of 0.5 G, and these motors will be driven at 5 volts which may result in even higher amplitudes of vibration. If testing indicates that this level of vibration is uncomfortable, a resistor


Figure 27. LilyPad Vibe Board

may be placed in series in order to lower the voltage to an acceptable point. It is unlikely that this will be an issue however as the motors themselves will not directly contact the user's hands.

f) *Miady 5000mAh Portable Battery*

This portable battery, seen in Figure 28, is relatively compact, allowing it to fit securely within the selected housing while also providing a battery capacity of 5000mAh at 5 volts, with a maximum current output of 2.4 amps. These specifications exceed the calculated minimum requirements of 4860mAh and 0.486 amps respectively. Additionally, because this is a portable battery pack rather than a standalone lithium ion or lithium polymer battery, it comes equipped with ports for simple charging and discharging with common USB cables as well as a battery indicator light for the user to easily determine the state of charge. These additions make the battery significantly more user friendly than traditional battery alternatives.

Figure 28. Miady Portable Battery

Safety Considerations

Appendix N shows a checklist of special safety considerations used to evaluate any potential safety concerns the product could involve during manufacturing, assembly, and testing. The list reviews some of the hazards to be considered such as effects of extreme weather, large power supply, moving masses and more. Based on this list, our final product has the potential of falling under gravity creating injury, being exposed to environmental conditions such as fog, humidity and cold and hot temperatures. Other than these concerns, our system proves to be more safe than unsafe for all aspects from manufacturing to testing. For the concern of a falling system, we plan to secure the dashboard at critical points to ensure its range of motion is restricted while our customer is commuting. More testing will be done to analyze how this method of attachment will be affected by turbulence from the bike. The dashboard is also made from a durable, impact resistant polycarbonate material which will limit the amount of impact the dashboard will take on in the case it does fall. As for weather, the dashboard will keep all major electrical components stored safely from most weather conditions. The sensor and the speaker are the only components that will not be fully enclosed in the dashboard, however, their orientation on the dashboard and surrounding cones, will protect them from these extreme weathers.

Maintenance and Repair Considerations

The maintenance and repair for the prototype was considered in terms of the enclosure and access to components within. Currently, our group has designed for the battery to be able to be charged from the exterior of the enclosure. This will allow for minimal maintenance to the interior of the box because access would be more limited. This in mind, access to the interior of the box includes unscrewing the four core screws with a phillips head screwdriver. From there, the customer will be able to make alterations to the upper tier of the box easily. To reach the bottom tier, the customer will need to unscrew and lift off the platform. We decided on a two tiered approach to the enclosure because the item needing to be accessed most is the battery. We wanted our customer to have the ability to remove and replace it as they see fit. The bottom tier contains the majority of the electrical components and is also relatively easily accessed. Here, the customer would be able to adjust elements on the breadboard or upload new code to the microcontroller. Because our customer, Mr. Higgins, has knowledge and background in working with other electrical projects similar to this, we wanted him to be able to easily make adjustments to the entire product. In terms of user maintenance, the entire product and its components within can be accessed using a single screwdriver, and the portable battery can be replaced once it is at the end of its lifecycle.

Sustainability

In order to create an environmentally sustainable prototype that meets the needs of our customer, we used many of the 7 Design for Environment aspects mentioned in lecture to ensure our product is both functional and sustainable. The first of the 7 Design for Environment aspects that was used in the final design was minimizing material usage. The design minimizes housing size and keeps the number of components to a minimum. This allows for the design specification of housing size to be met while keeping materials used in the design to the smallest number possible. The majority of the components in our final design are non-hazardous. In order to minimize hazardous materials, the only potentially hazardous component in our design is the battery. The next two Design for Environment aspects, design for disassembly and design for refurbishment, go hand in hand in this product. Our customer, Mr. Higgins, has previous experiences in working with different sensors for the purpose of his Smart Cane. Because of this experience we designed the product to be easily disassembled so in the future, he can maintain and make updates if he sees fit. This in turn leads to a design that is meant to be refurbished. The final of the 7 Design for Environment aspects that was used in the final design was design for recycling. Many of the components in our final design could be used in the future for other projects. Items like the speakers and speaker cones, lily pads, battery, and sensor could all be used in a variety of different products if the Smart Bike is no longer in use.

Product Realization

Updates to Final Design

During initial testing of the proposed design, it became clear that a single ultrasonic sensor would not adequately satisfy the requirements of this project. The ultrasonic sensor was rated for a range of 10 meters, however object detection was unreliable at this range. Additionally, the internal processing time of the sensor was too high and resulted in the prototype feeling sluggish while biking. An additional LIDAR sensor was added to the design to address these issues. Upon further testing with the two sensor system, speed and detection distance were improved without sacrificing the wide detection angle inherent to the ultrasonic sensor. In order to mount the additional sensor, a smaller box was mounted to the bottom of the primary box. The prototype with the additional sensor and housing hardware can be seen in figure 29 below.

Additionally, a latching power switch was added to the side of the prototype to allow the user to easily switch the entire device on or off. This can also be seen below in figure 29.

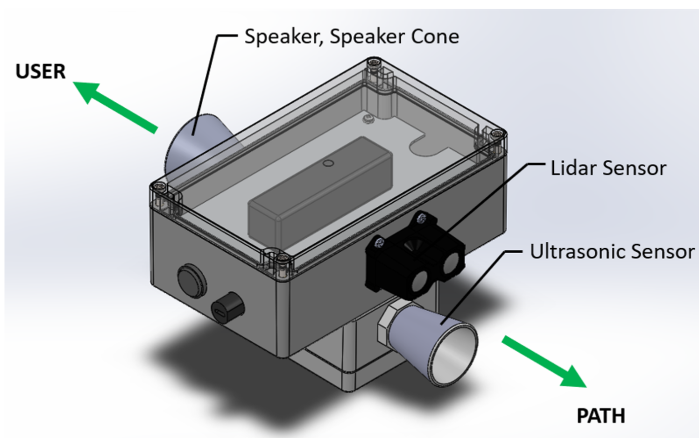

Figure 29. Updated Prototype with Additional Hardware

The MOSFET driver used to increase the volume of the piezo speaker was removed as it was determined that it was unnecessary in order for the prototype to meet the required specification. Additionally, including the MOSFET driver resulted in an audible “clicking” sound which could be distracting during use. The updated electrical component diagram can be seen below in figure 30.

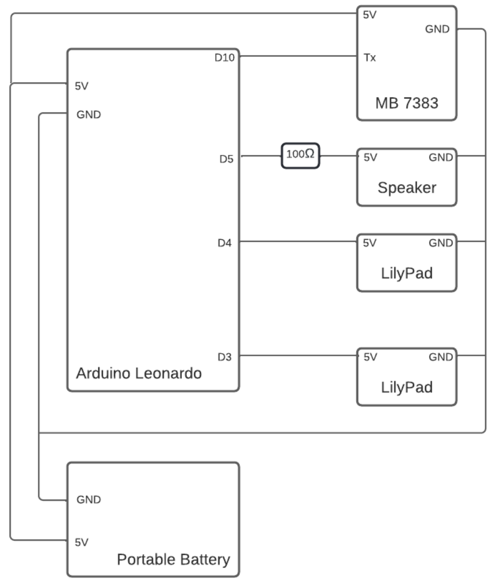

Figure 30. Updated Electrical Component Diagram

To mount the device to the handlebar riser, L brackets were added to increase the number of points of contact as well as to provide mounting hardware that would be stressed normally rather than purely in transverse shear. To ensure that the device would fit with the handlebar risers, various spacers were added to the design as well. See Appendix J and K for the vertical and horizontal attachments along with the corresponding bill of materials for this attachment. Additionally, Nyloc nuts were used with every bolt to limit the risk of road vibrations loosening the nuts over time.

Description of Manufacturing Processes

The speaker cone was one of the primary components manufactured through 3D printing as seen in the CAD model in figure 31. See Appendix M for the dimensioned drawing of the speaker cone. Using AutoCAD, a cone was modeled and used to amplify the sound from the piezo speaker. Additionally, a hole was drilled in the primary box and used to route the speaker wiring through the base of the speaker cone to the electronics within the dashboard. For this component, Cal Poly's Innovation Sand Box was used to manufacture this part using a Polycarbonate material which offers durability and UV resistance. Additionally, a smooth surface finish was used for a better quality of sound and overall presence.

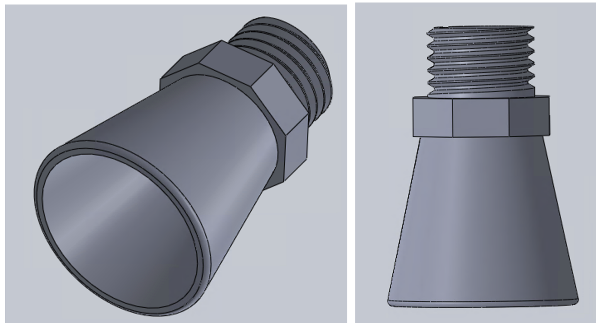

Figure 31. Speaker cone CAD Model

The second component manufactured was the platform, which helps with the organization of components by dividing the dashboard into two levels. Figure 32 below displays the CAD model for this platform.

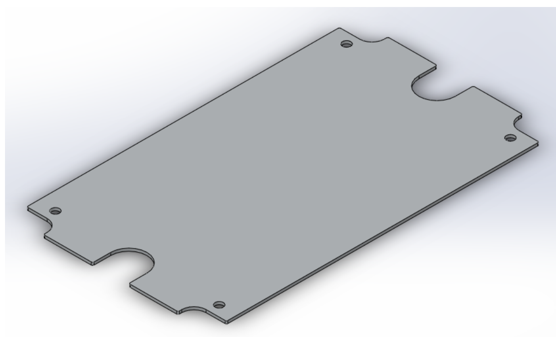

Figure 32. Platform CAD Model

The platform dimensions were obtained from an existing, compatible product from the Polycase company named “WX-30 Panel for WA/WP/WC Series Enclosures” (Part number: WX-30). The platform has two holes on each side along the center width of the platform, which can be used to lift up and/or remove the platform from the enclosure. This component was manufactured using a laser cutting machine to cut an acrylic sheet. Manufacturing this part was done using Cal Poly’s Mustang 60 shop which required no additional cost apart from the material itself. See Appendix O for a detailed drawing of the platform.

In order to attach the speaker cone, LIDAR sensor, power switch, and battery charging port to the dashboard, holes were drilled in the primary enclosure. The CAD model of the enclosure base is shown in figure 33 below. A detailed drawing of this component can also be found in Appendix P. Using the existing threads on each part and hex rings, these components were attached to the enclosure.

Additional holes were drilled in the bottom of the primary enclosure to allow the smaller secondary enclosure and the ultrasonic sensor to be mounted as well. These holes can also be seen in figure 33 below.

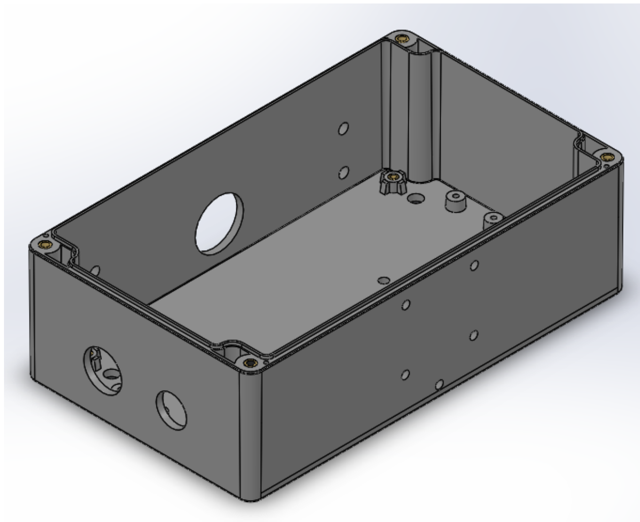

Figure 33. Primary Enclosure Base CAD Model

A smaller secondary box was included with holes drilled for the ultrasonic sensor and mounting holes which aligned with the holes drilled in the primary enclosure. These can be seen in figure 34 below. A detailed drawing of this component can also be found in Appendix Q.

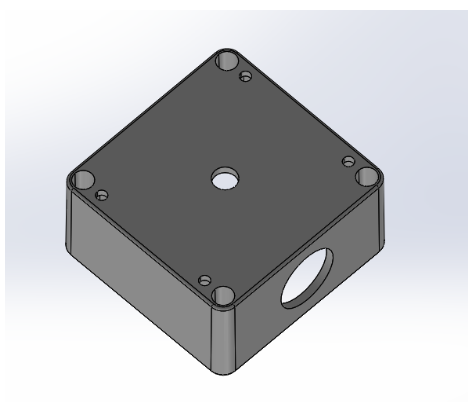

Figure 34. Secondary Enclosure Base CAD Model

In order to mount the device to the handlebar risers, two holes had to be drilled into each L bracket to provide the correct mounting locations for the bolts. See figure 35 for CAD model of Bracket and Appendix R for the detailed drawing. Eight holes had to be drilled into the primary enclosure to mount to the L brackets. With all of these holes drilled, the components could be assembled and mounted to the bike as seen in Appendix H.

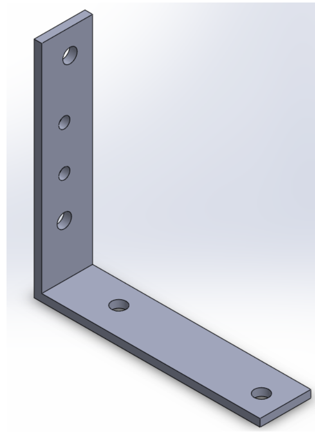

Figure 35. L Bracket CAD model

Internally, all electrical components were soldered with 22 gauge stranded wire to a solderable breadboard and from this board to the Arduino. Additionally, all wires were protected using marine grade heat shrink tubing. A snapshot of the soldering process can be seen in figure 36 below.

Figure 36. Soldering Electrical Components

Software Development

After several iterations, the software was refined to take in measurements using the ultrasonic and LIDAR sensors and then to provide feedback through the speaker and vibration motor based on whichever measured distance was smaller. This measurement and feedback process occurs at a frequency of approximately 5 Hz. The audible feedback was designed to use the distance to the nearest obstacle to modulate both the pitch and time interval between audible beeps.

Additionally, the code was documented in detail and set up in such a way that a user reasonably familiar with the Arduino IDE would be able to easily modify certain parameters such as the maximum detection distance and time interval between audible beeps.

Recommendation for Future Manufacturing

A future iteration of this project would be well served investing some time rethinking the placement of the drilled holes. One difficulty with assembling the various components of the device is accessing each of the bolts and screws to tighten or loosen. Additionally, manufacturing sturdier threads on the speaker cone would allow this component to be mounted more easily. Finally, when drilling larger holes in the polycarbonate cases, it would be beneficial to use a step bit to ensure that the proper size can be obtained.

Cost Estimation for Future Production

Table 3: Bill of Materials with Cost Breakdown for Updated Final Design

Item Name	**Vendor (with hyperlink)**	**# Units**	**Unit Cost ($)**	**Shipping Cost ($)**	**Total Cost ($)**	**Order Date**	**Delivery Date**
Garmin Lidar Lite v3 HP	Garmin	1	149.99	13.12	163.11	03/29/22	04/03/22
MB7383, HRXL-MaxSonar-WRLST	MaxBotix	1	131.95	12.56	144.51	01/25/22	01/31/22
Redcomets Bike Handlebar Extender	Amazon	1	79.99	0	79.99	04/07/22	04/11/22
WC-34 Clear Case Box	Polycase	1	29.45	18.12	47.57	01/26/22	02/01/22
Male-Female Threaded Hex Standoffs	McMaster-Carr	6	5.9	6.87	42.27	04/07/22	04/11/22
WP-31 Polycarbonate NEMA Enclosure	Polycase	1	18.25	9.46	27.71	04/28/22	05/05/22

Lilypad Vibe Board	SparkFun	2	7.5	10.59	25.59	01/26/22	01/29/22
Arduino Leonardo without Headers	Arduino	1	18.4	3.95	22.35	01/26/22	02/02/22
Adafruit Breadboard (3 pack)	Amazon	1	17.65	0	17.65	01/26/22	01/30/22
Miady 2 Pack Portable Charger	Amazon	1	16.99	0	16.99	01/26/22	01/30/22
Kydex Plastic Sheet Black	Amazon	1	14.99	0	14.99	04/28/22	05/01/22
Marine Heat Shrink Tubing	Amazon	1	14.57	0	14.57	01/26/22	01/30/22
Silver White Reflective Vinyl Permanent Adhesive	Amazon	1	14.48	0	14.48	04/28/22	05/04/22
Steel Spring Lock Washer	McMaster-Carr	1	7.59	9.46	17.05	04/07/22	04/11/22
Kydex Plastic Sheet	Amazon	1	13.73	0	13.73	03/29/22	04/04/22
Metric 18-8 Stainless Steel Pan Head Phillips Screws	McMaster-Carr	1	5.51	0	5.51	04/07/22	04/11/22
Charger Extension Cord	Amazon	1	11.98	0	11.98	03/29/22	04/03/22
AT-1750 Speaker	Digi-Key	2	1.42	7.45	10.29	01/26/22	02/01/22
Sugru Adhesive Putty	Amazon	1	9.78	0	9.78	01/26/22	01/30/22
On/Off Switch	Amazon	1	9.59	0	9.59	03/29/22	04/03/22
Micro USB Cable	Amazon	1	7.99	0	7.99	03/29/22	04/03/22

Velcro Strips	Amazon	1	5.99	0	5.99	03/29/22	04/03/22
Sigma Electric ProConnex Locknuts	Amazon	1	5.36	0	5.36	04/07/22	04/11/22
L Brackets	Ace Hardware	2	2.79	0	5.58	N/A	05/03/22
Handlebar Wrap	SLO Bike Kitchen	1	0	0	0	N/A	05/05/22
Handlebar Rod	SLO Bike Kitchen	1	5	0	5	N/A	05/05/22
M5-.80x20mm Screw	Ace Hardware	2	0.85	0	1.7	N/A	05/22/22
M5-.80x30mm Screw	Ace Hardware	2	0.99	0	1.98	N/A	05/03/22
M5-0.80 Nylock Nut	Ace Hardware	4	0.59	0	2.36	N/A	05/03/22
1/4-2" Screw	Ace Hardware	4	0.65	0	2.6	N/A	05/25/22
White 3/16 Spacers	Ace Hardware	2	0.35	0	0.7	N/A	05/03/22
Black M6 Spacers	Ace Hardware	4	1.19	0	4.76	N/A	05/22/22
3/16 Washers	Ace Hardware	4	0.3	0	1.2	N/A	05/03/22
1/4-20 Nylock Nut	Ace Hardware	4	1.29	0	5.16	N/A	05/25/22
M4-.80x35mm Screw	Ace Hardware	2	0.85	0	1.7	N/A	05/03/22
M4-0.80 Nylock Nut	Ace Hardware	2	0.55	0	1.1	N/A	05/03/22
M5-0.80x16 Screws	Ace Hardware	2	0.6	0	1.2	N/A	06/03/22
6-32 Nylock Nut	Ace Hardware	8	0.35	0	2.8	N/A	06/04/22
Total Prototype Cost					**762.89**		

Table 3 shows the final cost of the updated final design. As previously mentioned, for mass manufacturing, many of the costs would be reduced. The only costs that may increase would be for the handlebar wrap and rod that were acquired at the SLO Bike Kitchen. The handlebar wrap was gifted to us and the rod was sold to us for $5.00. When manufacturing, these items would likely need to be purchased from a manufacturer.

The ultrasonic sensor company offers price reduction on mass orders bringing the cost of that sensor down to about $88. For the handlebar extender, only the riser pieces were used in the final prototype, not the handlebar rod and charging unit. For mass manufacturing, a different product could be purchased with only the two riser components which would be less expensive. Polycase, the manufacturer of both enclosures, also offers cost reductions in bulk bringing that cost down to $19.28 per unit for the larger box and $9.19 for the smaller one.

Many of the components came in larger packs which were not all included in the final product. The breadboards came in a pack of three but only one was used in the final design. We ordered two portable chargers but only used one. The heat shrink material came in a pack of 180 pieces but only about eight were used. The steel spring lock washer and the metric 18-8 screws both came in packs of 100 but only four of each were included. The Surgu came in a pack of three and in our manufacturing we used about one of them. The on-off switches came in a pack of five of which we used one. The micro USB cables came in a pack of six which we used one of. The velcro came with eight strips of which only two were used. Finally the locknuts came in a pack of 20 and we used a total of two.

With the above reductions of cost taken into account for mass manufacturing, an estimate for the individual cost of each unit of our final product would be approximately $511.31. For the remaining components, mass manufacturing would reduce shipping costs and may be able to get further price reductions with the vendors however the estimate for this would be dependent on each vendor.

Design Verification (Testing)

Attached in Appendix S is a list of our verification and test plan which includes results and timing for each test. Testing was conducted to verify that the prototype met the specified requirements, each of which is detailed below.

Sensor Range

The range of the sensors were tested at various distances against static objects such as flat walls and cars. The ultrasonic sensor had a maximum range of 10 meters but produced unreliable results above 8 meters. The LIDAR sensor was tested up to 15 meters with unreliable results below 2 meters. This testing process can be seen below in figure 37.

Figure 37. Sensor Range Test

Audio Feedback

The sound intensity of the audible feedback produced by the speaker was measured using a variety of different smartphone dB meter apps. These apps all produced similar readings of approximately 79 dB when the cell phone microphone was held directly next to the prototype's speaker cone.

The apps used included Decibel: dB Sound Level Meter, Decibel X: dB Sound Level Meter, and Decibel Meter Pro.

Tactile Feedback

The tactile feedback was measured qualitatively by mounting the prototype to the bike and observing whether or not the vibrations could be felt while holding the handlebars. A variety of mounting options were tested and it was determined that the vibrations were the most intense when the lilypad motors were mounted rigidly to the inside of the prototype.

Detectable Object Size

To determine the detectable object size, a variety of different objects were placed in front of the prototype at several different distances from the center. The smallest object tested was a cell phone with dimensions of approximately 8 x 15 cm. Objects were dangled from a broom handle to avoid detecting the person holding the object by mistake. At a distance of 9 meters from the prototype, the cell phone was detected although it should be noted that the prototype had to be aligned precisely to detect the object.

Detection Angle

In order to test the detection angle, the ultrasonic sensor was held a known distance from a wall and an object was moved slowly from the outside closer to the center until it was first detected. The distance between the sensor and the point at which the object was first detected was recorded and used to calculate the effective detection angle of the ultrasonic sensor. From this test, the detection angle was determined to be approximately 16 degrees in the horizontal direction and approximately 10 degrees in the vertical direction. Figure 38 below shows the testing setup.

Figure 38. Detection Angle Test

Specification Verification Checklist

Table 4, shown below lists the required design parameters along with their requirements, the final solutions to those requirements, and whether or not the final design meets the specified targets.

Table 4. Verification of Engineering Specifications

Spec. #	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance	Current Selected	Meets Target?
1	Sensor Range	9 (m)	MIN	H	T	10 (m)	Y
2	Sensor Notification Range	7 (m)	+-1 (m)	H	T	7 (m)	Y
3	Audio Feedback	70 (dB)	+- 10 (dB)	H	T	79 (dB)	Y
4	Tactile Feedback	Detectable	MIN	M	T	Detectable	Y
5	Sensor Scan Rate	4.2 (hz)	MIN	H	T	6 (hz)	Y
6	Weight	10 (kg)	MAX	L	I	1.74 (kg)	Y
7	Dashboard Size	5 x 25 (cm)	+- 5 (cm)	M	I	12 x 20 (cm)	N/A
8	Blind ID Sign Size	21 x 28 (cm)	+- 5 (cm)	H	I	5 x 11 (in)	N/A
9	Detectable Object Size	40 x 61 (cm)	MIN	H	T	8 x 15 (cm)	Y
10	Electrical Housing Size	64 (cm^2)	MIN	M	I	N/A	N/A
11	Dashboard to Person Distance	51 (cm)	+- 8 (cm)	M	I	N/A	N/A
13	Battery Lifespan	2 (years)	MIN	L	A	15.8 (years)	Y
12	Sensor Lifespan	10 (years)	MIN	L	A	26.6 (years)	Y
14	Battery Length	10 (hours)	MIN	H	A	10.3 (hours)	Y
15	Hand Grip Length	10 (cm)	+- 0.5 (cm)	L	I	25 (cm)	Y
16	Impact Force for Collision	500 (N)	+- 400 (N)	L	A	126 (N)	Y

It should be noted that some items have been marked as no longer being applicable. The need for an electrical housing has been removed as the electronics now reside within the dashboard. The combined dashboard and electrical housing make the previous target dimensions meaningless. Additionally, the blind ID signage size was updated to adhere to the customer's specified dimensions and as such, the old targets no longer apply. Finally, the dashboard to person distance varies between bicycles and as such cannot be fully tested prior to delivery of the product. It should be noted that this parameter is adjustable and should not be an issue as the customer will be able to match their needs. The deviations from the final design experience from the initial targets have been approved by the sponsor and therefore are considered acceptable.

Conclusions and Recommendations

The fundamental design requirements were met to identify objects, notify the rider and protect components from weather conditions. The final design passes all of the formal design specifications set at the beginning of the project with a few minor adjustments noted in the previous section. While certain stretch goals such as a cowling to protect the rider from wind and weather conditions were not implemented, other improvements were made that were not included in the original problem statement. The inclusion of a latching power switch, an external charging port for the battery, a reflective and durable material for the "blind" signs, and user adjustable software are just a few examples of how this device exceeded the specified expectations of the project.

Future considerations for this project would include adding a cowling as mentioned previously, manufacturing a speaker cone with more robust threads, and a calibration system to ensure that the sensors are oriented properly on the bike. While none of these are critical, they would all make the device more functional or more user friendly. Additionally, after receiving feedback at the project expo, many people expressed concerns that the speaker was not loud enough. While testing indicates that the current speaker system passes the specified requirements, this could be a welcome inclusion in a future version of the project.

Acknowledgments

The authors would like to thank the Sencycle team for their excellent work on the previous iteration of the "smart bike" project. Their work provided a substantial foundation and body of knowledge upon which we were able to build and develop in our own directions. In addition, we would like to thank the TECHE lab for funding this project and being so amenable to increasing the budget when it became clear the initial estimate would not be enough to realize our goals. Finally, and perhaps most importantly, we would like to thank Mr. Higgins for his support along the way and his valuable feedback at every stage.

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<u>Appendix</u>

A. List of Common Identifiable Objects
B. House of Quality
C. Design Process Map
D. Higgins Handlebar and Dashboard Organization Concept Sketch
E. Morph Chart for Initial Brainstorming
F. Pugh Matrices
G. Hand Calculations for Concept 2
H. Dashboard Enclosures without Components Exploded View
I. Dashboard Enclosures with Components Exploded View
J. Dashboard Vertical Attachment Exploded View
K. Dashboard Horizontal Attachment Exploded View
L. Hand Calculations
M. Detailed Drawing of Speaker Cone
N. Design Review Hazard Identification Checklist
O. Detailed Drawing of Platform
P. Detailed Drawing of Enclosure Base
Q. Detailed Drawing of Bottom Enclosure
R. Detailed Drawing of L Bracket
S. Verification and Test Plan
T. Gantt Chart

Appendix A: List of common Identifiable objects

Technical specifications

22“ Clear path navigation 10 degrees in front of user.
Additional sensory information
Object detection and avoidance - center part of the body
Auditorily feel objects in front of you

INSPEX - Safety cocoon
Pedestrian -
Outdoors
Objects;
person 18”- 22”x 5’ 6”
Trash can 28” X 53”. (23” x 46”)
24” x 44”
Recyclable 30” x 45”
Sandwich board. 26” x 28” XT 44”
mailbox 20” x 21” x 50”. (16” X 36”)
Fire hydrant. 16”x 24”. (34”)(32”)
Sandwich board sign
For sale signs
park bench 20” x 30” x 40”
bus stop walls 14’ x 45” x 7’ 4”
Chain link fence
Guide wire 1/2 “ steel cable
Open gate
Steel cable guide wire
Children
Pets
5 gallon bucket

Signs
Private mail box
Fence railing
Tables - (28”). 30”
Chairs
Fancy garbage cans 28” x 39”
VA garbage can 22” x 41”
Newspaper stands 49” x 17” x 51”
Flower pots 24” x 32”
Tree. 12”
Tree branch / limbs
Rosebush

Orange construction cone. 28” x 14” x 14”
Orange construction tube 42”
Wet floor sign. 25” x 11” X 12”

Poles. 5”, 7”, (10”, 11” wooden pole)

Indoors
Doorways are 27” - 31” opening
Desk, Tables, and chairs

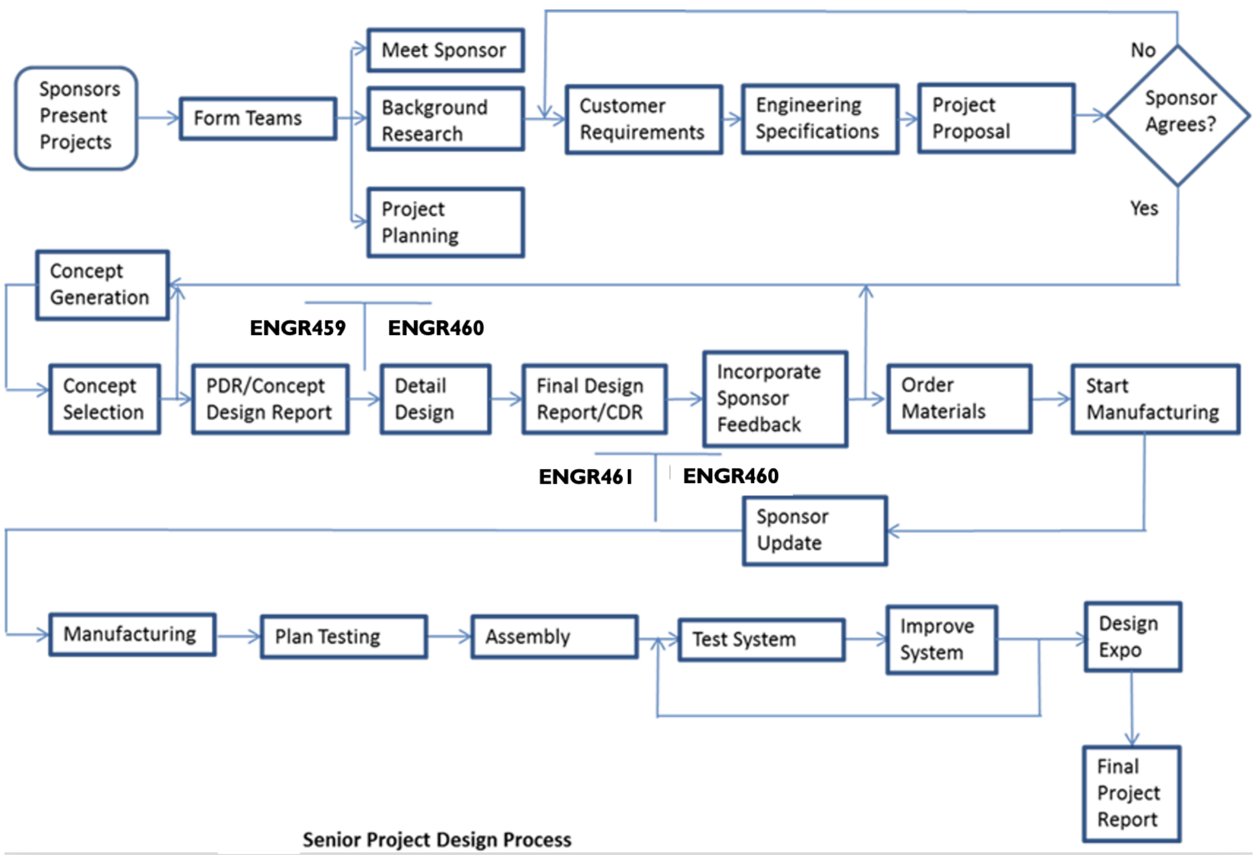
Appendix B: House of Quality

Engineering Requirements (HOWS) — Benchmarks

Mr. Higgins' Requirements (Whats) — Customer Requirements (Step #2)

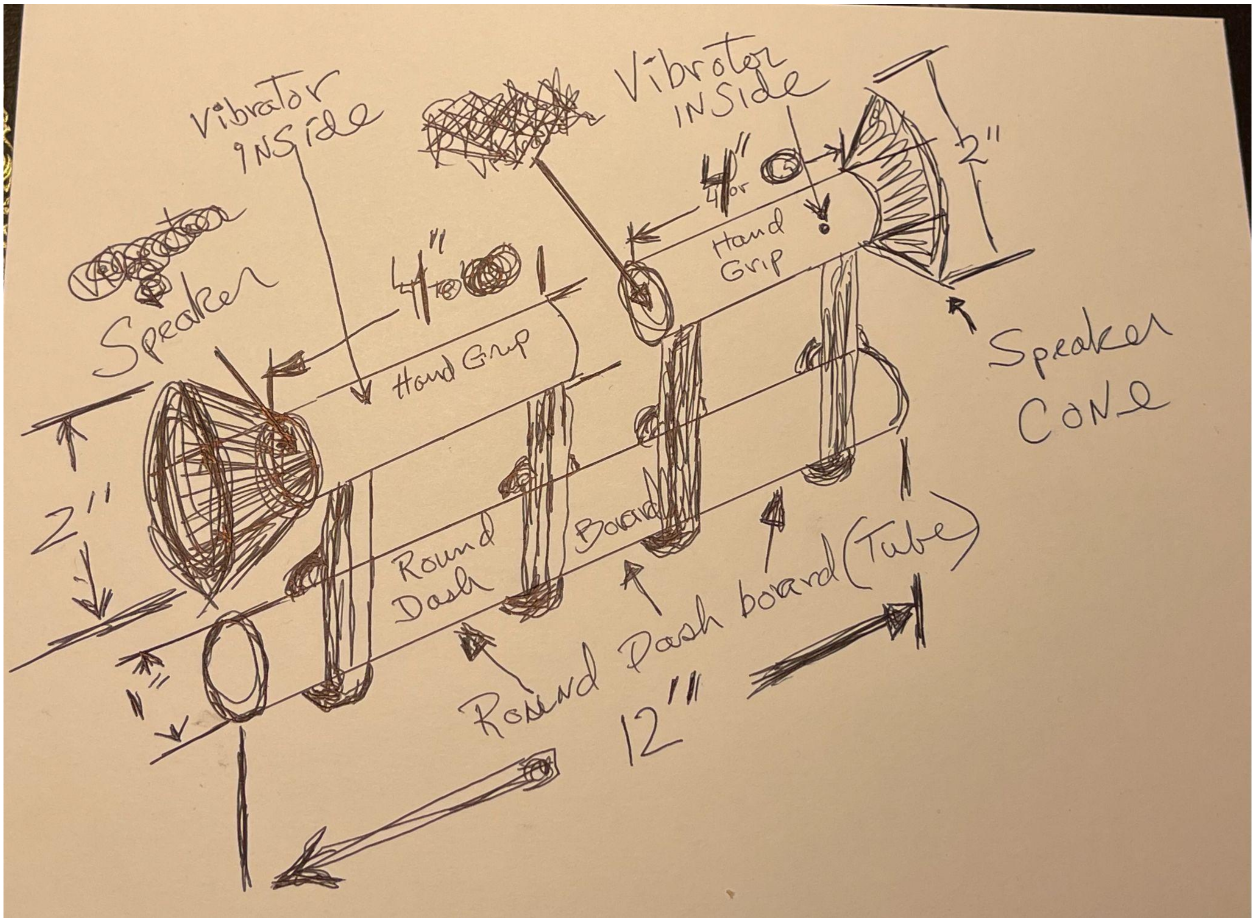
Category	Requirement	Weighting (1 to 5)	Sensor Range	Sensor Notification Range	Audio Feedback	Tactile Feedback	Sensor Scan Rate	Weight (Total - Bike)	Dashboard Size	Electrical Housing Size	Hand Grip Length	Detectable Object Size	Blind ID Sign Size	Maintenence Timeline	Impact Force from Collision	Dashboard-Person Distance	Sensor Lifespan	Battery Lifespan	Battery Length	Prototype 1	Ultrabike	Assisted Tandem Biking
Sensors	Works in the daytime & nighttime	5											9				9	9	9	1	5	5
	Detect moving objects (people/pets)	5	9	9			3					9					1			1	5	5
	Organization of wires	3								9	1		1	9	1		9	3		3	4	5
	Feedback to identify objects	5			9	9					9	1				9		9		3	3	5
	Detect static objects in path	5	9	9			3					9					1			1	5	5
Dashboard	Blind Rider identification (sign)	5						1	3	1	9		9		3				9	5	1	1
	Hand grips for comfort	4				9		1	1		9			3	3	9				2	1	1
	Accomodate bike lights	3						1		1	9		3							5	5	5
	Organized dashboard	5			3			1	3	9	9		9		3	3	3			2	1	1
	Phone holder with better hold	3								1	9		1	9	3	3				3	1	1
	Heat shrink wires	5								3				3	1		3	3	1	1	5	5
Cowling	Protection from weather	2						9	9	1	3			9			9	9		1	1	1
	Full enclosure	1						9	9	3	3				9	9	1			1	1	1
Miscellaneous	Weight	1						9	3	3	1		3		9					5	5	5
	Durability	3.5						9		3			1	9	9		9	9	3	2	5	5
	Safety bumpers	2						3	3						9		3			1	1	1
	Road compatibility	5	1	1	1		1	1	1			3				3				1	1	5
	Water resistance	3								3				9	3		9	9		2	2	5
	No need for outside assistance	5	9	9	9	9	3					9	3			3				1	2	1
	Units		m	m	dB	N	Hz	kg	cm^2	cm^2	cm	cm^2	cm^2	wk	N	cm	yr	yr	hr			
	Targets		8	7	70	0.2	10	10	5x25	64	10	1	21x28	4	500	51	10	2	10			
	Importance Scoring		140	140	110	126	50	96	75	126	238	155	172	158	136	144	196	191	106			
	Importance Rating (%)		59	59	46	53	21	40	32	53	100	65	72	66	57	61	82	80	44			

Appendix C: Design Process Map

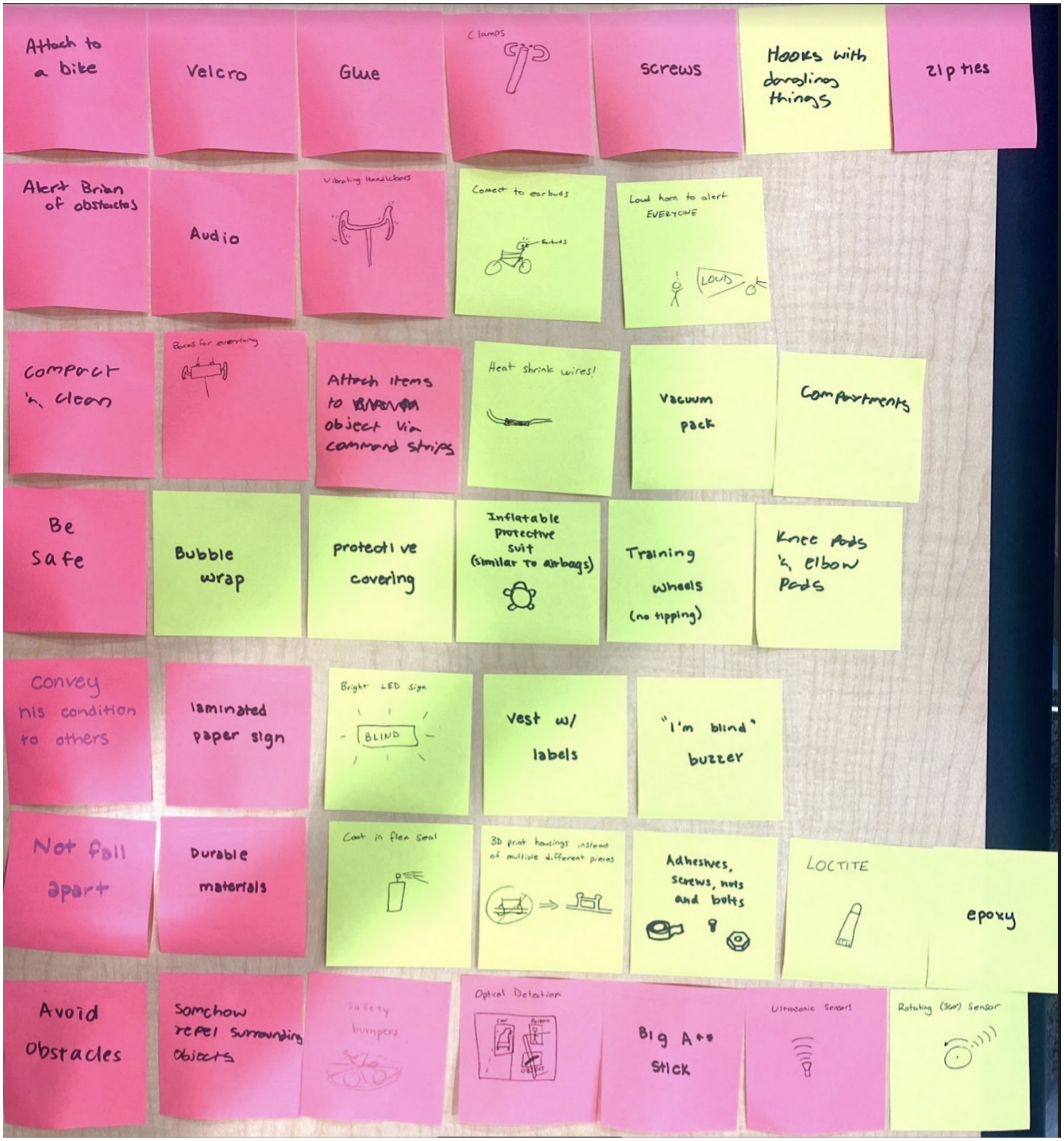


Senior Project Design Process

Appendix D: Higgins Handlebar and Dashboard Organization Concept Sketch

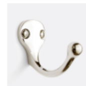


Appendix E: Morph Chart for Initial Brainstorming

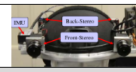
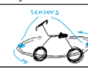


Appendix F: Pugh Matrices

Attachment to bike:

Concept	1. Velcro	2. Glue	3. Clamps	4. Hooks	5. Screws	5. Zip Ties
						
Criteria						
Safety	+	+	+	-	D	+
Compact	s	+	-	-	D	+
Stable	-	-	-	+	D	-
Detachable	+	-	+	s	D	-
Ease of Installation	+	+	+	s	D	s
Secure	-	-	-	-	D	-
Durable	-	-	s	+	D	-
SUM(+)	3	3	3	2	0	2
SUM(-)	3	4	3	3	0	4
SUM(s)	1	0	1	2	0	1

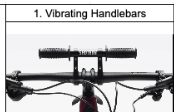
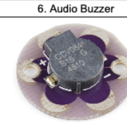
Avoid Obstacles:

Concept	1. Safety Bumpers	2. Ultrasonic Sensors	3. Rotating Sensors	4. Flashing Turn Lights	5. Sensor Feature on Helmet	6. Revolving Physical Boundary w/ Sensors
						
Criteria						
Safety	-	+	D	-	S	+
Reliability	+	S	D	+	S	-
Efficiency	-	+	D	-	-	+
Functionality	-	+	D	-	+	+
Durability	-	S	D	+	S	-
Usability	-	+	D	S	S	-
Weather Resistant	+	S	D	+	-	-
SUM(+)	2	4		3	1	3
SUM(-)	5	0		3	2	4
SUM(s)	0	4		1	4	0

Alert Pedestrians:

Concept	1. Laminated Paper Sign	2. LED Sign	3. Vest With Labels	4. Audio Declaring Condition
				
Criteria				
Visibility	D	+	s	-
Speed of Recognition	D	+	-	+
Not Space Invasive	D	s	-	+
Clarity	D	s	s	-
Cost	D	-	-	-
Ease of Production	D	-	s	-
SUM(+)	0	2	0	2
SUM(-)	0	2	3	4
SUM(s)	0	2	3	0

Alert User:

Concept	1. Vibrating Handlebars	2. Vibrating Gloves	3. Connect To Earbuds	4. Loud Speakers	5. Flashing Lights	6. Audio Buzzer
						
Criteria						Datum
Speed	+	+	+	s	+	
Efficacy	s	s	+	S	-	
Safety for Brian	s	+	-	s	-	
Safety for Pedes	+	+	-	-	-	
Comfort	-	-	-	s	s	
Annoyingness	+	-	s	-	+	
Reliability	+	+	+	+	-	
Ease of Use	s	-	s	s	s	
Ease of Impleme	-	-	-	-	s	
Durability	-	-	-	s	s	
SUM(+)	4	4	3	1	2	
SUM(-)	3	5	5	3	4	
SUM(s)	3	1	2	6	4	

Appendix G: Hand Calculations for Concept 2

Mechanical Engineering CAL POLY

Project CDR HAND CALCULATIONS Page ______ to ______

Author BIKE TO THE FUTURE Date 11/25/21

GOAL: DETERMINE OBJECT DETECTION RANGE

ASSUME: RIDER TRAVELS AT SPEED OF $V = 7\ m/s$ (~16 mph)

ALLOW REACTION TIME OF $\delta = 1\ s$

CALCULATE REQUIRED DETECTION DISTANCE:

$$d = V\delta$$

$$d = (7\ \tfrac{m}{s})(1\ s)$$

$$\boxed{d = 7\ m}$$

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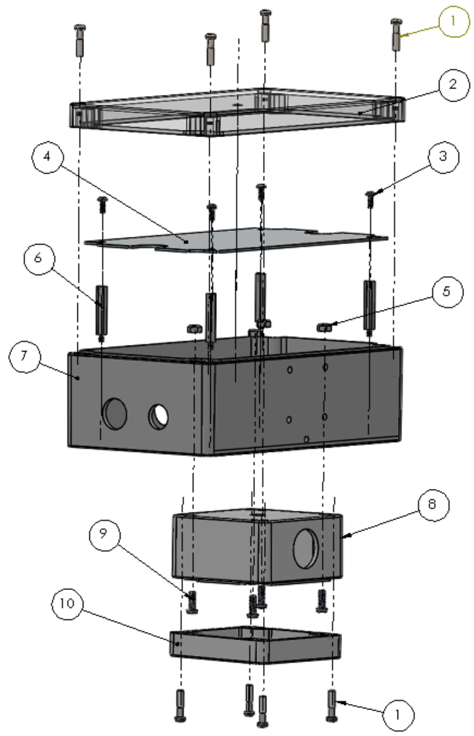
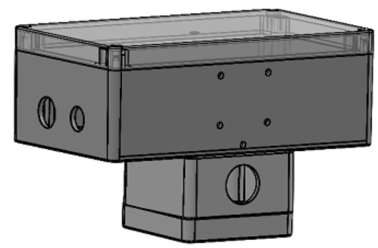
Appendix H: Dashboard Enclosures without Components Exploded View

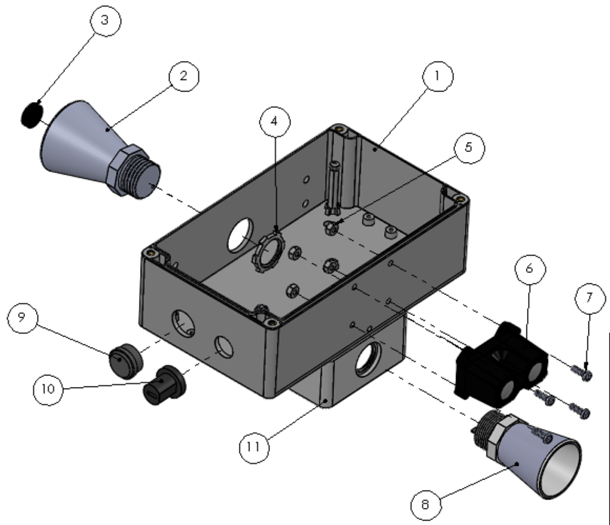


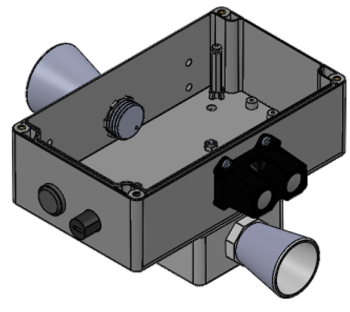


ITEM NO.	PART NAME	DESCRIPTION	MATERIAL	QTY.
1	SCREWS FOR ENCLOSURE COVER	SCREW TO SECURE COVER TO TOP ENCLOSURE. CAME WITH POLYCASE WC-34 ENCLOSURE	STAINLESS STEEL	8
2	CLEAR ENCLOSURE COVER	POLYCASE WC-34 OUTDOOR CLEAR COVER	POLYCARBONATE	1
3	18-8 PLATFORM SCREWS	PAN HEAD PHILLIPS SCREW FOR PLATFORM MOUNTING	STAINLESS STEEL	4
4	PLATFORM	MANUFACTURED USING DIMENSIONS PROVIDED BY POLYCASE ENCLOSURE.	ACRYLIC	1
5	6-32 NYLOCK NUT	NYLON-INSERT LOCKNUT FOR MOUNTING BOTTOM ENCLOSURE	STEEL	4
6	M3-35MMx6MM STANDOFF SPACER	MALE-FEMALE THREADED HEX STANDOFF	STAINLESS STEEL	4
7	TOP ENCLOSURE	POLYCASE WC-34 OUTDOOR ENCLOSURE	POLYCARBONATE	1
8	BOTTOM ENCLOSURE	POLYCASE WP-31 NEMA ENCLOSURE	POLYCARBONATE	1
9	6-33x1 /2IN SCREW	PHILLIPS HEAD SCREW TO ATTACH BOTTOM ENCLOSURE TO TOP ENCLOSURE	STAINLESS STEEL	4
10	BOTTOM ENCLOSURE COVER	POLYCASE WP-31 COVER	POLYCARBONATE	1

Cal Poly Mechanical Engineering		Title: DASHBOARD ENCLOSURES-EXPLODED VIEW	Drwn. By: WANJIKU GICHIGI
ENGR 461 - SPRING 2022		Date: 06/07/2022 · Scale: 1:2	

Appendix I: Dashboard Enclosures with Components Exploded View

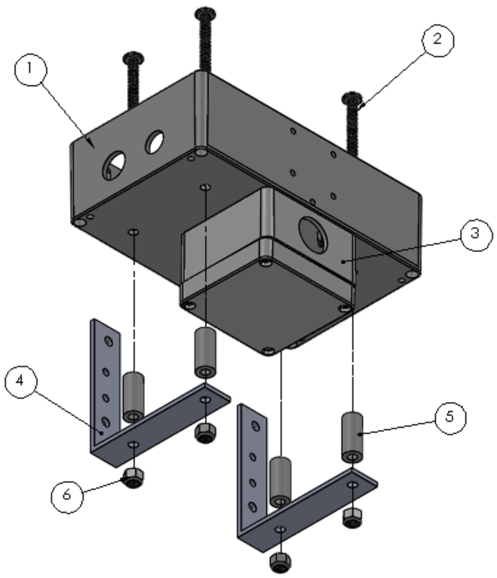


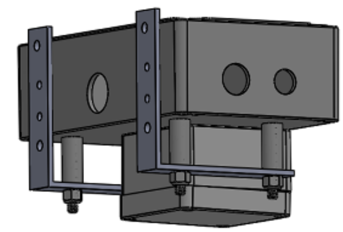


ITEM NO.	PART NUMBER	DESCRIPTION	Material	QTY.
1	TOP ENCLOSURE	POLYCASE WC-34 OUTDOOR ENCLOSURE	POLYCARBONATE	1
2	SPEAKER CONE	3-D PRINTED SPEAKER CONE	POLYCARBONATE	1
3	PIEZO SPEAKER	DIGI-KEY AT-1750 SPEAKER	N/A	1
4	1/2 IN LOCKNUT	SIGMA ELECTRICC PROCONNEX RIGID CONDUIT LOCKNUT	STEEL	2
5	6-32 NYLOCK NUT	NYLON-INSERT LOCKNUT FOR MOUNTING LIDAR SENSOR	STEEL	4
6	LIDAR-LITE V3	GARMIN LIDAR SENSOR	N/A	1
7	6-32x1/2IN SCREW	PHILLIPS HEAD SCREW TO ATTACH LIDAR TO TOP ENCLOSURE	STAINLESS STEEL	4
8	ULTRASONIC SENSOR	MAXBOTIX MB7383 HRXL-MAXSONAR-WRLST SENSOR	POLYCARBONATE	1
9	POWER SWITCH	SWITCH TO TURN SYSTEM ON AND OFF	N/A	1
10	USB CHARGING PORT	PORT TO CHARGE SYSTEM	N/A	1
11	BOTTOM ENCLOSURE	POLYCASE WP-31 NEMA ENCLOSURE	POLYCARBONATE	1

Cal Poly Mechanical Engineering
ENGR461 - SPRING 2022
Title: COMPONENTS_EXPLODED VIEW
Drwn. By: WANJIKU GICHIGI
Date: 06/07/2022
Scale: 1:2

Appendix J: Dashboard Vertical Attachment Exploded View

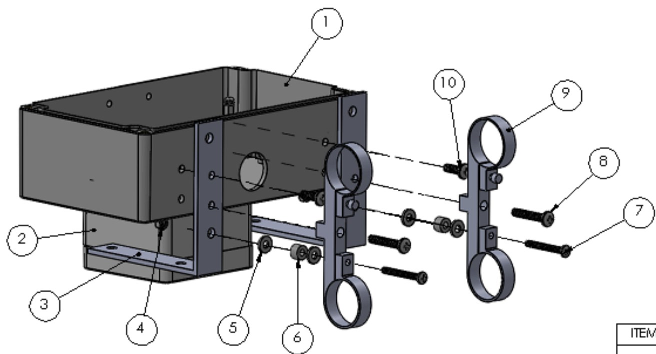


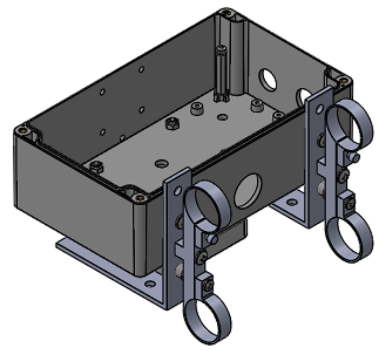


ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	QTY.
1	TOP ENCLOSURE	POLYCASE WC-34 OUTDOOR ENCLOSURE	POLYCARBONATE	1
2	1/4-2IN SCREW	PAN HEAD PHILLIPS SCREW FOR ATTACHING L-BRACKETS AND BOTTOM SPACERS	STAINLESS STEEL	4
3	BOTTOM ENCLOSURE	POLYCASE WP-31 NEMA ENCLOSURE	POLYCARBONATE	1
4	L-BRACKET	BRACKET FOR MOUNTING ENTIRE DASHBOARD TO BIKE HANDLEBARS	STEEL	2
5	M6 BLACK SPACER	NYLON SPACER TO OFFSET ENCLODURE FROM L-BRACKET	PLASTIC	4
6	1/4-20 NYLOCK NUT	NYLON-INSERT LOCKNUT FOR SECURING SPACERS AND BRACKET	STEEL	4

Cal Poly Mechanical Engineering		Title: VERTICAL ATTACHMENT_EXPLODED VIEW		Drwn. By: WANJIKU GICHIGI
ENG R461 - SPRING 2022		Date: 06/07/2022	Scale: 1:2	

Appendix K: Dashboard Horizontal Attachment Exploded View





ITEM NO.	PART NUMBER	DESCRIPTION		QTY.
1	TOP ENCLOSURE	POLYCASE WC-34 OUTDOOR ENCLOSURE	POLYCARBONATE	1
2	BOTTOM ENCLOSURE	POLYCASE WP-31 NEMA ENCLOSURE	POLYCARBONATE	1
3	L-BRACKET	BRACKET FOR MOUNTING ENTIRE DASHBOARD TO BIKE HANDLEBARS	STEEL	2
4	M4-0.80 NYLOCK NUT	NYLON-INSERT LOCKNUT FOR SECURING BRACKET TO RISERS	STEEL	2
5	0.188IN WASHER	Washer WITH ID ID 0.188 IN AND OD OF 0.438IN	STAINLESS STEEL	4
6	3/16IN WHITE SPACER	OFF-WHITE NYLON UNTHREADED SPACER	NYLON	2
7	M4-0.80x35MM SCREW	PAN HEAD PHILLIPS SCREW	STAINLESS STEEL	2
8	M5-0.80x30MM SCREWS	PAN HEAD PHILLIPS SCREW	STAINLESS STEEL	2
9	HANDLEBAR RISER CLAMP	REDCOMETS BIKE HANDLEBAR EXTENDER	ALUMINUM ALLOY	2
10	M5-0.80x16MM SCREWS	PAN HEAD PHILLIPS SCREW	STAINLESS STEEL	2

Cal Poly Mechanical Engineering		Title: HORIZONTAL ATTACHMENT_EXPLODED VIEW	Drwn. By: WANJIKU GICHIGI
ENGR461 - SPRING 2022		Date: 06/07/2022 / Scale: 1:2	

Appendix L: Hand Calculations

Senior Project Calculations

Sensor Parameters

```
V = 10; % Bike speed (mph)
T_r = 1; % Biker reaction time (s)
T_p = 0.82; % Computer processing time (s)

sensorRange = 10; % Max sensor range (m)
sensorFreq_max = 6; % Max sensor frequency (hz)
```

Battery Parameters

```
% Using maximum current draw
sensorDrain = 98; % Current draw from sensor (mA)
lilypadDrain = 85; % Current draw from lilypad (mA)
speakerDrain = 9; % Current draw from speakers (mA)
arduinoDrain = 200; % Current draw from Arduino (mA)
batteryCap = 5000; % mAh

life_req = 10; % Required battery life (hours)
```

Conversions

```
V = V/2.237; % Biker speed (m/s)
```

Calculate minimum detection distance

```
range_req = V*(T_r + T_p);
disp(['Required Range: ', num2str(range_req), ' m'])
```

```
Required Range: 8.1359 m
```

```
if range_req > sensorRange
    display('Required measurement distance is too high')
end
```

Calculate minimum measurement frequency

```
freq_req = V/(sensorRange - range_req);
if freq_req > 0
    disp(['Required Frequency: ', num2str(freq_req), ' Hz'])
end
```

```
Required Frequency: 2.3981 Hz
```

Calculate required battery capacity

```
current_req = sensorDrain + 2*lilypadDrain + 2*speakerDrain + arduinoDrain; % Required current output of battery (mA)
batt_req = current_req * life_req; % Required battery capacity (mAh)

disp(['Required Current Output: ', num2str(current_req), ' mA'])
```

```
Required Current Output: 486 mA
```

```
disp(['Required Battery Capacity: ', num2str(batt_req), ' mAh'])
```

```
Required Battery Capacity: 4860 mAh
```

Calculate minimum battery life

```
life_expected = batteryCap/current_req;
disp(['Minimum expected battery life: ', num2str(life_expected), ' hours'])
```

```
Minimum expected battery life: 10.2881 hours
```

Calculate Battery Lifespan

```
C = 300; % Total allowable charge cycles
commute = 0.75; % Commute time [hours]

hoursPerYear = commute*365*(5/7); % Hours per year commuting (assume 5 days a week)
```

```
chargesPerYear = hoursPerYear/life_expected;
years_expected = C/chargesPerYear;
disp(['Battery is expected to last: ', num2str(years_expected), ' years'])
```

```
Battery is expected to last: 15.7844 years
```

Calculate Sensor Lifespan

```
sonarLife = 232896; % Rated lifespan [hours] https://www.maxbotix.com/articles/ultrasonic-sensor-mtbf.htm

sonarYears_expected = sonarLife/(365*24); % Assuming sensor is on continuosly
disp(['Ultrasonic sensor is expected to last: ', num2str(sonarYears_expected), ' years'])
```

```
Ultrasonic sensor is expected to last: 26.5863 years
```

Calculate detection angles

```
angleDist = 3.5; % meters
horizontalDist = 0.5; % meters
verticalDist = 0.3; % meters

theta_h = rad2deg(2*atan(horizontalDist/angleDist));
theta_v = rad2deg(2*atan(verticalDist/angleDist));

disp(['Horizontal Detection Angle: ', num2str(theta_h), ' degrees'])
```

```
Horizontal Detection Angle: 16.2602 degrees
```

```
disp(['Verticale Detection Angle: ', num2str(theta_v), ' degrees'])
```

```
Verticale Detection Angle: 9.7982 degrees
```

Calculate bolt load

```
Sy = 90e3; % psi stainless steel
Sy_pc = 4060; % psi polycarbonate
Davg = 0.1; % Bolt diameter [in]
w = 10; % Box weight [lbf]
DF = 4; % Dynamic factor

sigma = (2*DF*w)/(pi()*Davg^2)
```

```
sigma = 2.5465e+03
```

```
SF_bolt = Sy/sigma
```

```
SF_bolt = 35.3429
```

```
SF_pc = Sy_pc/sigma
```

```
SF_pc = 1.5944
```

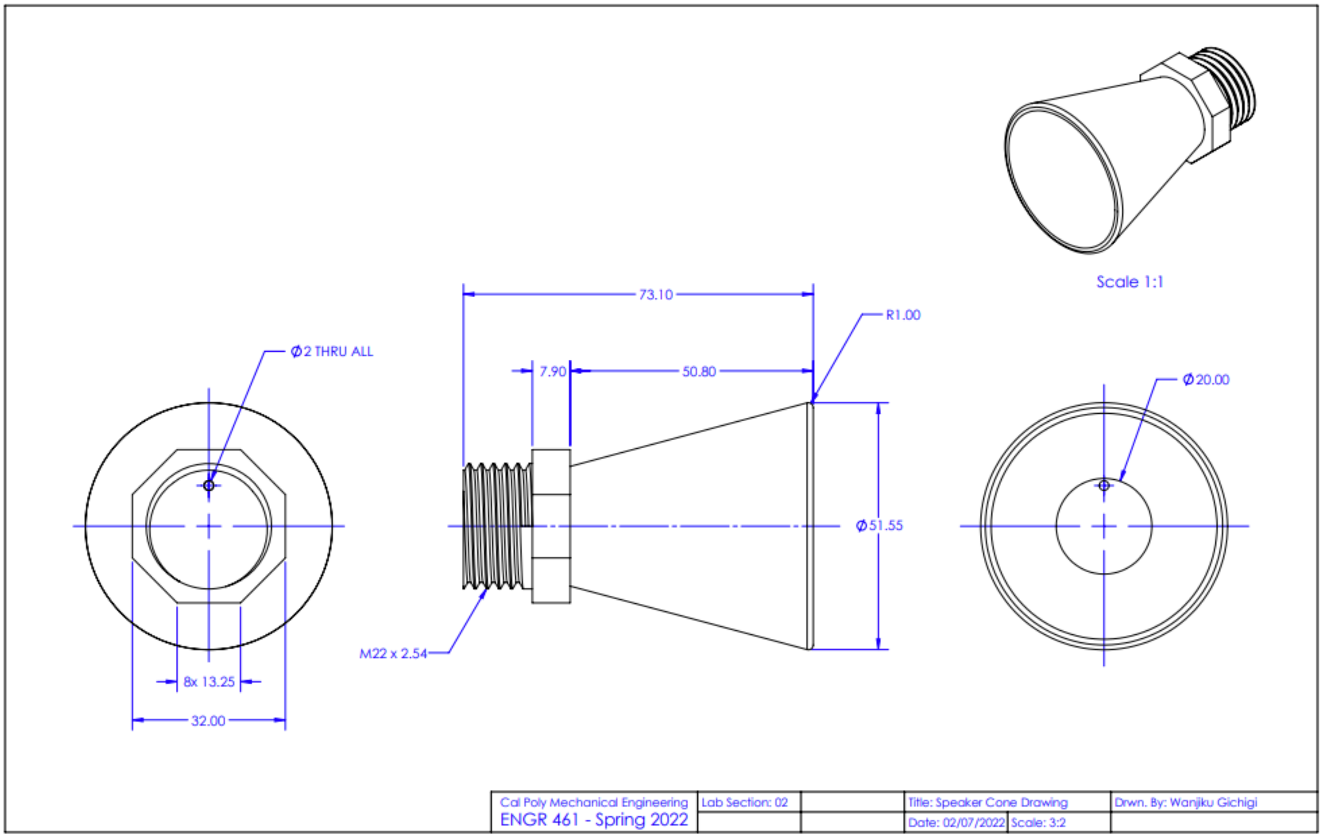
Impact Calculations

```
g = 9.81; % [m/s^2]
h = 0.5; % Drop Height [m]
V0 = 0; % Initial velocity[m/s]
dt = 0.1; % Impact time [s]
m = 3; % Box mass [kg]

t = (-2*V0 + sqrt(4*V0^2 + 8*h*g))/(2*g); % Free fall time [s]
V = V0 + g*t; % Pre-impact velocity [m/s]
forceImpact = m*g + m*V/dt;
disp(['Verified impact force: ', num2str(forceImpact), ' N'])
```

```
Verified impact force: 123.3928 N
```

Appendix M: Detailed Drawing of Speaker Cone

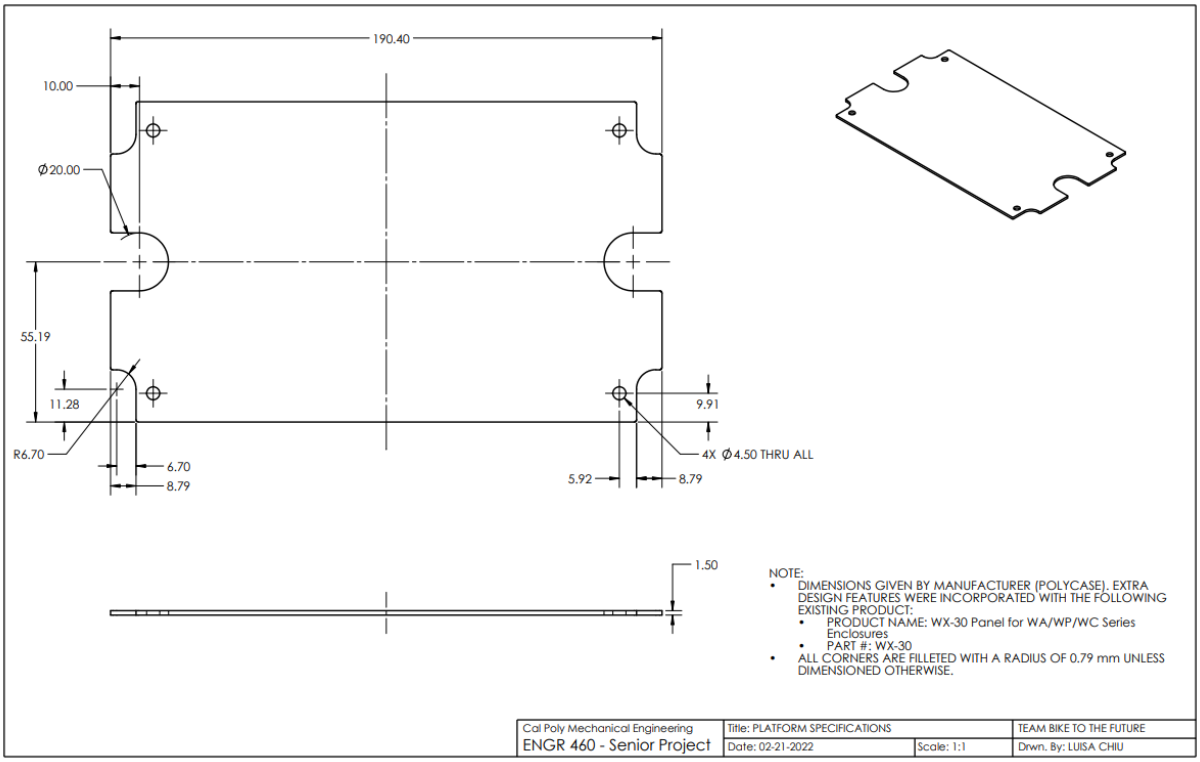


Appendix N: Design Review Hazard Identification Checklist

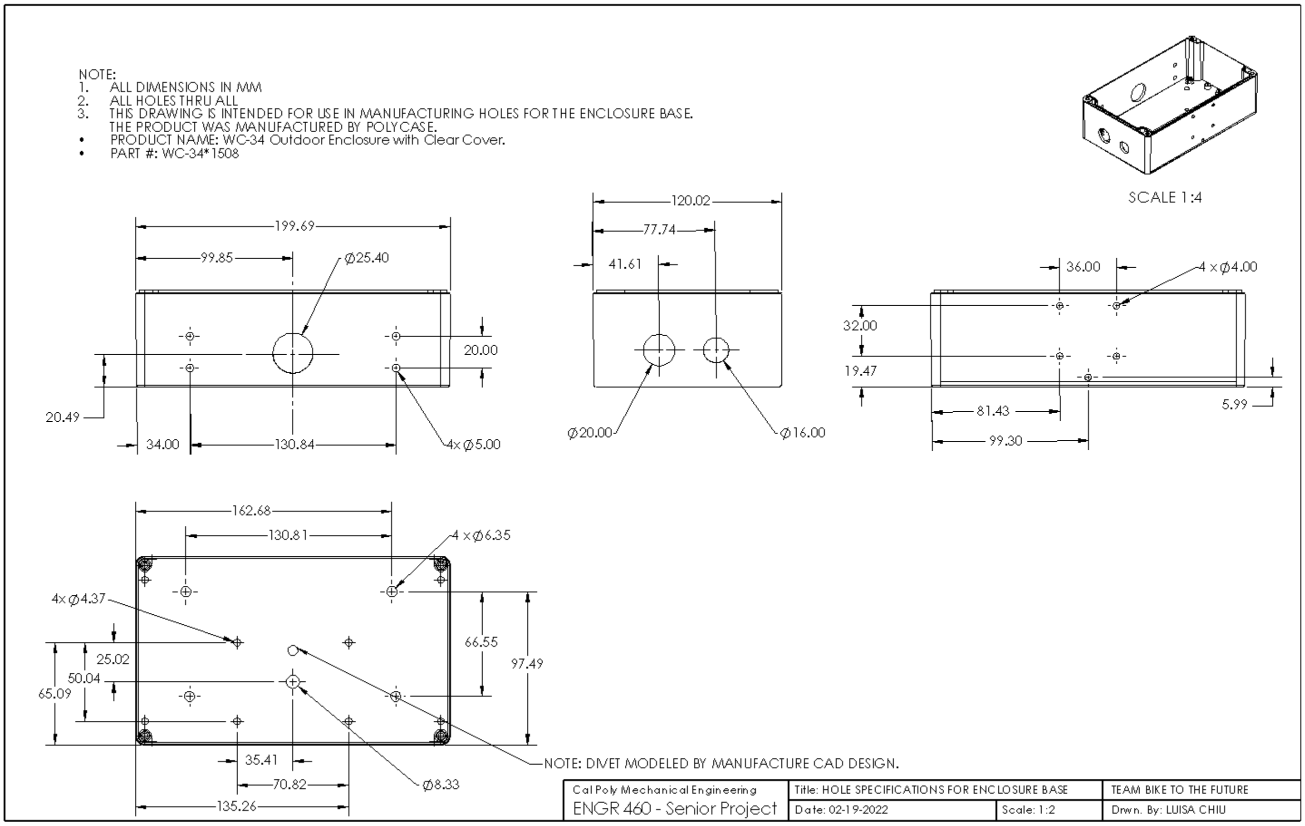
SENIOR PROJECT CONCEPTUAL DESIGN REVIEW HAZARD IDENTIFICATION CHECKLIST

Y	N	
☐	X	Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
☐	X	Can any part of the design undergo high accelerations/decelerations?
☐	X	Will the system have any large moving masses or large forces?
☐	X	Will the system produce a projectile?
X	☐	Would it be possible for the system to fall under gravity creating injury?
☐	X	Will a user be exposed to overhanging weights as part of the design?
☐	X	Will the system have any sharp edges?
X	☐	Will all the electrical systems properly grounded?
☐	X	Will there be any large batteries or electrical voltage in the system above 40 V either AC or DC?
☐	X	Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
☐	X	Will there be any explosive or flammable liquids, gases, dust fuel part of the system?
☐	X	Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
☐	X	Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
☐	X	Can the system generate high levels of noise?
X	☐	Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures ,etc…?
X	☐	Will the system easier to use safely than unsafely?
☐	X	Will there be any other potential hazards not listed above? If yes, please explain below?

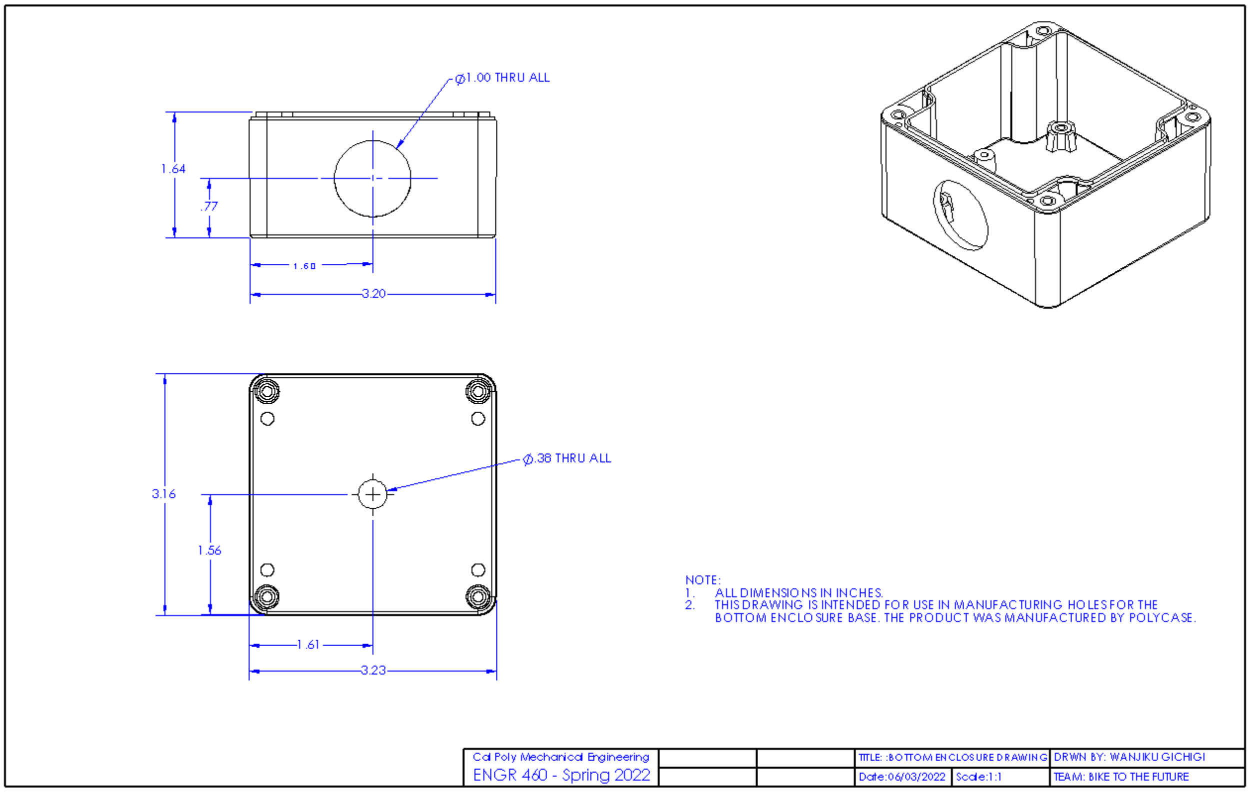
Appendix O: Detailed Drawing of Platform



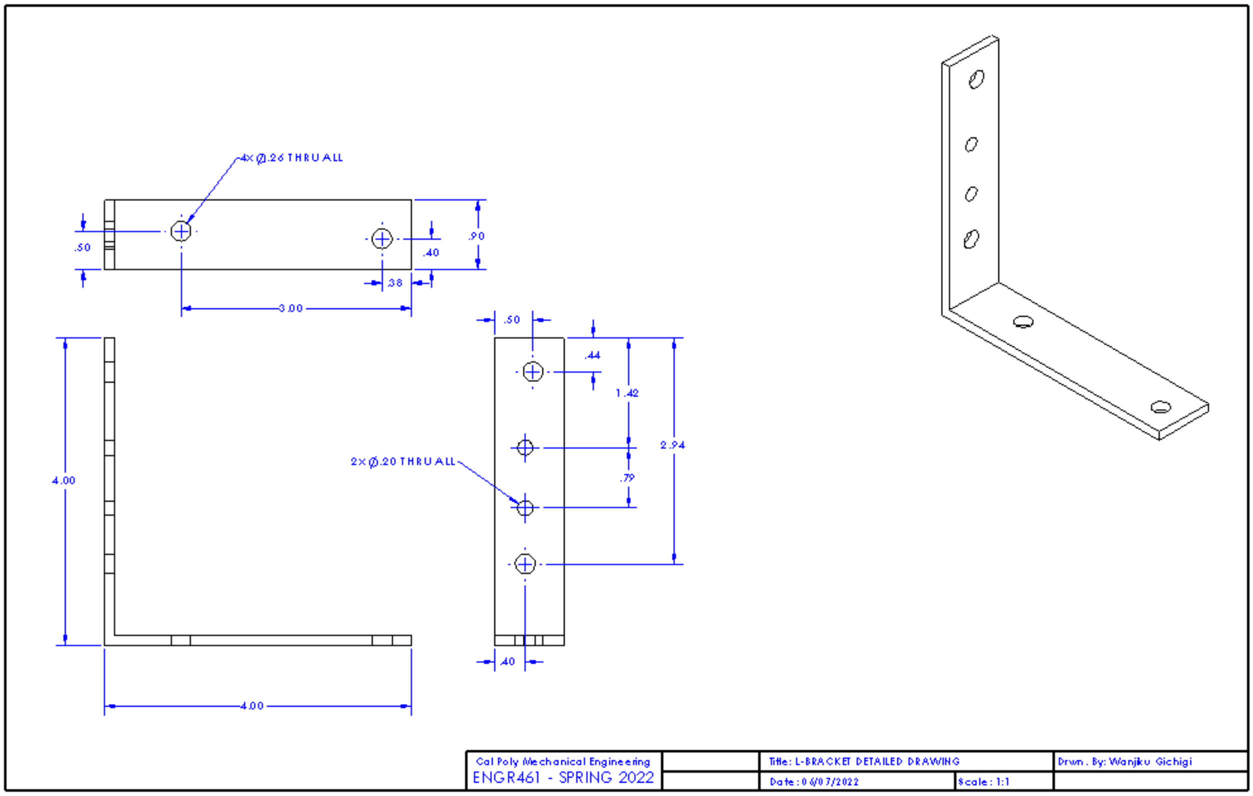
Appendix P: Detailed Drawing of Enclosure Base



Appendix Q: Detailed Drawing of Bottom Enslosure



Appendix R: Detailed Drawing of L Bracket

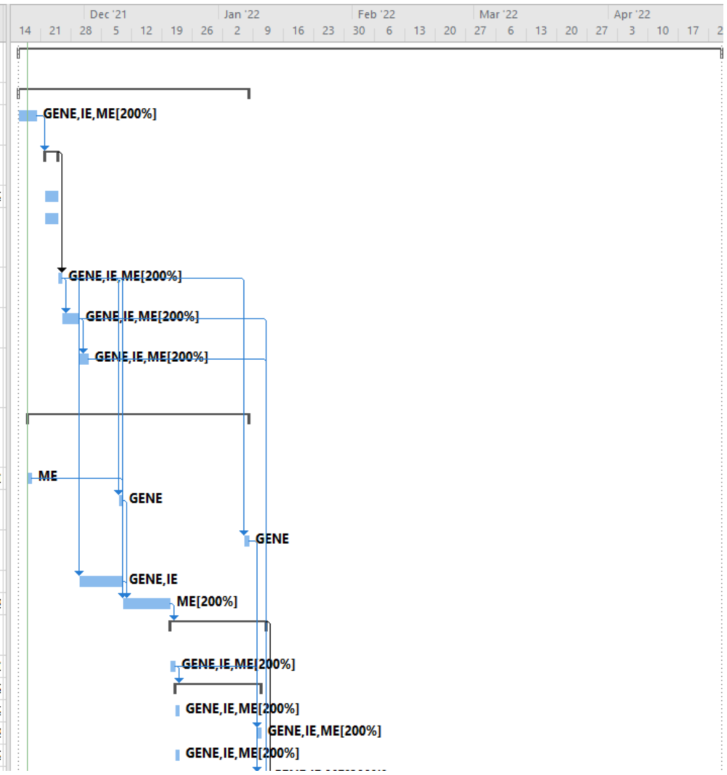


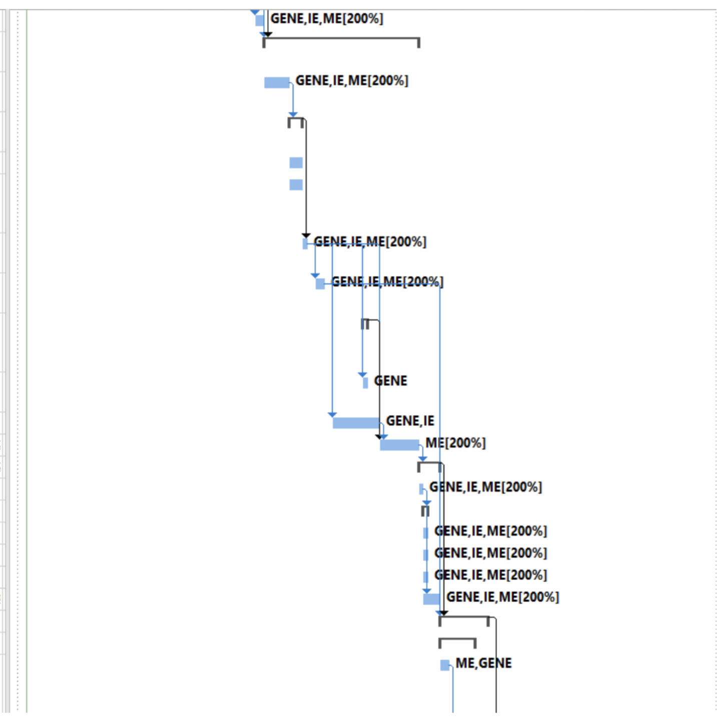
Appendix S: Verification and Test Plan

DVP&R													
Report Date			Sponsor									REPORTING ENGINEER:	
TEST PLAN										TEST REPORT			
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES TESTED		TIMING		TEST RESULTS			NOTES
						Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	Sensor Range	Sensor Test indoors	9m Sensor Range	Group	Design Verification	30	Measurement	1/24/2022	2/7/2022	Pass	27	3	Processing time ~1s
2	Tactile Feedback	Vibration Test on Lily Pads	0.2 N	Group	Concept Validation	1	Inspection	1/30/2022	2//2/22	Pass	1	0	Vibration stronger than expected
3	Battery Length	Required battery capacity	10 hrs Min	Group	Design Verification	1	Analysis	2/7/2022	2/7/2022	Pass	1	0	See Calculations
4	Sensor Range	Sensor Test outdoors	9m Sensor Range	Group	Design Verification	30	Measurement	2/11/2022	2/24/2022	In Progress	In Progress	In Progress	
5	Object Detection	Object Size Detection	Min Size: 40x61 cm	Group	Design Verification	30	Objects	2/22/2022	3/8/2022	In Progress	In Progress	In Progress	See list of common items
6	Scan rate	Sensor speed test (sensor on moving object)	4 Hz Minimum	Group	Design Verification	40	Measurement	2/29/22	3/19/2022	TBD	TBD	TBD	
7	Audio Feedback	Speaker	80 dB	Group	Design Verification	15	Inspection	3/19/2022	3/25/2022	TBD	TBD	TBD	
8	-	Attachment clamps Force analysis	-	Group	Concept Validation	1	Analysis	3/26/2022	3/30/2022	TBD	TBD	TBD	
9													

Appendix T: Gantt Chart

Task Mode	Task Name	Duration	Start	Finish
	Bike to the Future Project	**116 days**	**Tue 11/16/21**	**Tue 4/26/22**
	Initial Prototyping	**39 days**	**Tue 11/16/2:**	**Fri 1/7/22**
	Concept Generation	4 days	Tue 11/16/21	Fri 11/19/21
	Preliminary CAD Models	**3 days**	**Mon 11/22/21**	**Wed 11/24/21**
	Model Box	3 days	Mon 11/22/2	Wed 11/24/2
	Model Speaker Cones	3 days	Mon 11/22/21	Wed 11/24/21
	Choose Best Prototype	1 day	Thu 11/25/21	Thu 11/25/21
	Create Concept Design Report	2 days	Fri 11/26/21	Mon 11/29/21
	Create Concept Design Presentation	2 days	Tue 11/30/21	Wed 12/1/21
	Preliminary Material Procurement	**37 days**	**Thu 11/18/21**	**Fri 1/7/22**
	Get Bike	1 day	Thu 11/18/2:	Thu 11/18/2:
	Get Electronics	1 day	Thu 12/9/21	Thu 12/9/21
	Purchase Sensor	1 day	Fri 1/7/22	Fri 1/7/22
	Develop Code	8 days	Tue 11/30/2:	Thu 12/9/21
	Build Prototype	7 days	Fri 12/10/21	Mon 12/20/2
	Preliminary Testing	**16 days**	**Tue 12/21/21**	**Tue 1/11/22**
	Plan Testing	1 day	Tue 12/21/2:	Tue 12/21/2:
	Lab Test	**14 days**	**Wed 12/22/:**	**Mon 1/10/2:**
	Speaker Test	1 day	Wed 12/22/:	Wed 12/22/:
	Sensor Test	1 day	Mon 1/10/22	Mon 1/10/22
	Tactile Test	1 day	Wed 12/22/:	Wed 12/22/:
	Field Test	2 days	Mon 1/10/22	Tue 1/11/22
	Secondary Prototyping	**26 days**	**Wed 1/12/22**	**Wed 2/16/22**
	Concept Generation	4 days	Wed 1/12/22	Mon 1/17/22
	Secondary CAD Models	**3 days**	**Tue 1/18/22**	**Thu 1/20/22**
	Model Box	3 days	Tue 1/18/22	Thu 1/20/22
	Model Speaker Cones	3 days	Tue 1/18/22	Thu 1/20/22
	Choose Best Prototype	1 day	Fri 1/21/22	Fri 1/21/22
	Create Critical Design Report	2 days	Mon 1/24/22	Tue 1/25/22
	Secondary Material Procurement	**1 day**	**Fri 2/4/22**	**Fri 2/4/22**
	Get Electronics	1 day	Fri 2/4/22	Fri 2/4/22
	Develop Code	7 days	Fri 1/28/22	Mon 2/7/22
	Build Prototype	7 days	Tue 2/8/22	Wed 2/16/2:
	Secondary Testing	**3 days**	**Thu 2/17/22**	**Mon 2/21/2:**
	Plan Testing	1 day	Thu 2/17/22	Thu 2/17/22
	Lab Test	**1 day**	**Fri 2/18/22**	**Fri 2/18/22**
	Speaker Test	1 day	Fri 2/18/22	Fri 2/18/22
	Sensor Test	1 day	Fri 2/18/22	Fri 2/18/22
	Tactile Test	1 day	Fri 2/18/22	Fri 2/18/22
	Field Test	2 days	Fri 2/18/22	Mon 2/21/22
	Build Final Product	**9 days**	**Tue 2/22/22**	**Fri 3/4/22**
	Manufacturing	**6 days**	**Tue 2/22/22**	**Tue 3/1/22**
	3D Print Speaker Cones	2 days	Tue 2/22/22	Wed 2/23/22





Manufacture Box	4 days	Thu 2/24/22	Tue 3/1/22
Assembly	**7 days**	**Thu 2/24/22**	**Fri 3/4/22**
Wiring	1 day	Thu 2/24/22	Thu 2/24/22
Put together Dashboard	2 days	Wed 3/2/22	Thu 3/3/22
Mounting Prototype	1 day	Fri 3/4/22	Fri 3/4/22
Heatshrink Wires	2 days	Fri 2/25/22	Mon 2/28/22
Create Final Documentation	**12 days**	**Mon 3/7/22**	**Tue 3/22/22**
Finalize Logbooks	2 days	Mon 3/7/22	Tue 3/8/22
Compile Final Report	10 days	Wed 3/9/22	Tue 3/22/22
Create Poster	2 days	Mon 3/7/22	Tue 3/8/22
Customer Feedback	**12 days**	**Wed 3/23/22**	**Thu 4/7/22**
Send to Brian	1 day	Wed 3/23/22	Wed 3/23/22
Receive Final Feedback	1 day	Thu 3/31/22	Thu 3/31/22
Impliment Feedback	5 days	Fri 4/1/22	Thu 4/7/22
Senior Project Presentation	**13 days**	**Fri 4/8/22**	**Tue 4/26/22**
Compile Presentation	7 days	Fri 4/8/22	Mon 4/18/22
Practice Presenting	5 days	Tue 4/19/22	Mon 4/25/22
Present to Class	1 day	Tue 4/26/22	Tue 4/26/22