Electrical Engineering Department
California Polytechnic State University

Senior Project Final Report

Collision Avoidance Smartphone

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Abstract

There are many instances in day-to-day life where people cannot or would rather not pay full attention to their surroundings. Walking while preoccupied with a smartphone or walking while blind are excellent examples where technology could be used to make the task of avoiding

collisions reactive, instead of proactive. A device which monitors a user's surroundings and notifies the user when a potential collision is detected (and, additionally, notifying them as to where the obstacle is with respect to them) could be used to make walking distracted less of a hazard for the user and those around the user and potentially improve navigation for the visually impaired.

The device will connect with the smartphone via bluetooth and the information sent by the device will be displayed over a smartphone app, and haptic feedback for the visually impaired. The device should be rechargeable, self-contained, small enough to connect to a smartphone, and it should be able to communicate with any smartphone that has bluetooth capability making the device universal.

I. General Introduction and Background

Since the invention of the smartphone there has been a large increase in the number of pedestrian accidents caused by people walking while distracted by their mobile device. Walking while interacting with a mobile device greatly decreases the users sense of awareness. This leads to people walking around with large blind spots and generally puts them in danger of collisions with objects.

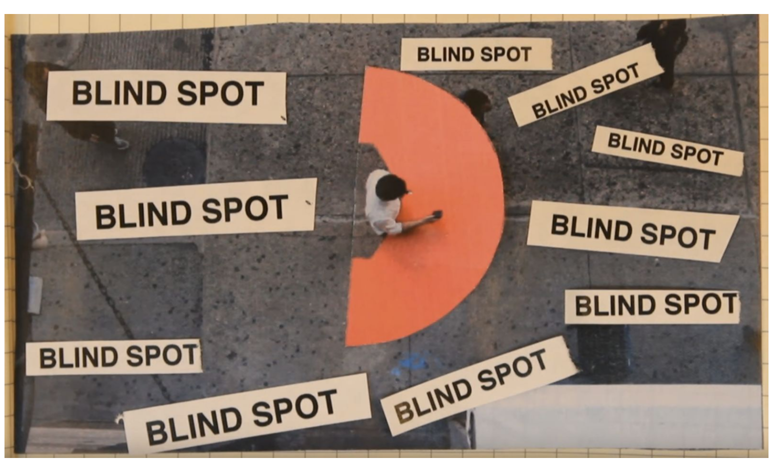


Figure 1: Limited Awareness while Using Smart Phone

At first glance most people view this issue lightly, thinking it could be dangerous but only for others because they are fully capable of walking safely while using their phone. In 2013 Liberty Mutual Insurance conducted a survey to see how many people walk while distracted by their phones. This study was condensed into the infographic seen below in Figure 2[1].

Figure 2: Liberty Mutual Insurance Survey Results[1]

This survey reveals that 60 percent of pedestrians walk while using their phones even though 70 percent acknowledge the dangers associated with this behavior. Walking while distracted puts pedestrians at a range of risks from minor injuries, to serious injury or death. This problem is only getting worse as the number of smartphone users continue to grow, and it is escalated by the fact that drivers, too, are more distracted than ever before. It is clear that smartphones are here to stay and it is difficult to stop people from using their phones while they walk, so the best way to increase pedestrian safety seems to be introducing a device that can help keep pedestrians aware of their surroundings.

II. Overview

The Collision Avoidance Smartphone device addresses the need for greater pedestrian safety. The target customers would primarily be average smartphone users, but especially people who live in crowded urban environments and often commute to work/school by walking. Additionally, the device should be flexible enough to be a useful tool for the visually impaired.

Product Description:

There is a need to address the distracted pedestrian problem, and this project aims to present a solution by creating a small device that can be used to to help monitor the user's surroundings and help them avoid potentially dangerous situations. The device should be able to warn the user that they are about to walk into traffic, step over a step/ledge, or collide into an object. Although this project's main target is the average smartphone user, it also has utility for the visually impaired. In order to maintain a maximum level of accessibility, the device is designed to be able to attach to, and work with, a smartphone, but also capable operating independently. Figure 3 shows the device.

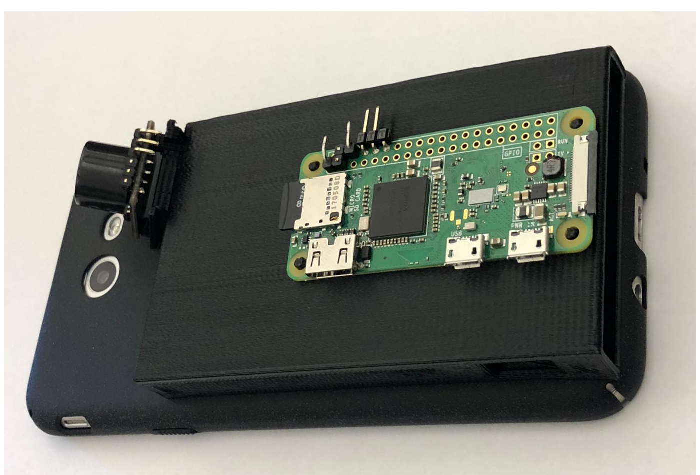


Figure 3: Collision Avoidance Device

Using ultrasonic transducers, the device will transmit signals out and asses its surroundings by using a Raspberry Pi to analyze the reflected waves that it picks up. Communication with smartphones will be achieved through the use of bluetooth. The device will also contain a computer vision aspect that will detect curbs and potential obstacles on the ground through the use of it's edge detection. Through the combination of the sensor and computer vision, the product will alert the user through a notification protocol via vibration.

Market Research:

There are only a few competitors in the Collision Avoidance Smartphone market. The most direct competition comes from an app called Type 'n' Walk[2]. This smartphone application allows the user to see through the camera on the back of their phone while they are texting as seen in figure 4. This essentially lets people to see the ground if they are talking with there head down, so they can see if they are about to walk into the street or over a ledge. The main strength of Type 'n' Walk is the fact that it does not require any additional hardware, so anyone with a smartphone just needs to download the app. The device proposed in this paper offers many advantages over Type 'n' Walk. For example, the ultrasonic sensors allow for a more three dimensional field of view that offers more awareness and protection than a camera looking at the ground can.

Figure 4: Advertisement from Type and Walk Website[3]

The main competitor in the market for the visually impaired, is the Smart Cane[3]. The Smart Cane is used like a regular cane allowing the user to feel the ground in front of them so they can tell if they are going to walk into anything. Traditional Canes cannot detect obstacles above knee height so the Smart Cane provides detection for obstacles from knee to eye height using ultrasonic sensors[3]. These devices work well, and the collision avoidance device being proposed could offers similar utility. Using bluetooth, the device can provide haptic feedback to a smartwatch or some other capable wristband. This combined with a regular cane could provide an experience essentially identical to the Smart Cane. This means it could meet the customer's needs without being physically connected to the cane, thus allowing for the flexibility to compete in multiple markets.

III. Customer Archetype

Smartphone Users

There is a continuous growth in smartphone users every year as they are becoming more and more popular. Per Digital Trends, nearly 1.5 billion smartphones were sold in 2016 which was a 5% growth from the previous year[4]. It is estimated that there are about 208 million smartphone users in the United States and with the continuous growth in smartphone users [5], there is clearly a very large market available for the adaptation of the Collision Avoidance Smartphone. The main target for the smartphone user category are pedestrians specifically in heaving populated cities. The heavier populated cities in the United States all have a mass amount of both pedestrians walking the streets and cars driving all over the city. Pedestrians walking across major cities like New York, Los Angeles, Chicago, that are filled with other people walking and cars driving, are all vulnerable to the potential injuries that can occur from the distraction of a smartphone. Figure 5 shows each state in the United States with their corresponding percentage of people that walk to work. This narrows our market but addresses a much needed solution. With the increase of entertainment applications for smartphone users, the desire to walk while on the phone will only increase as well. From just looking at the release of Pokemon-Go, there was more than 110,000 accidents in a 10-day period [6]. With the addition of the Collision Avoidance Smartphone, the troubles of colliding or getting hit by a car are nearly eliminated. The user is free to navigate while being on their smartphone without the worry of causing a minor or serious injury to themselves or others.

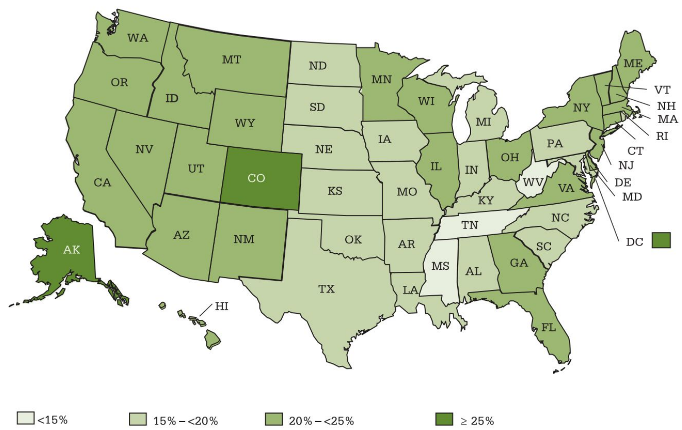


Figure 5: Map of States with Percentage of People Walking to Work [13]

Visually Impaired

Although the market for the visually impaired is much smaller than that of just smartphone users alone, the market is still available as there isn't much help for the visually impaired to navigate with easier and reassurance. With 1.3 million people registered in the United States as legally blind, the use of the Collision Avoidance Smartphone can be implemented to help visually impaired navigate with ease knowing the device will detect any obstacle or oncoming car that may cause an injury [7]. Implementing the device to the white cane with this device will allow a much larger range for detection and will allow communication between the user and the device with haptic feedback instead of relying on just the white can on its own. It was found in a survey that 33 percent of legally blind get bumped into by walkers that were on their phones every time they go out and that a little over 50 percent of the people surveyed had been injured once in their lives by people distracted while walking [8]. With the addition of this device to either end of the party (preferably both), this situation can easily be avoided.

Market Competitors

The market for this device is a very open market. The main competitors for those who are smartphone users is the app Type-n-Walk that allows users to see, through their camera (as shown in Figure 6), what's in front of them while they are texting or using their phones. This is the main application in the market that solves this problem although it restricted in many ways. The market for pedestrians that walk to work is estimated to be 107 million. An estimate of how many with smartphones wasn't available but it is safe to assume that a majority of the 107 million that walk to work have smartphones. The main competitor for the visually blind is the SmartCane (Device shown in Figure 7) which raises the detection level of the white cane from below knee height to above knee height with the use of sensors. Although this device does the same capabilities as the smartphone avoidance collision, it doesn’t get rid of the cane itself or have the universal feature of applying to the general smartphone users which opens the device to a bigger market from 1.3 million (visually blind) potential buyers to 107 million (pedestrians walking to work) potential buyers. Assuming that the amount of smartphone users will continue increasing for the next 5 years and with no real solution for both areas of customers, the device will be allowed to dominate the market that is very open and large with minimal competitors that don’t address all of the consumer’s needs.

Figure 6: Screenshot of the Type-n-Walk App

Figure 7: SmartCane Competitor Device

IV. Market Description

Current Market

As previously discussed, the proposed product will be capable of monitoring the user's surroundings and providing a warning if there is an imminent danger or obstacle close to them. Such things may be traffic, telephone poles, trees, curb edges, pits, or other commonly encountered hazards. Using sensors, the device will be able to detect these objects or hazards remotely and provide the warning in time for the user to be able to avoid it. The device will be small and able to attach to a smartphone to allow for increased user convenience. Further, the device will contain a bluetooth link so that it can communicate directly with smart devices and need not always be attached to the phone to be used. This alleviates the need for the user to always have their phone held in front of them.

While the main target market is any smartphone/smart device user, especially in crowded or urban areas, the product has another market as an aid device for the visually impaired. It improves on current technology to remotely sense objects around the individual.

Present products in both markets have obvious limitations. In the way of technology to help the average smartphone user, one current solution is the Type 'n' Walk app for iPhones [2]. The app works by overlaying texting on the phone camera, so that the user can essentially "see through" their device while using it. Successes and failures of the app are discussed further in the table below:

Table 1: Type n Walk App Analysis

Successes	Shortcomings
Allows user to see through phone, thus showing obstacles behind phone	Limited to camera area directly in front of phone (if user is texting looking down at phone, app is mostly useless)
	Limited to use with text-based apps. Many social media platforms, which users spend more time on, would not be supported.
Requires no new hardware, just app download - very user friendly	Doesn't automatically detect - still requires users to be alert
	Requires camera use, which is processor heavy

The only other main competitors to the proposed product are devices for the visually impaired. One device, called the Smart Cane [3], (an attachment to the traditional white cane) uses a similar sensor to detect objects at a higher altitude than the cane tip usually detects. This provides much more capability for visually impaired than the normal white cane, but it still has some drawbacks. It is analyzed below:

Table 2: Smart Cane Analysis

Successes	Shortcomings
Improved detection over white cane - can detect objects at higher elevation than cane tip (clotheslines, tree branches, railings, etc.)	Range in pricing, unaffordable for many in smaller countries
Automatically detects for user	Radius of the sensors

Market Opportunity

Both markets currently are not well served. As discussed earlier, the majority of consumers recognize the dangers of the distraction caused by using a smartphone, yet continue to do it [1]. A strong argument can be made that the reason for this is that there is no viable solution to the problem yet. Type n Walk has some advantages, but ultimately has too many limitations to be very useful to the average consumer. They need a device that will work independently of their effort - something they can attach and let the device handle the rest. Our product will be able to deliver this.

On the other side, the fast improvement of technology hasn't kept up well with aid for the visually impaired. Better and better hearing aids and prosthetic limbs have been developed for other disabilities, but many blind people still use a simple white cane to navigate. The Smart Cane is a much improved product, but our product can deliver the same capability with a better range for a cheaper price. Modern technology is completely capable of providing better assistance to visually impaired, and our product intends to bridge that gap by giving something much simpler, lighter, and easier to use.

Current products either sacrifice too much convenience for capability, or are very capable with a significant lack of convenience. Our product's main area of strength is that it can leverage both convenience and capability. It combines the ease-of-use of the Type n Walk app with the range, detection and automatic warning capabilities of the Smart Cane into one product. It has the potential to be a more optimal solution for both sides of the market.

Market Entry Factors

The largest obstacle to entering the market is going to be introducing the product to customers. Being a device that is relatively original (there are no direct competitors), there will be overhead in cost and time to sell the device to people. We estimate at least a year to finish designing, prototyping and testing the product. We expect this process will likely be about 200 dollars. Once this process is complete, we move to marketing. The usefulness of the product will need to be shown to the customers to show how its stress-alleviating ability. It may take several months or even years before the product starts to become recognised as a useful device. Because most of the marketing will be done through the website/social media/other digital channels, we expect costs to be relatively low and limited to advertising costs on the various channels. For example, Facebook has an average advertising cost of 0.58 cents per click [14].

There are two customer groups to target early: visually impaired individuals, and smartphone users living in cities.

Visually impaired customers require such technology to get through their day, and will likely be much more open to a device that works easier than a white cane or Smart Cane. They already know the benefit of an awareness/collision avoidance device, and won't need to be demonstrated the usefulness as heavily.

Smartphone users living in cities are the bigger customer base, and the easiest to demonstrate the product's value to. An urban environment provides the largest number of hazards (traffic, sidewalks/curbs, people, telephone poles, buildings, etc.) from which users would benefit directly from the product. Urban environments also provide many opportunities to market directly to customers (booths, live demonstrations, shops, etc.) which would make the actual marketing job simpler.

Several business partners would make the job of marketing the product easier. Since the product is first and foremost meant to work with smart devices, we would need to reach out to companies like Apple, Samsung, and Google about interfacing with their devices, and also about marketing the device with the product as they may stand to benefit from marketing the devices as compatible with our product.

Other crucial partners would be agencies that work to assist visually impaired. These could be government organizations, hospitals, and charities which work to make their lives easier. This would streamline the integration of the technology into the lives of blind individuals.

V. Business Model Canvas

<table>
<tr>
<td rowspan="2">Key Partners
Apple, Samsung, Google
- for interfacing our device with their operating systems

Digikey
- Component Selection

National Federation of the Blind, Braille Institute - Santa Barbara
- For device testing and customer relations</td>
<td>Key Activities
- Build and test full-functioning product
- Address needs of both customer archetypes
- Build 5-year-plan for device
- Build relationships with major companies for networking and distribution</td>
<td rowspan="2">Value Propositions
- Device enables customers to be aware of obstacles and hazards without being visually aware

- Device is portable, rechargeable, and universal

- Device is interfaceable with smartphones and communicates via bluetooth

- Device is cheaper and simpler than existing competing technology</td>
<td>Customer Relationships
- Smart phone users

- Non-profit organizations for visually impaired

- university clubs

- social media</td>
<td rowspan="2">Customer Segments
Smartphone users
- especially in major cities/crowded areas
- large potential customer base
- prevents everything from minor incidents/embarrassments to serious injuries

Visually impaired
- most ready need for device
- lighter, simpler, smarter alternative to white cane

Inital Target Customers
-Smartphone users in San Luis Obispo
-Braille Institute of Santa Barbara</td>
</tr>
<tr>
<td>Key Resources
- Hardware and software support
- Manufacturing and distribution
- Technical document for support
- Capital for R&D</td>
<td>Channels
- Direct sales to customer

- Social Media

- Website

- Advertisement</td>
</tr>
<tr>
<td colspan="3">Cost Structure
R&D - electrical components, test equipment, tooling, housing

Labor - design, testing, manufacturing, marketing/sales

Distribution and Marketing - advertisements, travel costs, other sales costs</td>
<td colspan="2">Revenue Streams
Sales from device - online/website, physical sales
Patent
Application support</td>
</tr>
</table>

VI. Marketing Requirements

Market Description

As technology becomes more prominent in everyday life, so does the potential for it to be misused or abused. A recently developed issue is the trend of (specifically millennial) consumers to walk and text / use their phone at the same time. A study from Ohio State University "estimated that in 2010 more than 1,500 pedestrians were estimated to have been treated for injuries related to using a cell phone while walking" [9] - and that number has almost doubled since the time of that study.

Figure 8: The Trend of Increasing Injuries due to Distracted Walking

Another study conducted by the American Academy of Orthopedic Surgeons involving over 2,000 adults found 11-32% of adults considered themselves primarily distracted walking on a street or in their house respectively [10]. The issue of navigating safely is even more pronounced in the blind than the distracted consumer, with 7,000,000 Americans being estimated to be visually disabled [11], where sight almost inevitably leads to difficulties navigating the world. Statistics on the use of long canes are scarce but in the late 90's over 100,000 Americans were estimated to use long (or white) canes, and current estimates have over 7,000 Americans using service dogs to overcome visual impairments [12].

There exists an unaddressed consumer need for a device to address the aforementioned issue of "distracted walking", which poses a considerable risk to consumers, especially consumers more prone to use electronic devices. Additionally, current solutions allowing the visually impaired to navigate the world are limited in the information they can give the user, and their ability to prevent collisions for their user. The two needs this product absolutely must fulfill are collision detection / alerts within some limited arc around the user, and a portable / rechargeable package. The product must be as accessible to the blind as to consumers who may be walking while distracted (primarily by their smartphones).

This device would address the unmet needs of all smartphone users, and in addition the visually impaired. The number of legally blind individuals in the United States alone is 1.3 million, while the number of smartphone users is 190.5 millions. This number increases as technology advances and becomes more available. Of those who use smartphones daily, the specific target audience would be those who take the role of pedestrians. As mentioned previously, there exists great risk for those who navigate while on their phone.

Table 3: Marketing Requirements Table

Customer Need	**Product Feature**
Automatic or assisted collision detection	Sensors, detecting at minimum obstacles / imminent collisions within 1m of user
Sensor signal processing external of smartphone	On-board microprocessor (Raspberry Pi Zero)
Portable Solution	Rechargeable Battery / independent casing (not dependent on smartphone)
Solution must not interfere with smartphone functionality	Optional bluetooth connection, on-board alert system (no alerts necessary over smartphone)
Easy to use	Minimum viable product must work with Android Smartphone and later versions can be ported to Iphones and other smart devices.

VII. Block Diagram, Requirements, and Specifications

Hardware Diagrams

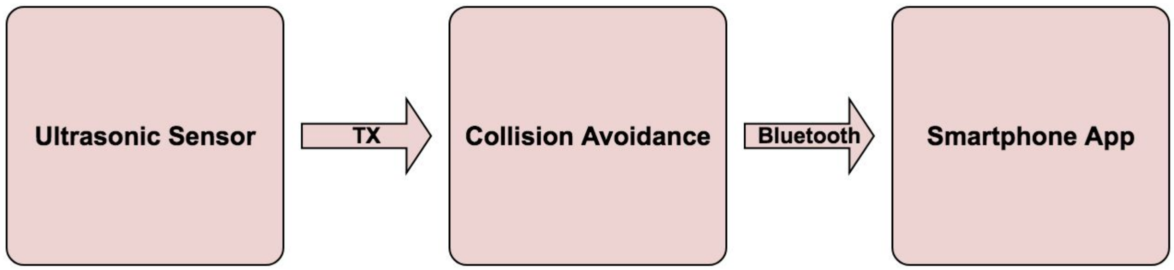


Figure 9: Level 0 Block Diagram

The high level block diagram for the Collision Avoidance Smartphone device is pictured above in Figure 9. This diagram covers the basics inputs and outputs of the system. Essentially the device will transmit a 40Khz ultrasonic signal and receive reflected waves back from the environment. Based on the received signal the device will determine if there is an obstacle that the user might collide with. If there is a potential collision the device will send a message via bluetooth to a smartphone that will then alert the user via a buzzing sound and some sort of haptic feedback.

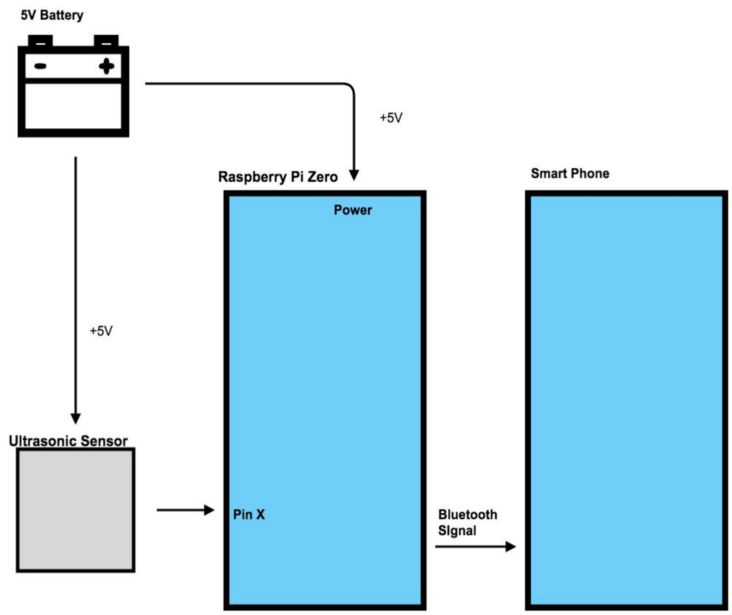


Figure 10: Level 1 Block Diagram

Figure 10 above shows a level 1 diagram for the collision avoidance device. A raspberry pi zero will be used as the heart of the project. An ultrasonic range finder will be used to to obtain a distance measurement and transmit the range data to the raspberry pi via a UART connection. The raspberry pi will be programmed to format the received data into a distance measurement before sending it to a smartphone application via bluetooth. The smart device will need to have a simple application that makes it vibrate and beep when it determines a potential collision is possible. The entire device, including the analog circuitry and the raspberry pi should be powered from a single supply of $5V_{DC}$. To ensure a constant and long lasting power supply a rechargeable lithium ion battery along with a voltage regulator will be used.

Software

A large portion of this process involves writing software to accurately determine if a collision may occur. Most of the calculations will be performed in the smartphone application. The app needs to be able to use the distance information provided from the pi along with it stand alone computer vision to determine if a collision is possible.

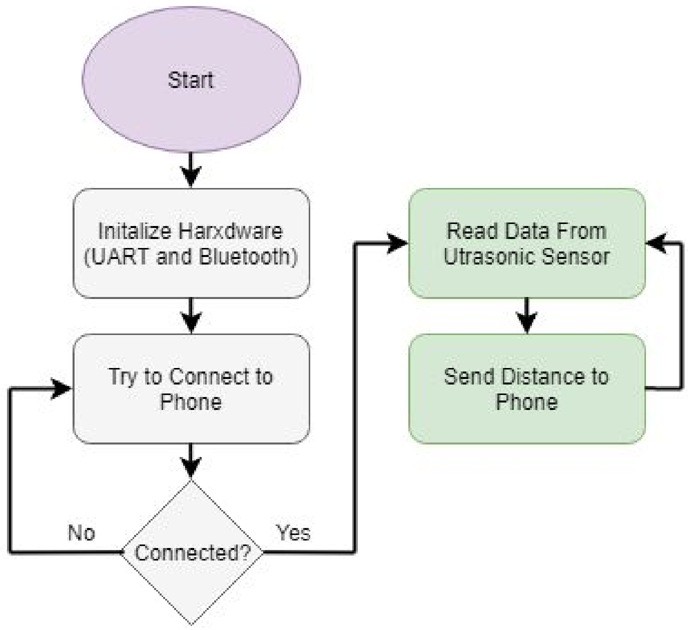


Figure 11: Software Diagram for Sensor

Testing and Verification

The testing and verification is broken down by each subsystem in our design. For our hardware testing, we will be using Oscilloscopes, Function Generators, and Power Supplies all provided by Keysight at Cal Poly Electrical Engineering Laboratories. Starting with the Raspberry Pi Zero, we will be testing first for functionality of the UART/Bluetooth library that the Raspberry Pi has built in. This will allow communication with the receiving end of the device and the Raspberry Pi itself. After this is tested, we will need provide firmware test for the

Bluetooth communication with a smartphone. The computer vision will be developed in parallel with the bluetooth and the main testing for the computer vision will be completed as a stand alone feature until software integration begins. Once the raspberry pi seems to be communicating with both the smartphone and the sensor and the computer vision is working individually, the second form of testing, verification, and integration will begin. This includes testing the product as a whole and going out and testing it with real life scenarios as well as creating an application that features both the computer vision and bluetooth protocol to work simultaneously. Data will then be gathered and further development will be made from there.

Engineering Requirements Table

Table 4: Market Requirements translated to Engineering Requirements

Market Requirement	Engineering Requirement
Ultrasonic sensors, detecting at minimum obstacles / imminent collisions within 1m of user	-40Khz Ultrasonic Receiver and Transmitter capable of 5m minimum range.
On-board microprocessor (Raspberry Pi Zero)	-Bluetooth Communication -UART Communication
Rechargeable Battery / independent casing (not dependent on smartphone)	-Battery must be regulated and supply $5V_{DC}$ to raspberry pi and analog components.
Product alert system	-Notification protocol (software implementation for vibration)
Minimum viable product must work with Android Smartphone and later versions can be ported to Iphones and other smart devices.	-Must work on the most widely used android versions (Jelly Bean-Oreo)

Team Responsibilities Table

Table 5: Team Member Responsibilities

Team Member	**Responsibility**
Aaron Parisi	Software Design - Computer Vision Design Software testing - Testing Edge-Detection Hardware Testing - Sensor
Matt Columbres	System Integration - Sensor and Raspberry Pi System Testing - Sensor and Raspberry Pi Networking and Marketing
Joey Schnecker	Hardware Design - Sensor and Raspberry Pi System Integration - Sensor and Raspberry Pi System Testing - Sensor and Raspberry Pi Software Design - UART and Bluetooth Software Design - Android Application
Luis Wong	Hardware Design - Sensor and Raspberry Pi System Integration - Sensor and Raspberry Pi System Testing - Sensor and Raspberry Pi Software Design - UART and Bluetooth
All Members	Sensor Research, and Market Research Hardware, Firmware, and Software Testing System Integration/Testing
Julien Doe	Leaving

VIII. Schedule, Cost, and Plan

Project Schedule

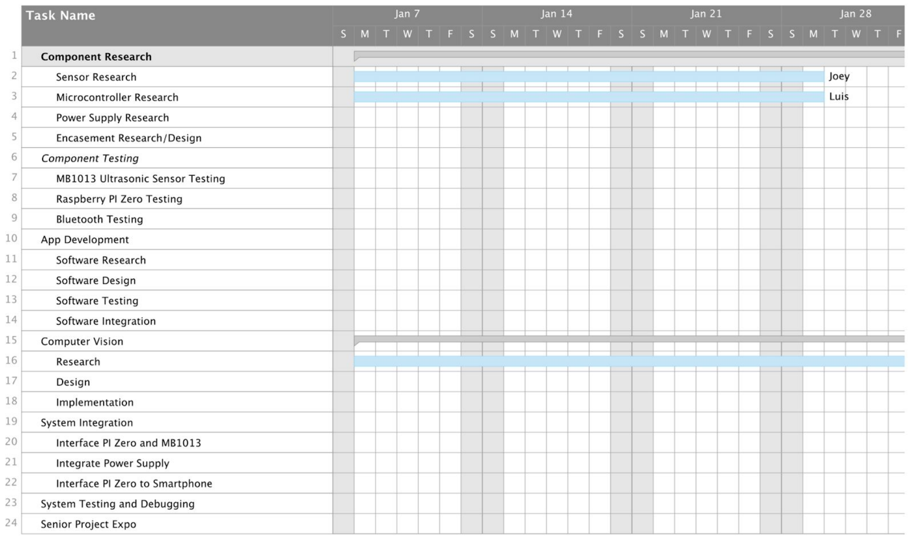


Figure 12: Project Gantt Chart

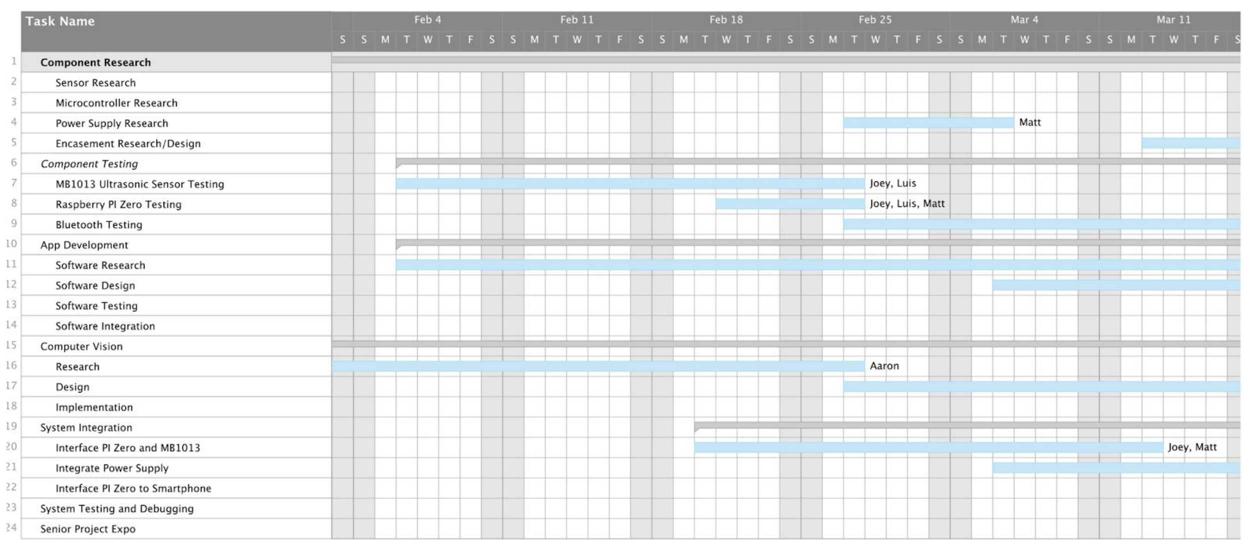


Figure 13: Project Gantt Chart Continued

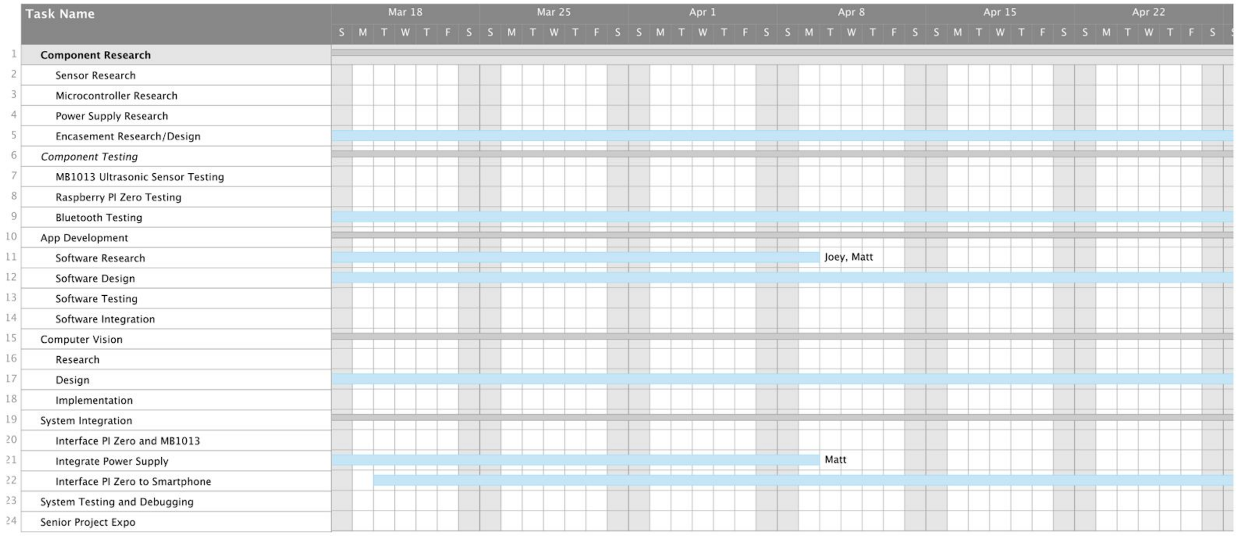


Figure 14: Project Gantt Chart Continued

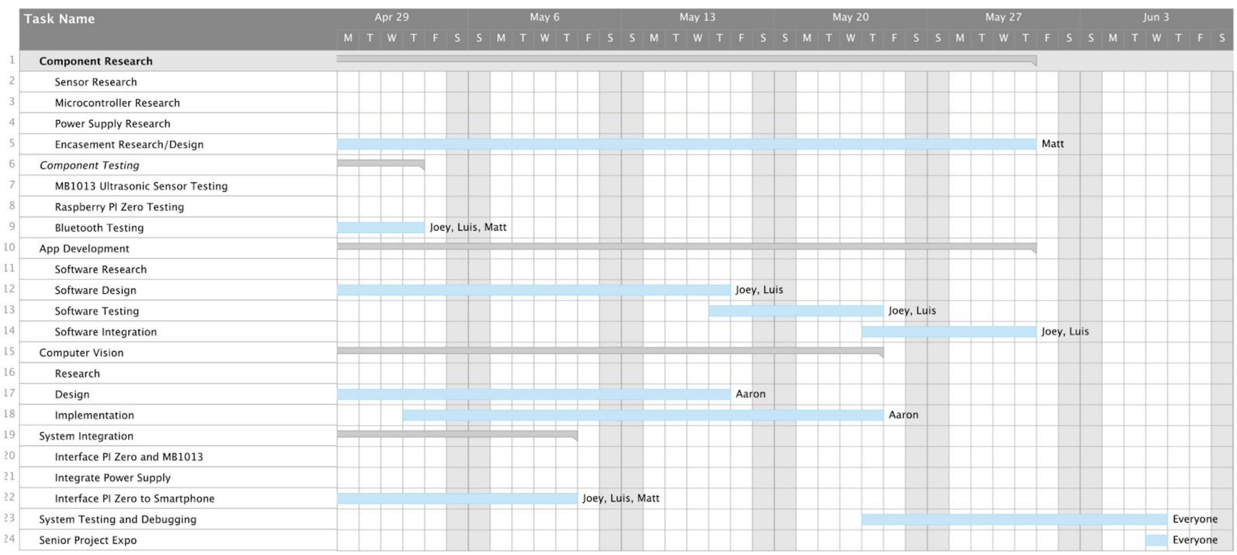


Figure 15: Project Gantt Chart Continued

High Risk Items:

- Electronics system integration has the potential to require additional time, if revisions need to be made to the electrical system in order to make the subsystems integrate cleanly without any inter-system interference.
- Bluetooth connection at times can be faulty, if this were to happen, the device is incapable of functioning.
- Smartphone app development has the potential to take longer, since no team member has experience developing a full android app.

Bill of Materials:

			Senior	Collision Avoidance Smartphone								
			TEAM:	Matthew Columbres, Joey Schnecker, Luis Wong, Aaron Parisi								
			DATE/REV:	June 7, 2018 VERSION V2.0								
											USA	Foreign
Sub	Sub	Sub	Sub	Description	Qty	P/N	Document	MFG	MFG P/N	LT - Weeks	1kpcs Price (USD)	1kpcs Price (convert)
Box Build - Model 1.0 - Retail Configuration					1	2000		Custom		6		
1	Final Assy - Unit "Collision Avoidance Smartphone"				1	2001	Instr	Custom	---	1		
	1	Main Assy			1	2002	Instr	Custom	---			
		1	Ultrasonic Sensor		1	2003	Spec	Matbotix	MB1013-000	2	34.95	29.7075
		2	Raspberry PI Zero W		1	2005	Spec	Adafruit	2885	2	10.0000	8.5
		5	Right Angle Connector		1	2006	Spec	Sullens	S1121EC-40-ND	1	0.9700	0.8245
		3	Female-Female Jumper Wire		4	2007	Spec	Adafruit	794	2	0.9875	0.839375
		4	2500 mAh Power Bank		1	2008	Spec	Dodocool	EL-19834	1	16.9900	14.4415
		5	Samsung J7 Shell Case		1	2009	Spec	Auxon	4326476039	1	5.9800	5.083
		5	Case, Housing, ABS Black unfilled		1	2010	Spec	3M	---	1	0.0560	0.0476
										Material Total	69.9335	59.4435
								If made in USA	0.5hrs x $30/hr	Labor+	15.00	12.75
								If made in Foreign	0.5hrs x $5/hr	OH		
								Product Shipping leadtime		Weeks	1	8.00
										Total	84.93	80.19

Resources

Financial assistance offered to all students in senior project will be used at least in-part in order to finance this project. Additional project funding may be sought via CPConnect. Professor Murray (and potentially Professor Derickson) will provide advising / technical assistance throughout the year to help keep the project on-task, and will additionally oversee all design reviews.

Key Skills

- Analog circuit design / testing
- Experience in Bluetooth Protocol
- Experience in UART Protocol
- Software Development (Computer Vision)
- CAD 3D Modeling (for device case)
- Mobile App Development (for integrating device with smartphone)

IX. Analysis of Senior Project

Summary of Functional Requirements:

The device is battery powered (rechargeable), self contained, user-friendly, and contains stand alone computer vision capabilities. For obstacle detection, the device uses computer vision capabilities to detect obstacles from the phone's camera, while the ultrasonic rangefinder detects obstacles at a distance and reports back that distance to the smartphone via bluetooth communication. If an obstacle or potential hazard is found from either computer vision or ultrasonic rangefinder, the phone has a notification protocol that alerts the user through vibration from the phone.

Primary Constraints:

The device must communicate using bluetooth and run in the background when paired with the smartphone. This is important because the device is marketed as something that eliminates the need to multitask. The product must also be lightweight and compact, as a cumbersome device is not an attractive product for users.

Economic:

Human Capital: This device will create jobs in the following sectors: Engineering, software and app development, manufacturing, sales, and technical support.

Financial Capital: This product will have a large market. There is no direct competitor. The customer will not have much of a financial impact as the product will be priced at $79.99, something that ensures safety this low price will appeal to the public.

Manufactured or Real Capital: The manufactured capital will be the inventory of this product.

Natural Capital: Raw components are needed to create the casing, and components.

If Manufactured on a Commercial Basis:

Estimated number of devices sold per year: 100,000 (0.1% of the Smartphone market) + 10,000 (1% of visually impaired)

Estimated manufacturing cost for each device: Approximately $65

Estimated Purchase price for each device: $80

Estimated profit per year: 110,000 x (80-65) = $165,000

Estimated cost for user to operate device: $0

Environmental:

This product can affect the environment in all stages of its life cycle. The components used to make the device require raw materials such as silicon, metals, and liquids. While in use by the customer, it is important to keep in mind that some animals such as dogs can hear sound waves above 20 kHz. We need to choose a frequency that has minimal to no impact on animals. At the end of the life cycle, the product will have minimal environmental impact as the product and most components can be recycled. The battery itself will have to be disposed properly to a location that recycles batteries.

Manufacturability:

The majority of the manufacturing will come from 3-D printing as the housing has all the necessary compartments to store the product and its components. The only labor necessary for this design is latching the components into their respective locations and soldering the ultrasonic sensor to the Raspberry Pi which involves 3 wires: power, ground, and TX for UART communication.

Sustainability:

Possible concerns mainly deal with the failure rate of any components used, such as the sensor, or battery. All components have rated lifetimes. Otherwise, no other challenges are immediately apparent. In terms of software, the device must be compatible with the most recent and relevant phone firmware versions. The project actually beneficially contributes to the sustainable use of resources, especially if reliable components are chosen. The rechargeable battery also eliminates waste that would have been generated by non-rechargeable batteries. The design can mainly benefit from size reduction to be less intrusive for users. Upgrades include using smaller/more advanced components. If possible, using hardware that incorporates the sensor and bluetooth device on one board would reduce the size. In summary: issues include: generating funds for smaller components and manufacturing everything to operate on a smaller scale.

Ethical:

In the possible situation that the device does not alert the user to a collision when there is one, consideration must be given to who bears responsibility for the accident. It could be debated that the device (and therefore the device manufacturers) is at fault for failing to report or the user for being too dependent on the device. At the bare minimum, a warning must be given to users that it is possible for the device to not detect certain collisions, and possibly information about what types of situations the device is most likely to fail in. Unlike average smartphone users, visually impaired cannot function without the device, so our design must ensure a minimum level of functionality. The device can create a moral hazard situation; one in which insurance against a danger can cause the user to act more dangerously. We must balance a successful device without reinforcing users to not watch their surroundings.

Health and Safety:

While the device will most likely present no health concerns, consideration must be given to sensor choice and battery choice. Some sensors may use EM radiation which can be harmful to humans, and these types must be avoided. Also, if using a lithium ion battery (for future development), the design must be careful to not draw too much current and risk exploding the battery.

Social and Political:

The device has the potential to greatly empower visually impaired individuals. It will be easier to use than a standard white cane. Because of this, it could contribute to greater social and political equality for visually impaired. It may allow them to fit roles or do jobs they were previously incapable of doing.

Development:

Time was spent from January 2018 through June 2018 developing the first prototype device. The first phase began with component selection and research. Once this was completed, the first product was built. At this point, the testing phase began. Testing included extensive verification of the sensor, hardware, and software components. Some design revision was necessary as issues were discovered. Once the device was sufficiently tested, App development, Bluetooth/UART communication, and Computer Vision began. Through extensive software development, the three were successfully compatible with each other and ran on one user-friendly application. The complete project was then presented at the Senior Project Expo.

X. Preliminary Design Analysis

One of the first decisions we had to make was whether the device would be an independent gadget, or if it would interface with a smartphone. Below are points considered:

Table 6: Design Ideas Considered

Device Type	Pros	Cons
Independent Device	• Allows freedom to design shape/size/etc. • No interface hardware/software required for smartphone compatibility • Removes need to partner with smartphone companies (potentially costs money)	• Inconvenient for user (hard to use two devices at once) • Device still needs to be small regardless of whether it attaches to smartphone or not • All hardware/software on device must be complete; can't have help from smartphone
Smartphone Attached Device	• Easier to integrate into normal life for consumer • Allows "piggybacking" on smartphone company marketing • Requires less hardware (can use smartphone for some help)	• Requires hardware/software to integrate with smartphone • Restricts physical design to something that fits with smartphone

After considering both options, we believe the smartphone integrated device will work the best. The convenience of attaching to a smartphone is undeniable for the user.

Since all designs will require a sensor, we looked at different options for the choice of sensors

Table 7: Sensors Considered

Sensor Type	Pros	Cons
Ultrasonic Sensor	• Inexpensive • Easy to implement	• Not as accurate as other types • Possibility of ultrasonic interference
Laser Sensor	• Extremely accurate • Lowest chance of interference • Small	• Expensive • Power inefficient • Small beam scan area
Radar	• Accurate • Lower chance of interference	• Expensive • Big • Possibility of radiation harm to people
Infrared	• Large field of view • Cheap • Small	• High chance of thermal interference • Low ability to calculate distances

Due to the low cost as well as the effectiveness of ultrasonic sensors, we believe now it is the best choice. The downsides of its use don't outweigh the benefits, as the chance for interference is low and the accuracy is good enough for this application

Another design consideration was what kind of microcontroller to use on the device. However, after looking at device capabilities, only the raspberry pi zero met the project needs. All other MCUs were either too large or did not have all of the functionality (bluetooth compatible, sensor compatible, 5V supply, etc.) that the project necessitated.

Figure 16: First 3D Printed Encasement

XI. Experimentals and Prototypes:

Pre-Experimental Data:

An experiment was performed in order to determine what angle most people hold their phones in order to build a device that would accommodate to most people using the device. We found that out of 20 people sampled, the average phone angle was 25 degrees when walking and texting. The measurement was taken by stopping people being surveyed and measuring with a protractor to get an approximate degree.

Table 8: Experimental Data on Angle of Phones When Walking

Sample Number	Angle
1	~25°
2	~30°
3	~25°
4	~25°
5	~30°
6	~35°
7	~5°

8	~15°
9	~30°
10	~25°
11	~25°
12	~30°
13	~30°
14	~30°
15	~15°
16	~30°
17	~20°
18	~25°
19	~30°
20	~25°

Average: 25.25°

When looking at the results of the experiment, it was evident that a majority of people walk and text on their phones at a 25° angle. This will be used when implementing the sensors and mechanical aspect of the design to fit the phone and capture as much as possible from the sensors.

Ultrasonic Rangefinder:

The rangefinder was the first step in beginning the hardware design process for our collision avoidance device. A lot of research was put into deciding which rangefinder to pick. Certain specs had to be met and we had to find an affordable one as well. When researching for rangefinders, the most important specifications we looked into were the distance it covers, the beam angle, and the current draw to make sure we were not power hungry as we drew current from the raspberry pi. We finally came to the conclusion that the MatBotix 1013R was the best choice.

Once we actually received the rangefinder, we had to do preliminary test on it to make sure it was working and so we could see what kind of data we should expect to receive and observe in the raspberry pi. We initially tested the rangefinder using its analog voltage output as it was a very easy set up. We powered the device with an arduino and measured its output with a hand multimeter and walked around to test its reliability. Figure 17 shows the test taking place and the change in voltage after detecting a car in the way. Table 9 shows the actual distance measurements we read and their corresponding voltages we read.

Figure 17: Readings for Analog Voltage Output from Sensor

Table 9: Experimental Data for Sensor Reading

Distance (inches)	Distance(mm)	Voltage (volts)	Scaling Factor(V/mm)
20	508	.30	5.906e-4
47	1193.8	.63	5.277e-4
128	3251.2	1.13	3.476e-4

146	3708.4	2	5.393e-4
166	4216.4	2.15	5.099e-4
172	4368.8	2.3	5.265e-4
196	4978.4	2.5	5.022e-4
218	5537.2	2.8	5.057e-4
> 218	>5537.2	2.9	
Average Measured Scaling Factor			5.062e-4

After testing, we noticed two problems with this approach. We would have to use an external ADC to convert the data so that the raspberry pi could read it and the analog voltage was just slightly too slow to detect objects that are moving. When testing with stationary objects, the device worked fine but when someone would walk across the device, there was a slight delay that could potentially cause problems. So we decided to use another form of communication for this device, TTL.

We went to the rangefinder's data sheet to understand how the TTL/RS232 data output was sent and we hooked the device to the oscilloscope to physically read the data. Figure 18 shows the experimental set up and Figure 19 shows the reading on the oscilloscope.

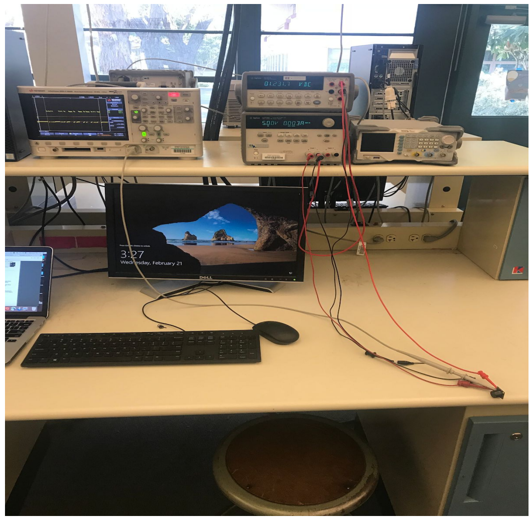


Figure 18: Experimental Setup for Sensor

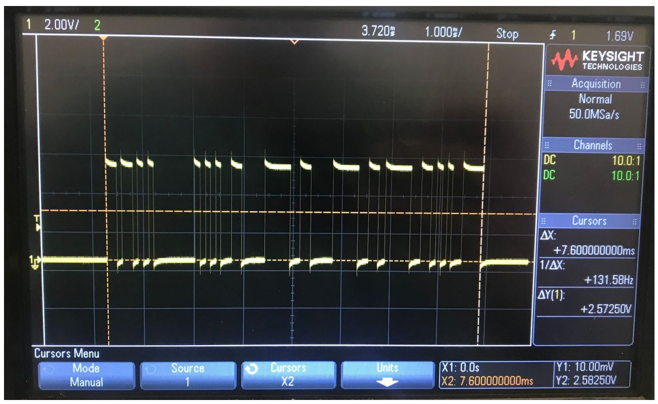


Figure 19: Oscilloscope Data from Sensor

We were having some trouble reading the data as the oscilloscope wasn't giving us a very clear reading. We knew from the data sheet that we should be expecting a start bit, 8 data bits (corresponding to an ASCII character), no parity bit, and a stop bit for a total of 10 bits. But when we looked into the actual bits in the oscilloscope, it seemed like we were getting some junk bits that didn't belong which was throwing off all of our data interpretation by hand. We were able to read the beginning letter “R” which the data sheet said it would send, and we were able to find the data which was an ASCII carriage return. But in between we weren't able to make anything out of the data. So instead, we decided to try to write the python script to handle any missed data and determine whether it is used or not and it ended up fixing our problem and returning the right data via UART communication with the sensor.

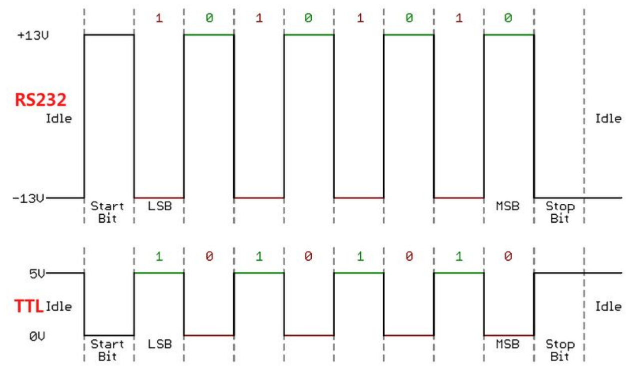


Figure 20: Timing Diagram for RS232

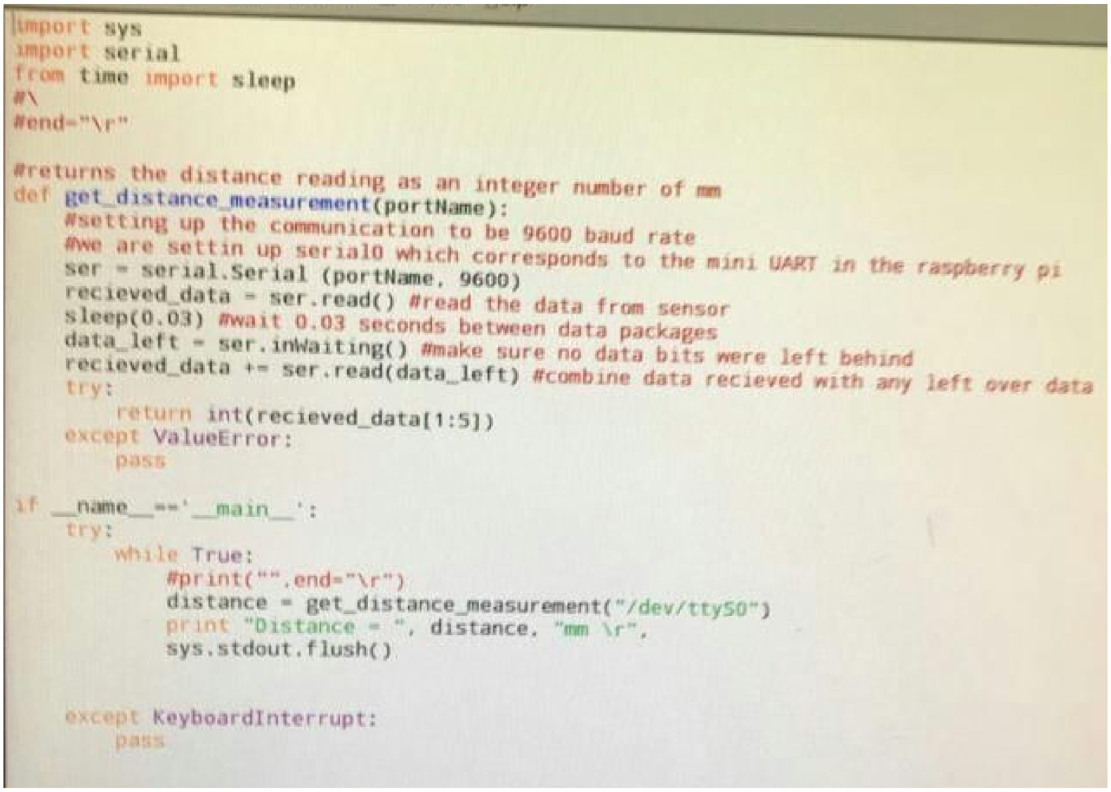
Raspberry Pi Zero/Rangefinder Integration:

A Raspberry Pi Zero W was purchased from Amazon as part of a Canakit bundle. The Canakit bundle came with a pre partitioned 8GB SD card that had the Raspbian OS ready to be installed. The testing setup for the pi requires a monitor, keyboard, mouse, usb hub, and power supply [16]. Once the pi was was set up and updated integration with the ultrasonic rangefinder could begin.

To communicate via TTL serial communication with the MB1013 ultrasonic rangefinder, the GPIO on the pi had to be configured to work with the mini-uart. The Raspberry Pi Zero has two hardware uarts available for use [14], but bluetooth is only capable of working with the more powerful PL011 UART, so the serial communication needed to work with the less robust mini-uart. Getting communication set up between the rangefinder and the Pi involved configuring the Raspberry Pi to enable the mini-uart on the GPIO pins, and then writing a python script that was capable of obtaining and interpreting the TTL data.

In order to configure the Raspberry Pi GPIO for serial communication via the mini-uart the line “enable_uart=1” needed to be added to the /boot/config.txt file on the Raspberry Pi. It should be noted that many outdated tutorials exist online that have you take unnecessary steps to configure the uart on the pi [17]. Many tutorials claim that the PL011 is necessary for serial communication and that the bluetooth needs to be disabled so it can be used to get adequate results. However this is not true, the mini-uart works for serial communication as long as the Pis clock frequency is set to 250Mhz. The reason people used to think the mini-uart didn't work was because a seperate line needed to be added to the /boot/config.txt file to set the clock to 250Mhz. If this was not done then the baud rate of the mini-uart was not consistent, so it appeared as if the mini-uart was not working. As of May 2016 The Raspbian OS has been updated so that the “enable_uart=1” command will also fix the clock to 250 Mhz so it is the only command needed to configure the PI for serial communication via GPIO pins 14(Tx) and 15(Rx) [19].

Once the Pi was configured a python script to read the serial data from the Ultrasonic sensor needed to be developed. In order to read the TTL data from the mini-uart the pyserial python library was used. The code was compiled into a simple function that can be used in the future to easily grab data from the mini uart. Using the function pictured below (Figure 21) distance information can be processed so that the pi knows when to send a warning via bluetooth to the android phone. Processing the distance information on the Pi will allow the collision avoidance device to use less of the phones processing power so the user experience is slightly improved.



```
import sys
import serial
from time import sleep
#\
#end="\r"

#returns the distance reading as an integer number of mm
def get_distance_measurement(portName):
    #setting up the communication to be 9600 baud rate
    #we are settin up serial0 which corresponds to the mini UART in the raspberry pi
    ser = serial.Serial (portName, 9600)
    recieved_data = ser.read() #read the data from sensor
    sleep(0.03) #wait 0.03 seconds between data packages
    data_left = ser.inWaiting() #make sure no data bits were left behind
    recieved_data += ser.read(data_left) #combine data recieved with any left over data
    try:
        return int(recieved_data[1:5])
    except ValueError:
        pass

if __name__=='__main__':
    try:
        while True:
            #print("",end="\r")
            distance = get_distance_measurement("/dev/ttyS0")
            print "Distance = ", distance, "mm \r",
            sys.stdout.flush()


    except KeyboardInterrupt:
        pass
```

Figure 21: Python Script for Data Reading from Sensor

Computer Vision/Android Development:

The original intent of the Winter Quarter 2018 with regards to computer vision was to investigate the feasibility of a computer vision system capable of detecting obstacles in the path of a moving camera (like a smartphone camera held by a distracted millennial). Initial attempts at finding a good image processing pipeline to get satisfactory results included the use of edge detectors operating on raw image data, attempting to cluster images into foreground / background and identifying “foreground” objects getting closer, the application of background subtraction, and [redacted] (redacted to protect IP).

However, all of these approaches were very inefficient and inaccurate - and even if they worked, it was unlikely that they would be portable to something with such strict resource limitations like a smartphone. The best algorithms for this task turned out to be a [redacted] feeding into a basic Canny edge detection algorithm which simply attenuates everything in an image but "edges", defined by local regions of sharp "contrast" in an image.

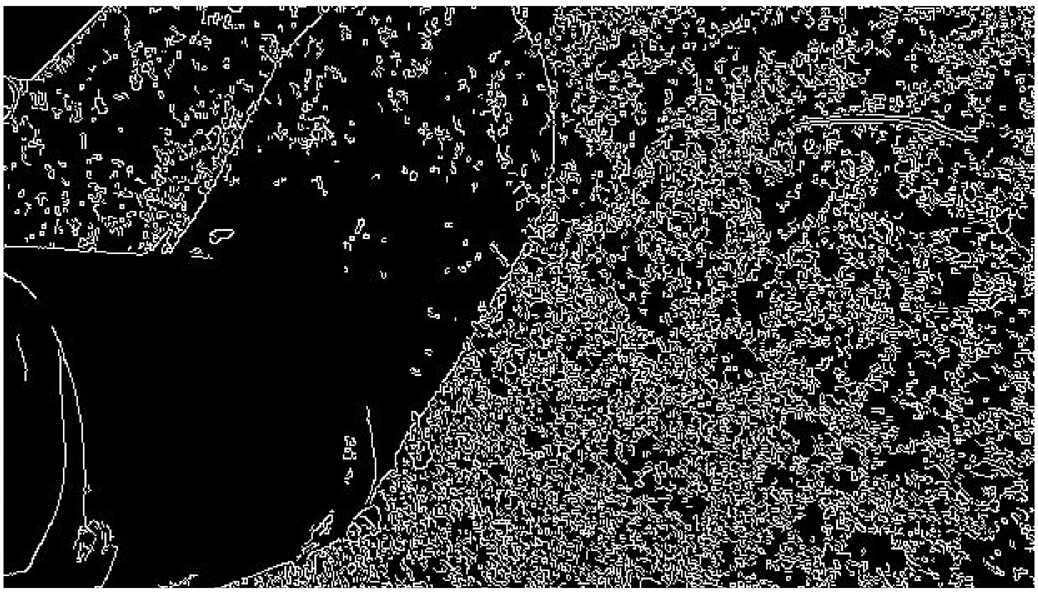


Figure 22: Edge-detection run on raw frame data

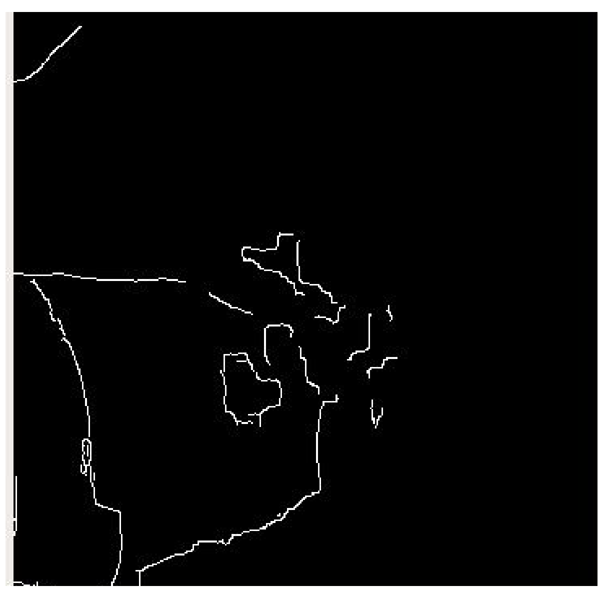


Figure 23: Edge-detection pre-processed with [redacted] algorithm.

It is a fairly simple matter to determine the “size” of detected obstacles from this pipeline - and this means that this pipeline can be used to directly satisfy customer needs / wants for this project. An Android app providing the basic functionality of detecting, if a user is walking and “on their phone”, oncoming obstacles, could easily be marketed.

Future plans for the computer vision pipeline include porting the pipeline to the Android OS, to be run on a smartphone, which will entail getting the processing algorithms onto an Android app in some capacity as well as making sure that the algorithms can be run at a reasonable rate, despite the resource constraints a smartphone imposes. Additionally, there may be some ways to make this pipeline quicker, as the research paper [redacted] is based off of notes some assumptions they made when relaxing the process to approximate [redacted] in a video, and these relaxations could potentially be taken a step further to reduce the computational requirements of this algorithm.

The final computer vision protocol utilized a package called JavaCV to port the OpenCV library to the Android platform. The aforementioned algorithms were implemented with JavaCV wrapper methods / objects which allowed for the exact same calls to be made as the Python demo which was used in the experimental phase to demonstrate the viability of the particular algorithm pipeline. The majority of this work was using the algorithm within the Android environment, which abstracts away the process of interacting directly with certain hardware features of an Android phone but at the same time that abstraction really obfuscates the code and has a steep learning curve. Thus, certain compromises had to be made to get the code to work. Namely, the resolution of the image had to be stripped down to enable any tolerable framerate during the filtering process (the process of removing noisy "surfaces" like shadows, grass, and pavement discussed in the experimental design section).

To gauge how likely it was that an obstacle is in front of a user from the edge data, a certain subsection of the image, shown below, had its non-black pixels counted. If that count was above a certain threshold, it was safe to assume that an obstacle was in the frame. This works circumstantially in different environments and different angles; having different settings for different use cases is a recommended feature to look into to make this more viable.

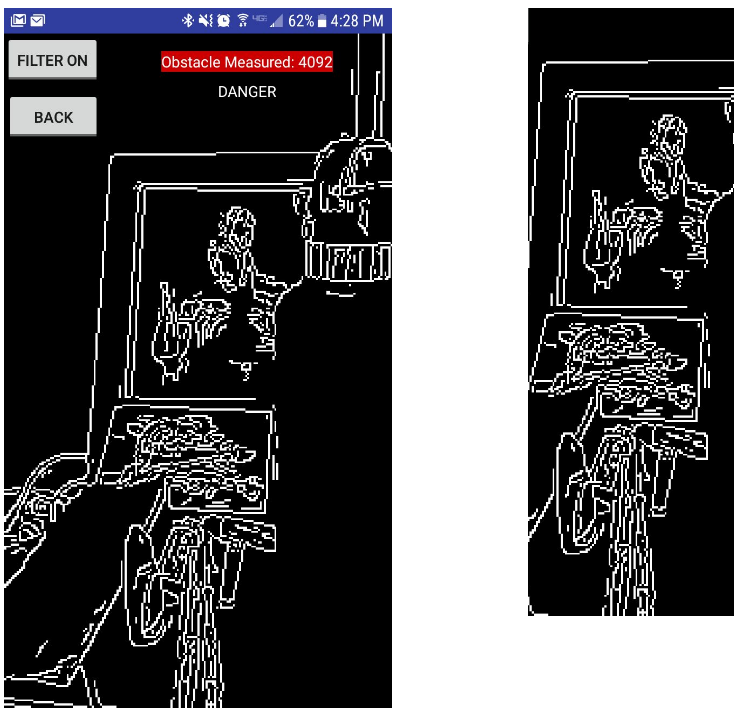


Figure 24: Original Edge Data/User Interface.

Note: The image on the right for Figure 23 shows the effective portion of image used for counting non-black pixels to determine obstacle presence from edge data.

To signal a user of danger two methods were employed: one, a readout of the count of non-black pixels was displayed; its background color and a corresponding text display below the readout would change (correspondingly) to green / “SAFE”, yellow / “CAUTION”, or red / “Danger”, based on the pixel count. Additionally, the Android-hardware interface was used to trigger a vibration when the pixel count exceeded the threshold for “Danger”.

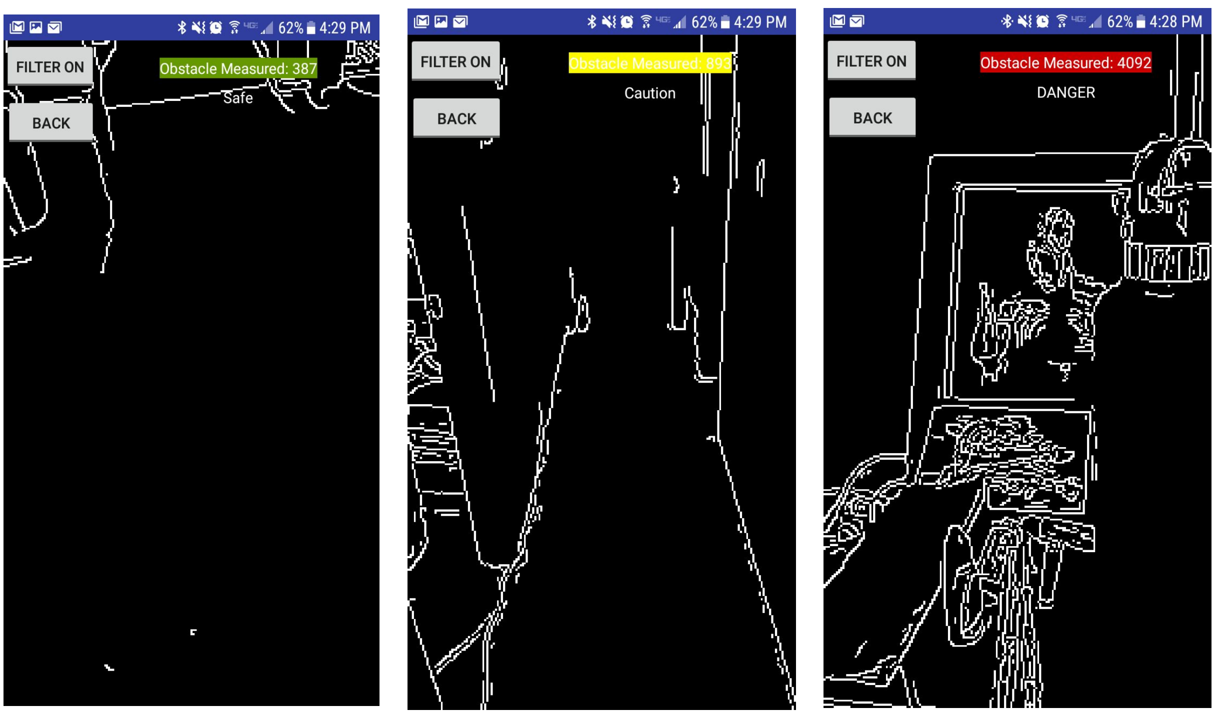


Figure 25: The Final User Interface For The Computer-Vision

Note: The color and text displays which give a readout of how many non-black pixels were counted, as well as an indication of whether or not a user is at-risk of colliding with an obstacle.

Finally, it is worth mentioning that the bluetooth activity, which connects to the Raspberry Pi and receives ultrasonic rangefinder readings over bluetooth, runs in the background while the computer vision activity is run, if the phone and the sensor were connected before the computer vision activity was initialized.

Power Supply:

The power source is arguably the most important part of any product. Choose a power source that is unreliable, and the consumer may be faced with a faulty product that doesn't even turn on or work. Utilize an unstable power source and your product might behave erratically, potentially damaging particular components and possibly harming the consume. This is why it was important to research all of the requirements for the components that are being used in the product.

The power source will be powering the following components: Raspberry PI Zero, MB1013 ultrasonic Rangefinder. According to Matbotix's provided datasheet for the MB1013 Rangefinder, it takes either a 3.3V or 5V power input, but previous experiments show that it performs best at 5V (increased range/accuracy). The Raspberry Pi Zero operates off of 5V/2A, while its processor runs at 3.3V. The Pi Zero can also supply up to 5V depending on which pin is used. The Raspberry Pi and Maxbotix datasheet tells us that the HRLV-Maxsonar sensor can be powered directly off the Raspberry Pi, as it is part of the rangefinder series that is optimized for use with microcontrollers.

Taking all of this into account, in addition to the fact that lithium ion batteries have historically shown to be unreliable/unstable for 'prototype' applications (without extensive testing and safety measures, lithium ion batteries can overload components and introduce danger to its surroundings), the power supply type that was chosen is a power bank, specifically the RAVPower 6700mAh Power Bank, which can provide 5V/2A, perfect for the Raspberry Pi Zero.

The power bank also offers the longest battery life, compared to other rechargeable batteries that were researched.

Unfortunately, after the rangefinder and UART were successfully implemented together off a traditional power source off a lab bench, when transitioning to the RAVPower Power Bank, data off the serial output pin of the rangefinder seemed to be ‘corrupted’ and not decipherable compared to using the prior power source. This could be because at the time of testing, a capacitor was not used as recommended by Matbotix, or because Python had not yet been implemented to interpret the serial output data. Another cause of concern was that when testing the 5V and 3.3V power supply pins of the PI Zero, multimeter readings indicated that only about half of that voltage was being supplied at the respective pins.

Additional experiments need to be completed to determine if the RAVPower Power Bank is the correct choice for a power source. These tests will take place after another PI Zero has been ordered, and if the RAVPower continues to underperform another power bank of a different brand will be ordered.

Bluetooth:

One of the main specifications of the project was to make the collision avoidance hardware communicate with a smartphone via bluetooth. The goal was to be able to stream the distance data to the phone so the app could determine if there was a potential collision. In order to get this functioning code needed to be developed for both an android smartphone as well as the raspberry pi to setup a server client relationship. The client, raspberry pi, waits to accept the connection from the server, android phone. As of right now the pi and smartphone need to be manually paired before they can connect, but this is something that could be added to the software in the future.

The raspberry pi code was written in python using the pybluez module. The code sets up the bluetooth module on the pi to be discoverable and waits in a loop for a connection from a known paired device. Once the connection message is received a bluetooth socket is opened so RFCOMM bluetooth communication can begin. Once the socket is opened the distance measurements are converted to strings before being sent to the android app for further processing.

The android application conde was a bit more complicated than the python code, and it was based largely on the documentation provided by google. Specifically the bluetooth chat application example proved on the android developer website was used and modified to get the bluetooth portion of the application up and running. The app starts by turning the phones bluetooth on and making the phone discoverable. Once this is completed the app searched for discoverable devices nearby that it could potentially connect to. The nearby discoverable devices are displayed in a list view and when the user selects the raspberry pi the connection process can begin. By tapping on the start connection button the phone will send the connection message to the raspberry pie and the two devices will set up a communication channel assuming they were properly paired. Once the connection is established the phone converts the message to an integer value distance in millimeters and checks whether the distance is within a 1.5 meter threshold. If there is an object closer than 1.5m the phone warns the user via text on the screen as well as vibrating the phone.

Encasement:

Through the entire project design period up to final integration of all subsystems, several prototypes of the device encasement were designed and printed. Common developmental changes throughout this product include: form-fitting design updates (changed as we decided what components to use), decreased size, optimal component location/placement. The final prototype includes and overhead case for the ultrasonic sensor (not displayed in picture for debugging purposes). The prototypes are shown below, in order of creation.

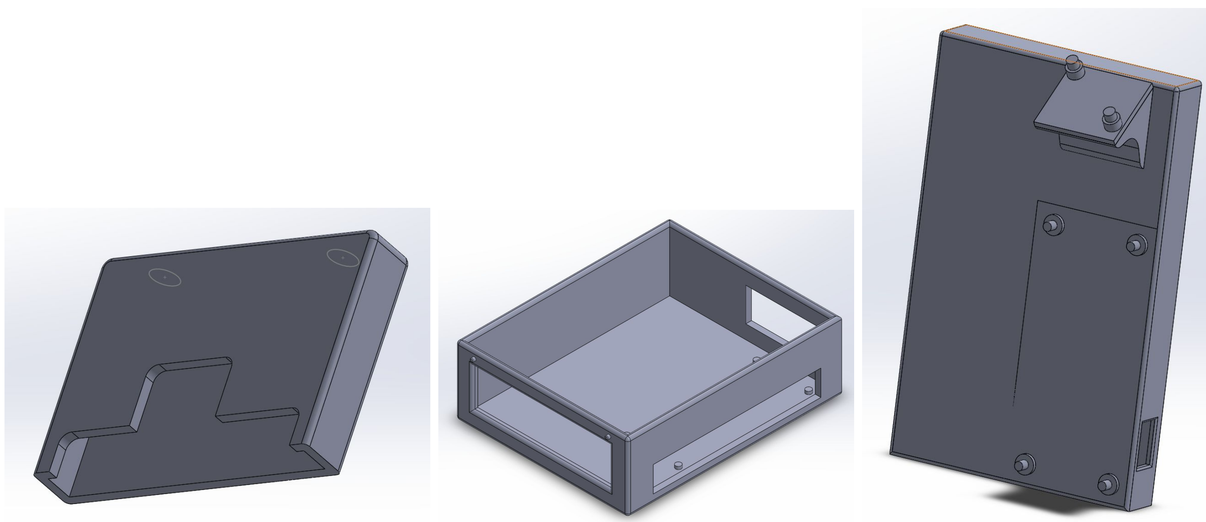


Figure 26: V1, V2, V3 Encasement Prototypes Respectively

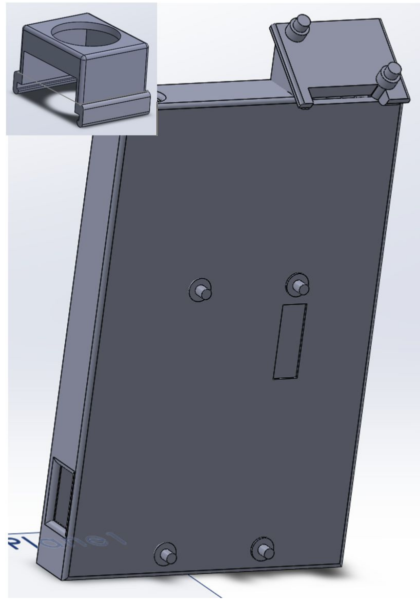


Figure 27: Final Prototype With Sensor Case

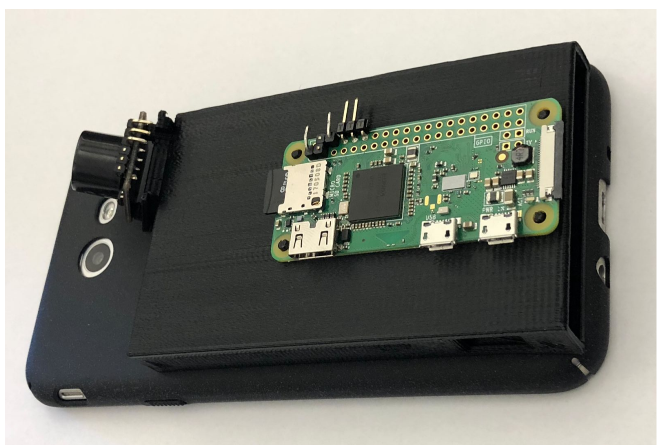


Figure 28: Final Prototype With Components Mounted

After several iterations, the final design featured a slim case that houses the rechargeable battery, with a cutout on the side allowing the battery to be charged via USB-C, and an opening on the bottom of the case to allow easy connection to the Raspberry Pi Zero W. The slim case has four mounting pegs on its face for the Raspberry Pi Zero W, with enough clearance for any components under the Pi.

On the top of the case is an angled mount for the ultrasonic sensor- the angle is 25 degrees (using the data from last quarter's phone hold experiment). The case is then attached to a basic flat shell phone case using heavy duty super glue, and the phone case is then ready to be put on the phone. The sensor cover (not pictured in Figure 28) simply clips onto the sides of the sensor mount using snap-fit joints by placing the cover over the sensor and pressing downward.

Notification Protocol:

After the final prototype was designed and tested, we added the notification protocol to alert the visually impaired (although the vibration still alerts smartphone users in general). In both the computer vision and the sensor distance calculations, we added thresholds that read as incoming obstacles in a dangerous distance. For the sensor, we tested how much time the average person would need to react to a vibration on their phone to set the best value for the threshold. We decided 1.5 meters was enough distance and time to alert the user without getting too close to the detected obstacle. Once the threshold was tested, we added the vibration function to our code that would alert the user that an obstacle was detected. For the computer vision, we added a threshold that measured the number of pixels found in the image and with all the filtering, we set a threshold that measured the number of pixels for an incoming obstacle. Through the combination of the two, the notification protocol was designed and implemented to the final prototype.

XI. References:

[1]"New Study Shows Three out of Five Pedestrians Prioritize Smartphones over Safety When Crossing Streets", *Libertymutualgroup.com*, 2017. [Online]. Available: https://www.libertymutualgroup.com/about-lm/news/news-release-archive/articles/new-study-shows-three-out-of-five-pedestrians-prioritize-smartphones-over-safety-when-crossing-streets. [Accessed: 16- Oct- 2017].

Description: This infographic shows the results of a survey conducted by Liberty Mutual Insurance regarding the issue of pedestrian safety while walking and using their phones. The survey helps illustrate that people understand the risks of walking while distracted, and shows why our product is needed.

[2]"Type n Walk", *Type-n-walk.com*, 2017. [Online]. Available: http://www.type-n-walk.com/. [Accessed: 16- Oct- 2017].

Description: This is the website for the Type n Walk app. This smartphone app is the main competition in the Collision Avoidance Smartphone market, and this website provides information on it. There are not a ton of references to Type n Walk on the internet so their website provide the most reliable source of information.

[3]"Overview - smartcane", *smartcane*, 2017. [Online]. Available: http://smartcane.saksham.org/overview/. [Accessed: 16- Oct- 2017].

Description: This is the website for the SmartCane. The SmartCane would be the main competitor in the visually impaired market, and this website explains what it is, and how it works.

[4]J. Chokkattu, "Nearly 1.5 billion smartphones were sold in 2016, a 5 percent increase from 2015", *Digital Trends*, 2017. [Online]. Available: https://www.digitaltrends.com/mobile/2016-smartphone-sales/. [Accessed: 16- Oct- 2017].

Description: This is an article on the sales of smartphones between Apple and Samsung which makes up a majority of the smartphone market. It compares the sales of the two companies against each other and as a whole.

[5]"Number of smartphone users in the U.S. 2010-2022 | Statista", *Statista*, 2017. [Online]. Available: https://www.statista.com/statistics/201182/forecast-of-smartphone-users-in-the-us/. [Accessed: 16- Oct- 2017].

Description: This is a statistical article on the increase of smartphones users in the past couple of years and shows the trend of increasing users for the next couple of years.

[6]"Over 110,000 road accidents are caused by Pokemon Go in just 10 days", *Mail Online*, 2017. [Online]. Available: http://www.dailymail.co.uk/sciencetech/article-3793050/Don-t-Pokemon-drive-110-000-road-accidents-caused-game-just-10-days.html. [Accessed: 16- Oct- 2017].

Description: This is an article on the effects of the release of Pokemon-Go and the increase in traffic accidents from both distracted drivers and distracted pedestrians on their phones playing the game.

[7]"Fact Sheet Blindness and Low Vision", *National Federation of the Blind*, 2017. [Online]. Available: https://nfb.org/fact-sheet-blindness-and-low-vision. [Accessed: 16- Oct- 2017].

Description: This article aggregates statistics on the visually impaired, and describes the lifestyle and adaptations such populations have adopted.

[8]"Smartphone addiction: blind people knocked over, injured", *Northern Star*, 2017. [Online]. Available: https://www.northernstar.com.au/news/smartphone-addiction-blind-people-knocked-over-inj/3236108/. [Accessed: 16- Oct- 2017].

Description: This is a study done on the the visually impaired and how often they get bumped into or knocked over due to pedestrians walking while being on their phone.

[9]"Distracted Walking: Injuries Soar for Pedestrians on Phones", *Ohio State News*, 2017. [Online]. Available: https://news.osu.edu/news/2013/06/19/distractwalk/. [Accessed: 16- Oct- 2017].

Description: A study by Ohio State University which correlates an increase in smartphone use with an increase in injuries for pedestrians.

[10]*DISTRACTED WALKING STUDY: Topline Summary Findings*. AAOS, 2017, pp. 1-6. [Online]. Available: http://www.anationinmotion.org/wp-content/uploads/2015/12/AAOS-Distracted-Walking-Topline-11-30-15.pdf [Accessed: 16- Oct- 2017].

Description: A study which polled adults from various demographics and compiled the results of their answers on distracted walking.

[11]"Blindness Statistics", *National Federation of the Blind*, 2017. [Online]. Available: https://nfb.org/blindness-statistics. [Accessed: 16- Oct- 2017].

Description: This article provides additional statistics about the lifestyle of blind or visually impaired individuals.

[12]"Facts and Figures on Adults with Vision Loss - American Foundation for the Blind", *Afb.org*, 2017. [Online]. Available: http://www.afb.org/info/blindness-statistics/adults/facts-and-figures/235#lifestyle. [Accessed: 16- Oct- 2017].

Description: This article provides statistics about adults coping with vision loss, and how it affects their lives.

[13]"Here Are The States Where The Most People Walk Or Bike To Work", *Businessinsider.com*, 2014. [Online]. Available: http://www.businessinsider.com/here-are-the-states-where-the-most-people-walk-or-bike-to-work-2014-7. [Accessed: 29- Nov- 2017].

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[19] W, R. and Kit, S. (2018). *Getting Started with the Raspberry Pi Zero Wireless - learn.sparkfun.com*. [online] Learn.sparkfun.com. Available at: https://learn.sparkfun.com/tutorials/getting-started-with-the-raspberry-pi-zero-wireless [Accessed 23 Mar. 2018].

Description: Instructions from setting up Raspberry Pi for serial communication with mini-uart.