Vehicle Detection Cane

Team 42 - ECE445 - Spring 2020 - Design Document

Neva Manalil, Nick Halteman, Aditi Panwar
TA: Johan Mufuta

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1. Introduction

1.1 Objective

In 2016, pedestrian fatalities accounted for 16% of all traffic fatalities [1]. Those who are severely visually impaired are more susceptible to being involved in a traffic accident as they are not able to see oncoming traffic. Instead they either have a guide dog or rely on using a cane and their hearing to determine if an area is safe to walk. Gas fueled vehicles make a loud noise when driving by, but electric vehicles are virtually silent. With electric vehicles becoming more common it becomes more difficult for blind people to navigate as they cannot easily determine if a street is safe to cross.

Our solution for determining if an area is safe to walk is a battery-powered cane attachment that detects and alerts the user when a vehicle is passing in front of them. When activated by pressing a button, it uses a radar sensor to determine if there are cars or other fast moving vehicles in front of the user and alerts the user with vibration if it is not safe to walk.

1.2 Background

In an article by The Telegraph [2] on how a visually impaired woman was narrowly saved by a pedestrian from being hit by an electric vehicle, she mentioned that even her guide dog failed to recognise the car since there was no noise or fumes from the exhaust. This incident has really impacted her confidence of walking outdoors alone. This is just one of the many stories and electric cars are now viewed as a hazard for the visually impaired.

There have been a number of solutions proposed to solve this problem. One of which is making the electric cars emit a warning sound [3]. This hasn't been implemented yet and might also be expensive to incorporate in the cars.

A number of smart canes have been made to assist visually impaired in walking by themselves. weWalk [4] is a smart white cane that uses an ultrasonic sensor to detect any obstacles above chest level and warns the user by vibrating their handle. It can be paired with smartphones to use voice assistance and google maps with a cost of $500.

UltraCane [5] is also another smart cane that detects obstacles with a dual range, narrow beam ultrasound system.The ultrasound transducers provide range data on the closest potential hazards. It cost around $760 and can detect street obstacles within 2 to 4 metres.

Bat 'K' Sonar Cane [6] radiates ultrasonic waves to insonify objects in the path of a blind walker. The reflection from the objects return to the sonar unit and converted electronically into a unique sound based "image" of the landscape that gets transmitted to a set of headphones worn by the blind traveler. It costs $640 and also doesn't target moving obstacles.

One of the most successful smart canes is the "EyeCane" [7], developed by a team of researchers at The Hebrew University of Jerusalem, which uses infrared rays to detect obstacles within 5 metres, and communicated with the users through sound and vibration. It is relatively faster at detecting obstacles than other similar devices but still focuses on stationary objects.

Our solution is designed for visually impaired people to protect themselves from electric cars and give them more autonomy.

1.3 Visual Aid

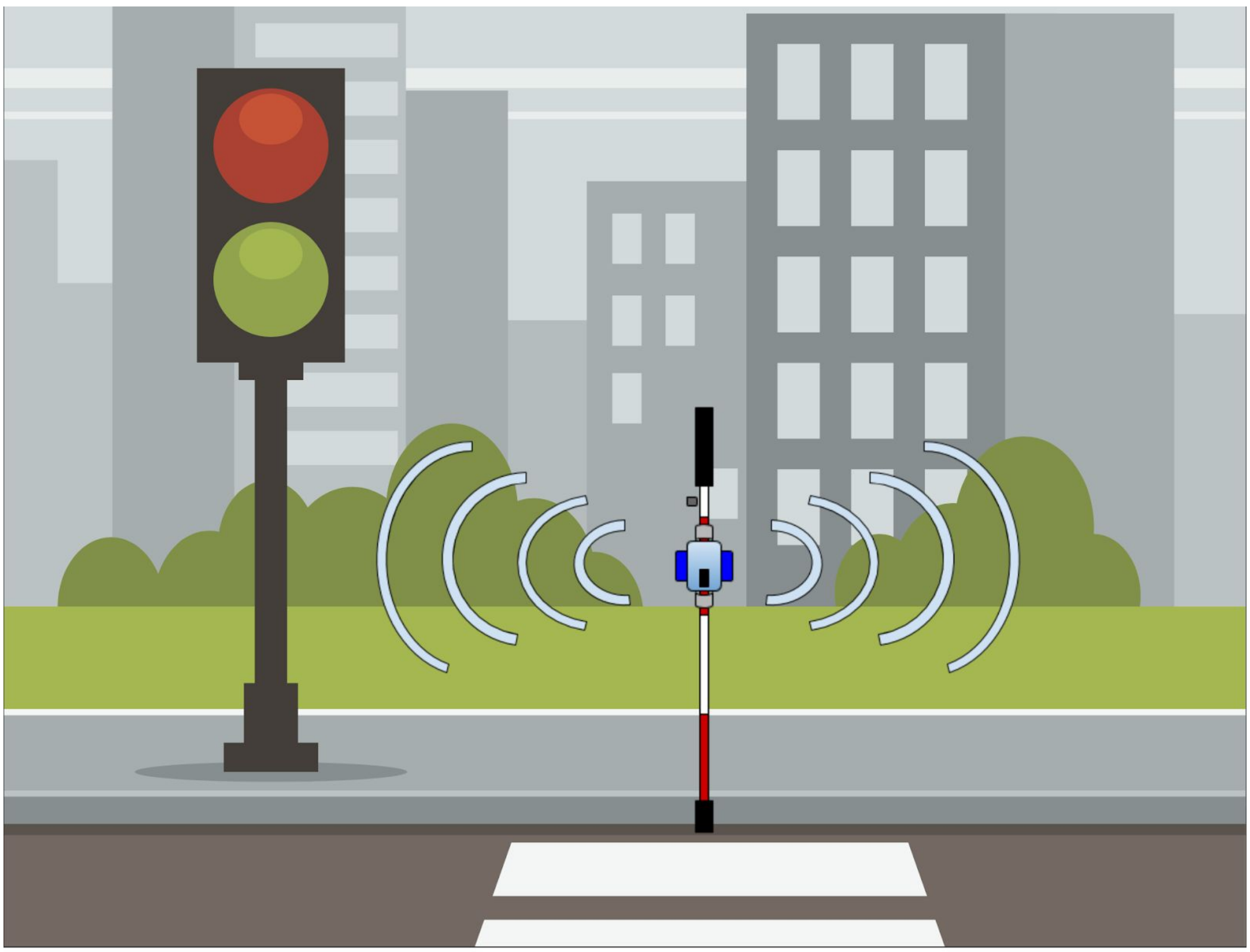

Fig 1 Visual Aid: When the user approaches a crosswalk, they can activate the vehicle detection cane attachment which will use a doppler radar to detect oncoming traffic (represented with blue lines). If a vehicle is detected, then the device will notify the user through vibration feedback.

1.4 High-Level Requirements List

1. The device only detects vehicles travelling faster than 5mph.

2. The device selectively detects cars approaching the crosswalk.

3. The device can attach to a standard blind cane.

2. Design

Our design is made of three subsystems: the sensor/control subsystem, the user interface subsystem, and the power subsystem. The power supply subsystem is responsible for supplying stable 5V and 3.3V power to the other subsystems. An additional raw battery voltage signal is output to check the battery level. The sensor/control subsystem scans for vehicles and controls components in the user interface subsystem. The user interface subsystem consists of all components that interface with the user.

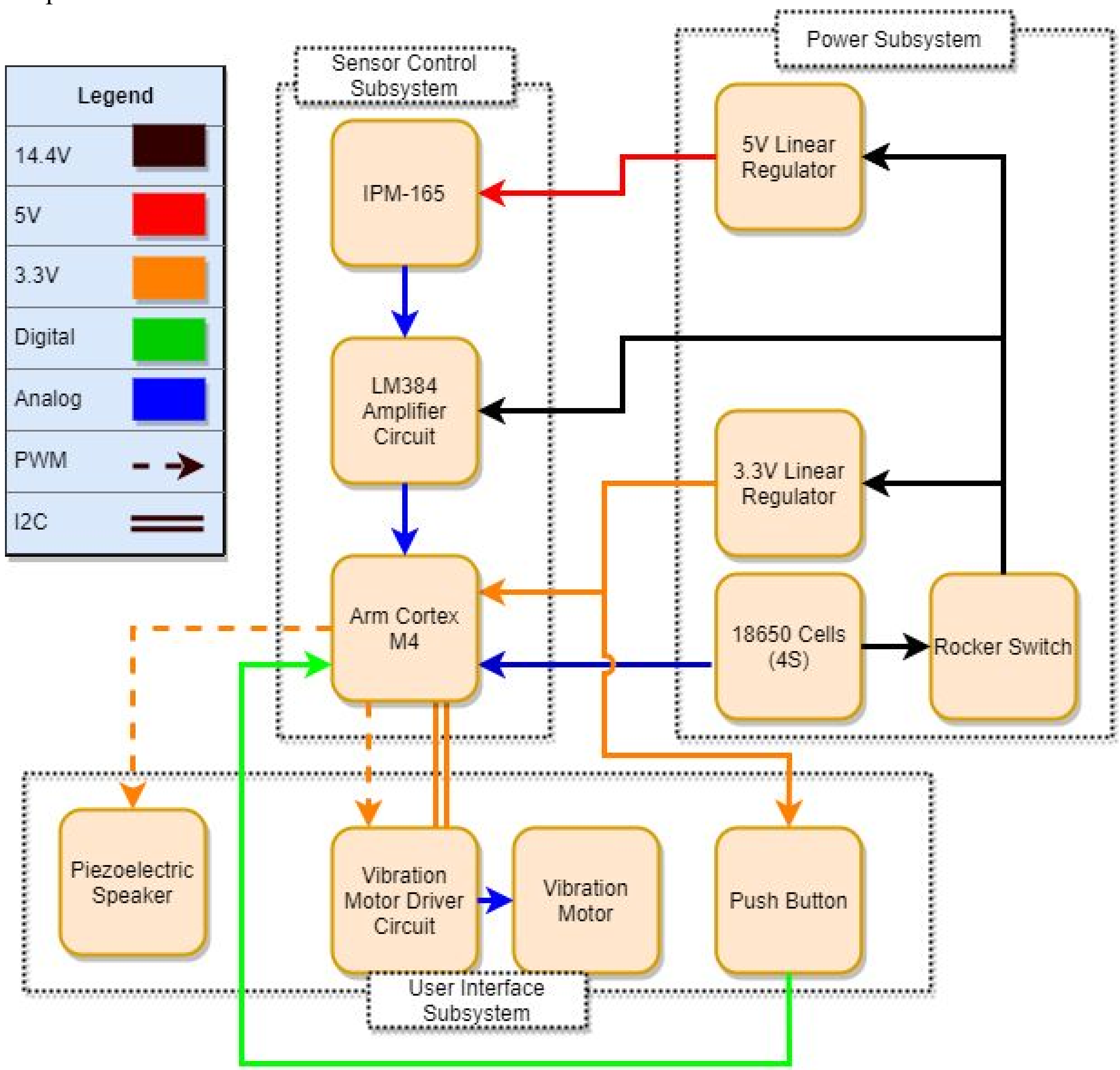

Fig 2 Block Diagram: Our design is divided into three main subsystems: Power, Sensor Control, and User Interface.

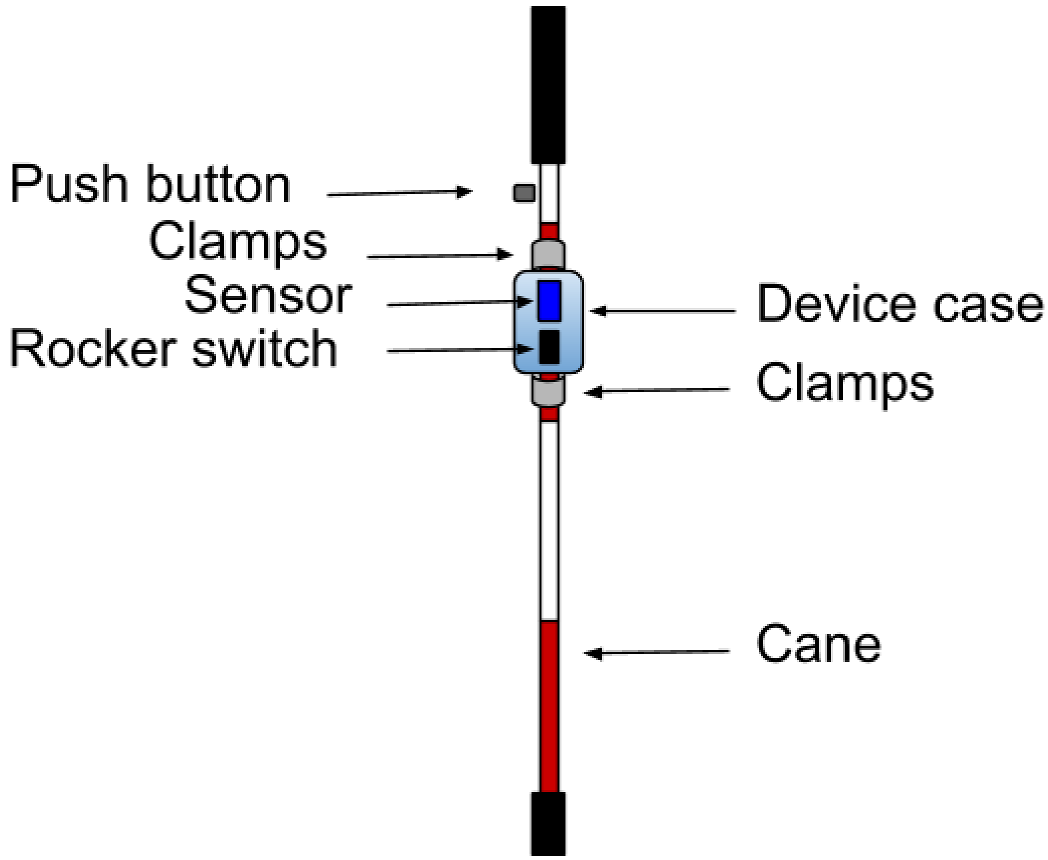

Fig 3 Physical Design: The device attaches to the body of the cane using clamps. The user will hold it in an upright position to scan the environment. The push button is easily accessible on the back of the device facing the user to be easily accessible during operation and serves as a reference for the location of the scanner.

The system is designed to attach to the handle of a cane using clamps. The main body is detached from the cane shaft to allow it to be gripped the same during normal operation. The push button needs to be easily accessible during scanning, so it is positioned at the rear near the user's thumb. The push button's location also serves as a physical reference to aid in aiming the scanner.

2.1 Sensor Control Subsystem

The Sensor Control subsystem is responsible for detecting vehicles and controlling the user interface of the system. The function of this subsystem is very critical as it is majorly responsible for our first two high level requirements.

To detect incoming vehicles, our design calls for a doppler radar sensor, for which we have selected the IPM-165. The IPM-165 is a 24GHz radar sensor module with a very simple analog interface consisting of only 3 connections. 2 pins are used for power (+5V and GND) and the other is an analog output signal. Our primary reason for selecting this sensor over others is cost as higher grade radar sensors can easily exceed $100. Additionally, as compared to other cheap radar sensors, the IPM-165 operates at 24Ghz which will help improve the range of the device as compared to lower frequency options.

The IPM-165's output signal needs to be amplified before it can be of any use, so to amplify the signal before it goes to a DAC, we will use a LM384 audio amplifier. This amplifier will be powered by the 12V regulator in the power supply and have a 10k potentiometer to adjust the output level to the DAC. This potentiometer will not be accessible to the user from the outside of the device and is only for debugging/repair.

The heart of the subsystem is the ARM Cortex M4 Microcontroller. We selected this microcontroller because it has many functions available to accelerate common DSP operations. It also has enough PWM and I2C outputs to control the various devices in the user interface subsystem. It will be powered by the 3.3v linear regulator.

<u>2.1.1 Microcontroller Programming</u>

The programming of the microcontroller is possibly the most crucial aspect to the success of the design. Once the device is powered on, the microcontroller will have two main modes of operation: standby and scan.

While the device is powered, but the push button is not depressed, the device is in standby mode. In this mode the device will periodically poll the push button input pin, waiting for it to go low (pullup resistor setup).

When the push button input drops low, the microcontroller will transition into a scanning loop, which reads data from the DAC into a large buffer. The size of the buffer will be adjusted as necessary to maximize detection accuracy. Once the buffer is full, new data will go in one end and the old data will be shifted back. Data at the end of the buffer is deleted. By analyzing the frequency content of the buffer, the microcontroller will determine the velocities of objects in front of the sensor and perform filtering to ignore objects that aren't vehicles. If there is an object moving faster than 5mph approaching the sensor, the microcontroller will trigger the vibration motor over I2C with the intensity indicating the urgency of the detection, faster objects being more urgent.

Regardless of which mode the device is in, it will check the voltage level of the battery (input on an analog pin) and if it indicates the battery is below 5% it will exit scan mode (if applicable) and emit periodic PWM bursts to the piezo buzzer to indicate the low battery state.

Requirement	Verification
The sensor control subsystem detects cars travelling above 5mph.	1. Mark a spot 20m away from a designated scanning area on the side of the road. 2. Drive a car at 5mph over the spot while scanning with the device from the side of the road. 3. The device should vibrate.
The sensor control subsystem does not detect people.	1. Have a person walk in front of the sensor while it is scanning at 5m, 10m, 15m, 20m, and 25m. 2. The device should not vibrate. 3. Repeat at 10mph increments up to 45mph.

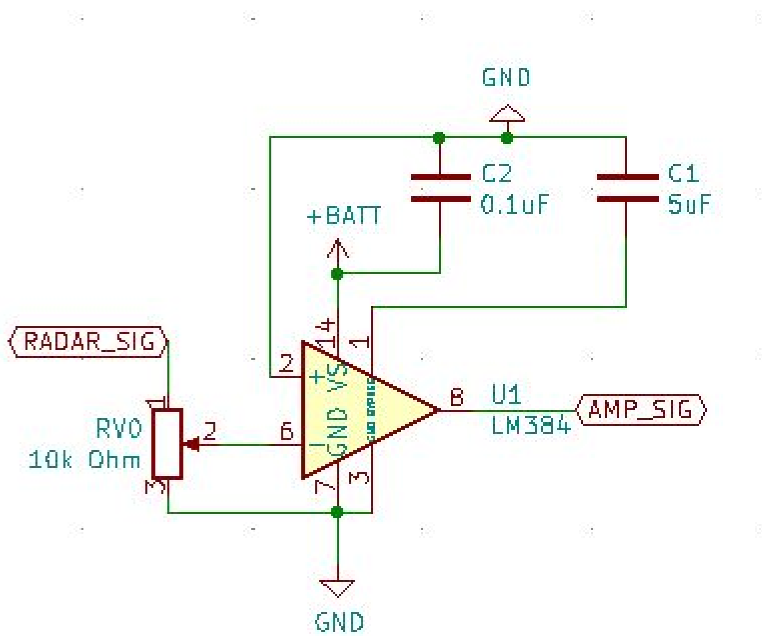

Fig 4 Amplifier Circuit

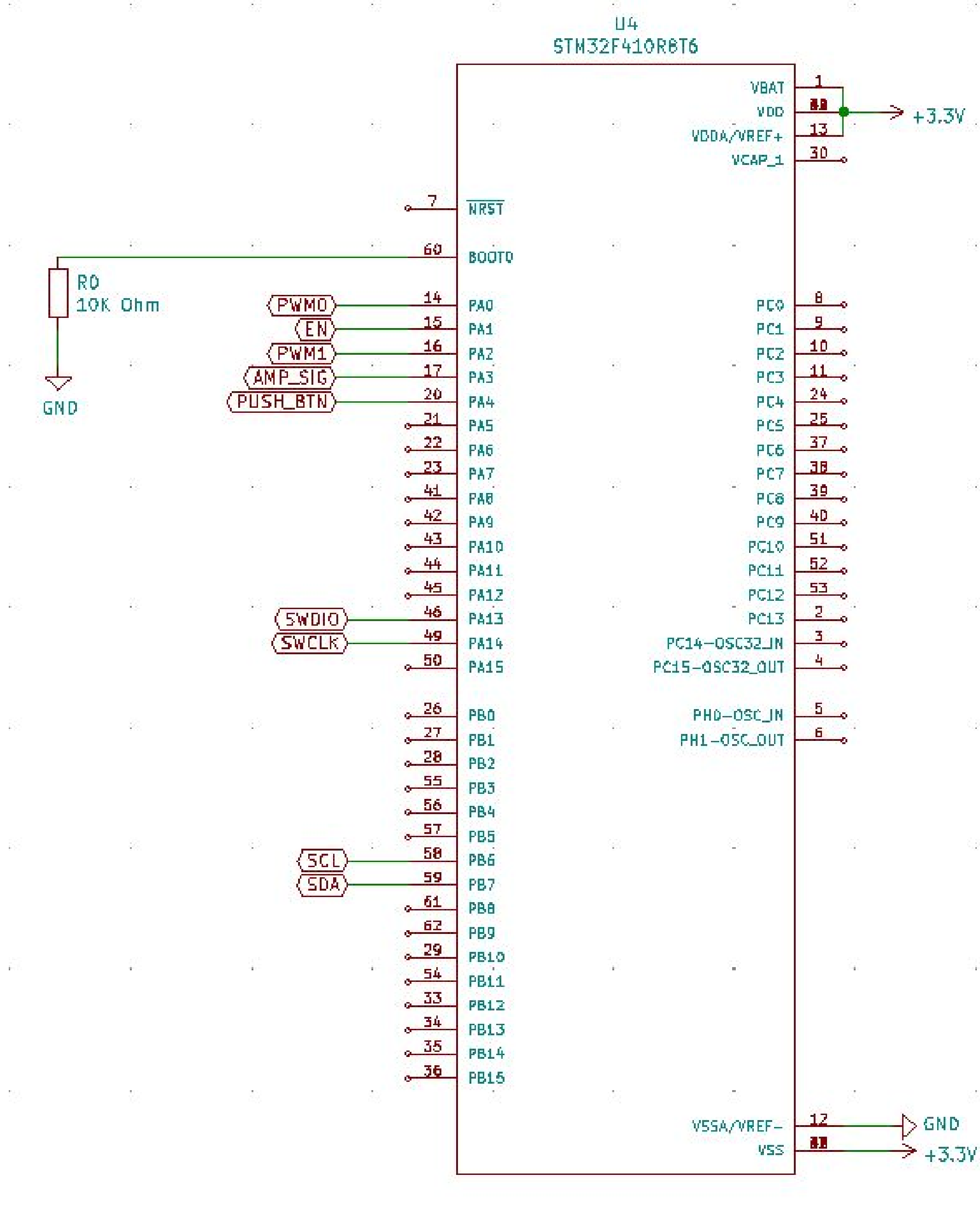

Fig 5 ARM Cortex M4 Microcontroller Circuit

2.2 User Interface Subsystem

The user interface subsystem is responsible for providing user input and feedback to the user when a vehicle is detected.

As the user is severely visually impaired, all user input will have a notification tone from the piezoelectric speaker. A rocker switch is used to turn the device on and off. Turning the device on and off will each have a unique tone played. The speaker will also play a tone when the device reaches a low battery state, when the battery is at 10% capacity.

A push button is used to enable the sensor control subsystem and set it to an active mode. If the sensor subsystem is not active, then the user will not receive any vibration feedback when a vehicle is detected. The push button must be depressed in order to activate the sensor control subsystem.

A vibration motor provides vibration feedback to the user when a vehicle is detected by the sensor control subsystem.

Requirement	Verification
When the battery voltage is read to be less than 10%, the speaker periodically beeps.	1. Use a benchtop power supply in place of the battery cells. 2. Set the voltage to simulate 10% charge. 3. The device should beep periodically.
The device scans when the button is pressed	4. Mark a spot 20m away from a designated scanning area on the side of the road. 5. Drive a car at 5mph over the spot while pressing the button with the device from the side of the road. 6. the device should buzz.

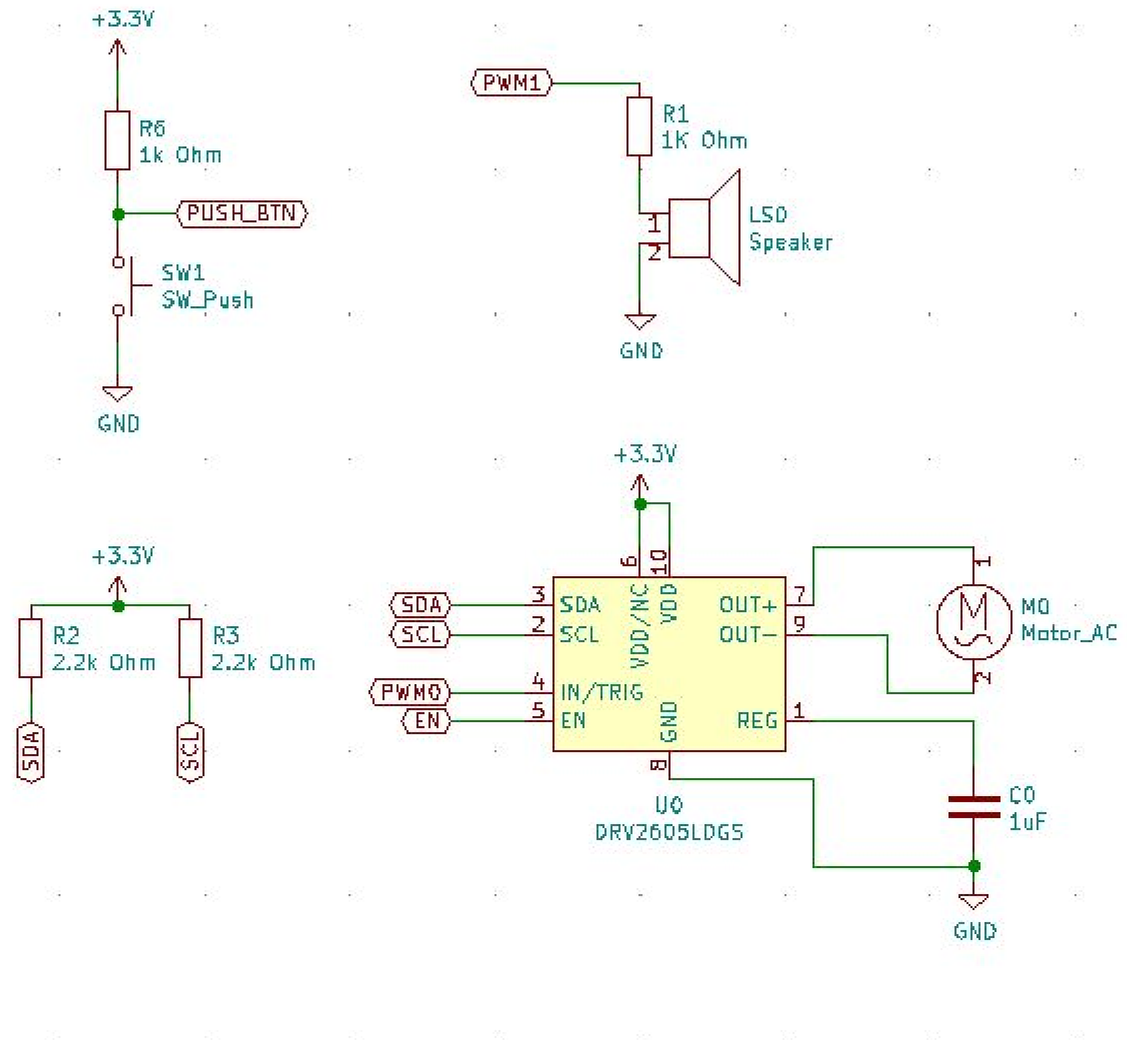

Fig 6 User Interface Subsystem Circuits

2.3 Power Subsystem

The power system is responsible for providing set voltages to the other subsystems. It outputs a raw approximately 14.4v level straight from the battery, and two regulated levels at 3.3v and 5v. The regulated levels are produced by two linear voltage regulators at their respective voltage levels. There is an additional ⅕ the battery level that is used to measure the voltage of the battery. This is produced with a simple resistor voltage divider.

The batteries we selected are 18650 cells because of their higher voltage and ease of recharging. They are held in two dual 18650 cell holders that can be accessed via a panel for removal and charging with a seperate charger.

Requirement	Verification
All voltage levels remain within 10% of their expected values during a scan.	1. Use a benchtop multimeter to probe the output of each linear regulator 2. Measure the voltage during a scan.

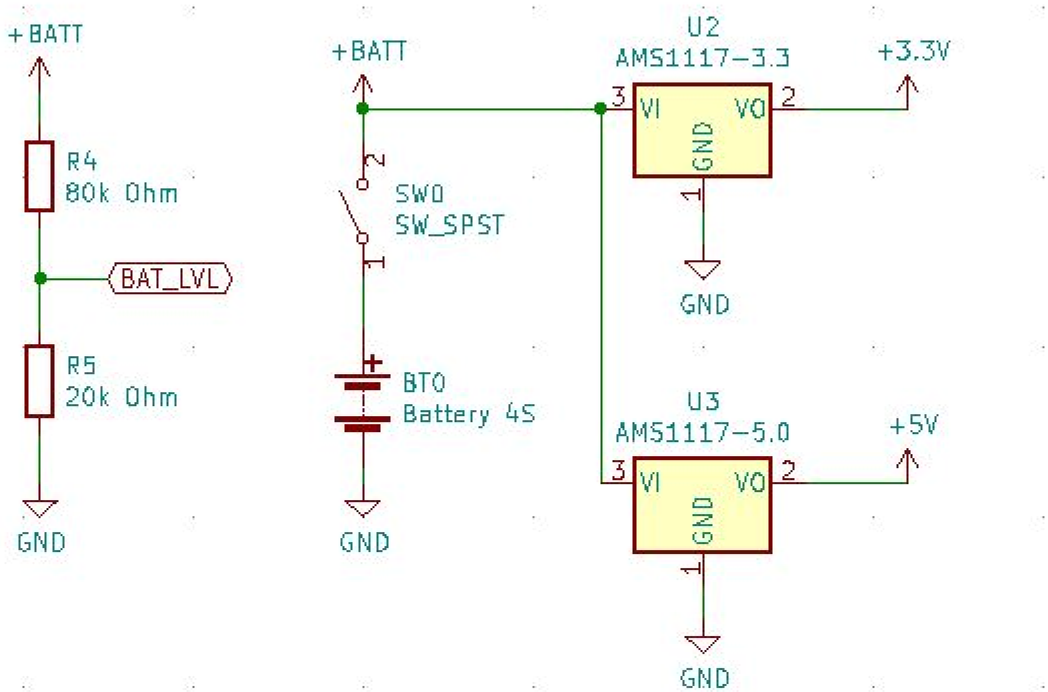

Fig 7 Power Subsystem Circuits

2.4 Tolerance Analysis

The most critical aspect of our design is the vehicle detection through the use of a doppler radar. Our requirement is to detect vehicles moving faster than 5mph. For our radar an amplifier circuit is necessary in order to prevent any unwanted noise from being registered as a vehicle. For the tolerance analysis, we will determine the cutoff frequency for the amplifier in order to most accurately detect vehicles that approach a crosswalk. First, typical vehicle stopping distance will be examined. Second, the vehicle stopping distance will be applied to the doppler formula to determine the cutoff frequency for the amplifier circuit.

2.4.1 Vehicle Stopping Distance Tolerance

Detecting vehicles early enough is critical to the safety and effectiveness of our project. A bare minimum required detection range can be established by estimated vehicle stopping distances. It is critical we detect vehicles before they are closer to the user than their stopping distance. A detection within the stopping distance does not allow the driver to stop before reaching the user, which poses obvious safety problems.

Vehicle stopping distances are dependent on vehicle type, environmental conditions, and vehicle speed as shown in Figure 5. To ensure our device is the safest it can be, it needs to be able to detect all types of vehicles and have a safety tolerance for dangerous situations, like brake power assist failure. Accounting for the worst case scenario keeps our users the safest.

TABLE II - STOPPING DISTANCES

Vehicle Test Speed (miles per hour)	Stopping Distance in feet for tests indicated															
	I-1st (preburnished) & 4th effectiveness; spike effectiveness check				II-2d effectiveness				III-3d (lightly loaded vehicles) effectiveness					IV-Inoperative brake power and power assist unit; partial failure		
	(a)	(b)	(c)	(d)	(a)	(b) & (c)	(d)	(e)	(a)	(b)	(c)	(d)	(e)	(a)	(b) & (c)	(d) & (e)
30..................	[1]57	[1,2]65	[1,2]69 (1st) [1,2]65 (4th and spike) [1]72	88	[1]54	[1]57	78	[1,2]70	51	57	65	84	70	114	130	170
35..................	74	83	91	132	70	74	106	96	67	74	83	114	96	155	176	225
40..................	96	108	119	173	91	96	138	124	87	96	108	149	124	202	229	288
45..................	121	137	150	218	115	121	175	158	110	121	137	189	158	257	291	358
50..................	150	169	185	264	142	150	216	195	135	150	169	233	195	317	359	435
55..................	181	204	224	326	172	181	261	236	163	181	204	281	236	383	433	530
60..................	[1]216	[1]242	[1]267	388	[1]204	[1]216	[1]310	[1]280	[1]194	[1]216	[1]242	[1]335	[1]280	[1]456	[1]517	[1]613
80..................	[1]405	[1]459	[1]510	NA	[1]383	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
95..................	[1]607	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
100.................	[1]673	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

[1] Distance for specified tests. [2] Applicable to school buses only. NA = Not applicable
Note: (a) Passenger cars; (b) vehicles other than passenger cars with GVWR of less than 8,000 lbs; (c) Vehicles with GVWR of not less than 8,000 lbs and not more than 10,000 lbs; (d) vehicles, other than buses, with GVWR greater than 10,000 lbs; (e) buses, including school buses, with GVWR greater than 10,000 lbs.

Figure 8: National Highway Traffic Safety Administration vehicle stopping distance test results indicate a maximum stopping distance of 358ft (109m) for vehicles travelling below 45mph [8]

Considering our device's use case being urban environments, where facilities exist to enable cane users to navigate walkways and street crossings in the first place, we shouldn't expect our users to need to cross streets with a speed limit above 45mph. This could be a rated warning for the device that users must obey. In Illinois, urban streets have a speed limit of 30mph unless otherwise posted [9], 15mph lower than this maximum rating. It is reasonable to expect crossings above this limit to either have facilities in place to allow for safe crossings (eg. signals that stop all cross traffic to allow pedestrians to cross safely) or have an available alternate route, which would allow cane users to navigate any urban environment.

Using the data from Figure 5, in the worst case scenario any vehicle can stop within 358ft or 109m from an initial speed of 45mph. Adding a 20% safety tolerance we should consistently detect vehicles within 130m. Using medium range radar techniques, we can reasonably expect our radar sensor to detect metal objects at up to 150m, which is well above the safe 130m mark.

2.4.2 Amplifier Circuit Tolerance

Our goal is to detect vehicles moving in the cross traffic approaching and in front of the user. The amplification circuit is responsible for both amplification and bandwidth limitation. The doppler formula, as shown in InnoSenT Application Note III is [9]:

$$f_{Dopp} = 2f_0 \cdot \frac{v}{c_0} \cdot \cos \alpha$$

f_{Dopp}	Doppler- or differential frequency
f_0	transmit frequency of the radar
v	velocity of the moving object
c_0	speed of light
α	angle of the direction of the object motion with the direct connecting straight line between sensor and object

We are using a 25 GHz transmit frequency radar which then simplifies the equation to:

As described in section 2.4.1, in the worst case scenario a vehicle will stop from an initial speed of 45mph. In our high level requirements, we outline a minimum speed of 5mph. By applying this to the equation above, we can conclude that the doppler frequency of the amplifier circuit should be between 220 Hz and 3.2 kHz.

3. Cost and Schedule

3.1 Cost Analysis

3.1.1 Parts

Item	Part # or Manufacturer	Count	Price
IPM-165 24GHZ Radar Module	80.00000061	1	$15.29
LM384 Audio Amplifier	LM384	1	$1.95
Dual Operational Amplifier	MC33078	1	$0.54
3.3v linear regulator	AMS1117-3.3	1	$1.57
5v linear regulator	AMS1117-5.0	1	$1.57

Dual 18650 cell holder	SACKORANGE	2	$6.99 x 2
18650 charger	Lorox	1	$13.99
18650 cell 4 pack	18650	1	$9.99
STM32 Dev Board x2 + Programmer	initeq	1	$18.99
ARM Cortex M4 Microcontroller	STM32F410R8T6		$3.31
Vibration Motor	ROB-08449	1	$2.15
Haptic Motor Driver	DRV2605LDGSR	1	$2.66
Piezoelectric speaker	CPT-1625-80-SMT-TR	1	$1.53
Rocker switch	KGC2ANB1BBD	1	$5.36
Push button	KFB2ANA1BBB	1	$3.85
1k Resistor		2	$0.10 x 2
2.2k Resistor		2	$0.10 x 2
10k Resistor		1	$0.10
20k Resistor		1	$0.10
80k Resistor		1	$0.10
10k Potentiometer		1	$1.99
0.1uF Capacitor		1	$0.10
1uF Capacitor		1	$0.10
5uF Capacitor		1	$0.10
Total Cost	**$97.57**		

3.1.2 Labor

From the ECE Illinois website, the average starting salary for a student graduating with a degree in computer engineering is $84,250 [11]. If working 52 weeks a year for 40 hours a week that salary is equivalent to earning $40.50/hour. We estimate our work period to be 16 weeks with an estimated work week of 15 hours per week. For three people this would lead to a total cost of:

3 people x $40.50/hour x 15 hours/week x 16 weeks x 2.5 = **$72,900**.

3.1.3 Total Cost

$97.51 (Parts) + $72,900 (Labor) = **$72,997.51**

3.2 Schedule

Week	Neva	Aditi	Nick
2/24	Complete Design Document		
	Initial conversation with machine shop		Research antenna design
3/02	In depth research about the components we need to purchase and their power consumption		
	Revising the design document		
3/09	PCB Design		
	Familiarizing with the software used for the sensor and writing basic scripts for the sensor		
	Purchase Components		
3/16	Spring Break		
3/23	Order the PCBs		
	Testing the radar		Programming the microcontroller
3/30	Radar Testing and Debugging		
4/6	Radar Testing and Debugging		
	Final Assembly, Report, and Presentation		
4/13	Final Report and Presentation		
4/20	Mock Demo		
4/27	Demonstration		

5/4	Final Presentation

4. Ethics and Safety

There are a few safety hazards that must be taken into consideration with our product. As an electrical device designed to be used outdoors, the device will be subjected to conditions such as potential water damage or being accidentally stepped on. Our component could also be conductive if there is any short or open circuit. Thus to avoid all these problems we'll make sure the electrical component is well covered to protect the system and the user.

We are using rechargeable batteries to power all our other subsystems so we need to make sure that the power subsystem is secure and doesn't heat up with long duration of use since it could be uncomfortable for the user and harmful to the other subsystems.

Since our product caters to the need of visually impaired, we must be realistic in stating claims about the features and success of the product, in accordance with IEEE Code of Ethics #3 [12]:

'to be honest and realistic in stating claims or estimates based on available data'.

We will make sure we vigorously test our product with different parameters each time to get a better accuracy of the success of our product.

Since we'll need to test the product with an actual vehicle approaching at different speed and distance we need to ensure the safety of our team which adheres to ACM Code of Ethics #3.1 [13]:

'Ensure that the public good is the central concern during all professional computing work'.

This covers the point that we create the most optimum design for the safety of our target customers as well.

For the success of this product we will consider all the constructive criticism and suggestion on improving the performance which adheres to the IEEE Code of Ethics #7 [12]:

'to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others'.

We understand the difficulty of our project and that it'll require a great level of testing and modification to be finally used as a product that visually impaired can rely on.

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