BLUETOOTH SPEAKER WITH MOTION-BASED AUTOMATED VOLUME ADJUSTMENT

Design Document

Team #69
Chirag Kikkeri
Raj Pulugurtha
Dhruv Vishwanath

ECE 445
Spring 2023
TA: Abhisheka Mathur Sekar

Table of Contents

Introduction

Problem

When driving and listening to music, oftentimes we want to change the volume based on the speed of the vehicle. For example, when moving at higher speeds, drivers will raise the volume to better hear the music, and when stopped at a stop light, will lower the volume significantly. This issue is a clear nuisance, but can also present a major safety hazard that takes the user's concentration away from driving and to adjusting the volume, especially for drivers who do not use the car sound system.

This problem doesn't only pertain to drivers. Anyone who is on any type of vehicle, be it a bike, scooter, or skateboard, will suffer from the same problem of not being able to hear their media at high speeds, or the volume being too high at low speeds.

Solution

Our solution is to create a speaker that will automatically increase and decrease volume based on the speed that the speaker is moving. The speaker will be a portable Bluetooth speaker that the user can take in and out of the vehicle. Users will also have the ability to set the minimum and maximum volumes to better personalize their listening experience. It will also contain a strip of LEDs that tell the user the current volume as more LEDs are lit. The speaker system will have two modes: one for when it is moving, and one for when it is stationary. When it is in the stationary mode, the user can increase and decrease volume with buttons. When it is in moving mode, the automatic volume control is turned on, so that the user focuses on driving.

Visual Aid

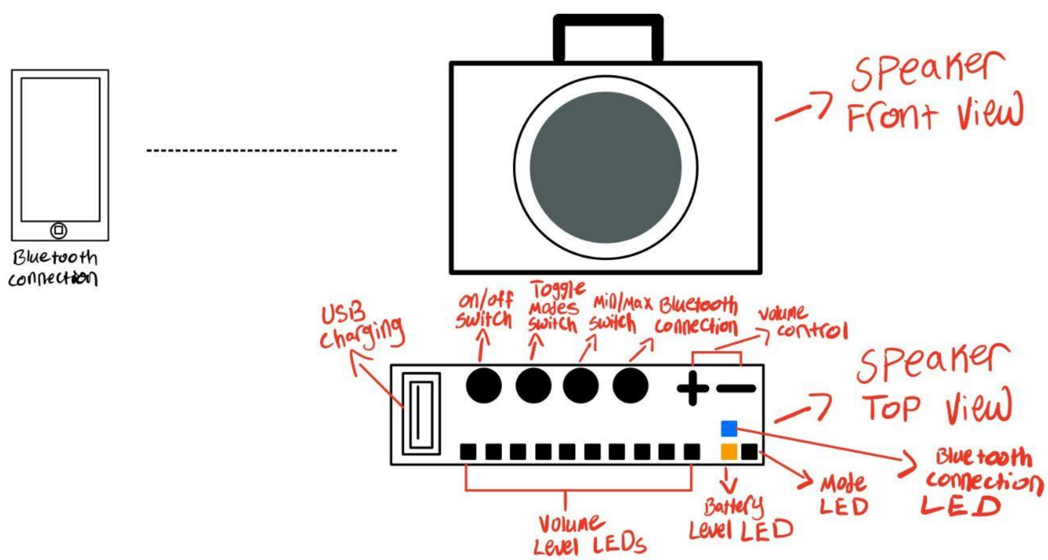

Figure 1: Visual aid for the speaker's aesthetic and appearance

High Level Requirements

- Speaker volume changes automatically in driving mode at a fixed rate of 3dB for an increase/decrease of 15 MPH, while also staying in range of the users' minimum and maximum volumes.
- If in stationary mode, the speaker shouldn't change in volume depending on your speed, and instead should be controlled manually using buttons.
- Any bluetooth device should be able to transmit media continuously to the system at 2.1 Mbps and the system will play media at an audio quality of 80 dB Signal to Noise ratio [6]

Design

Block Diagram

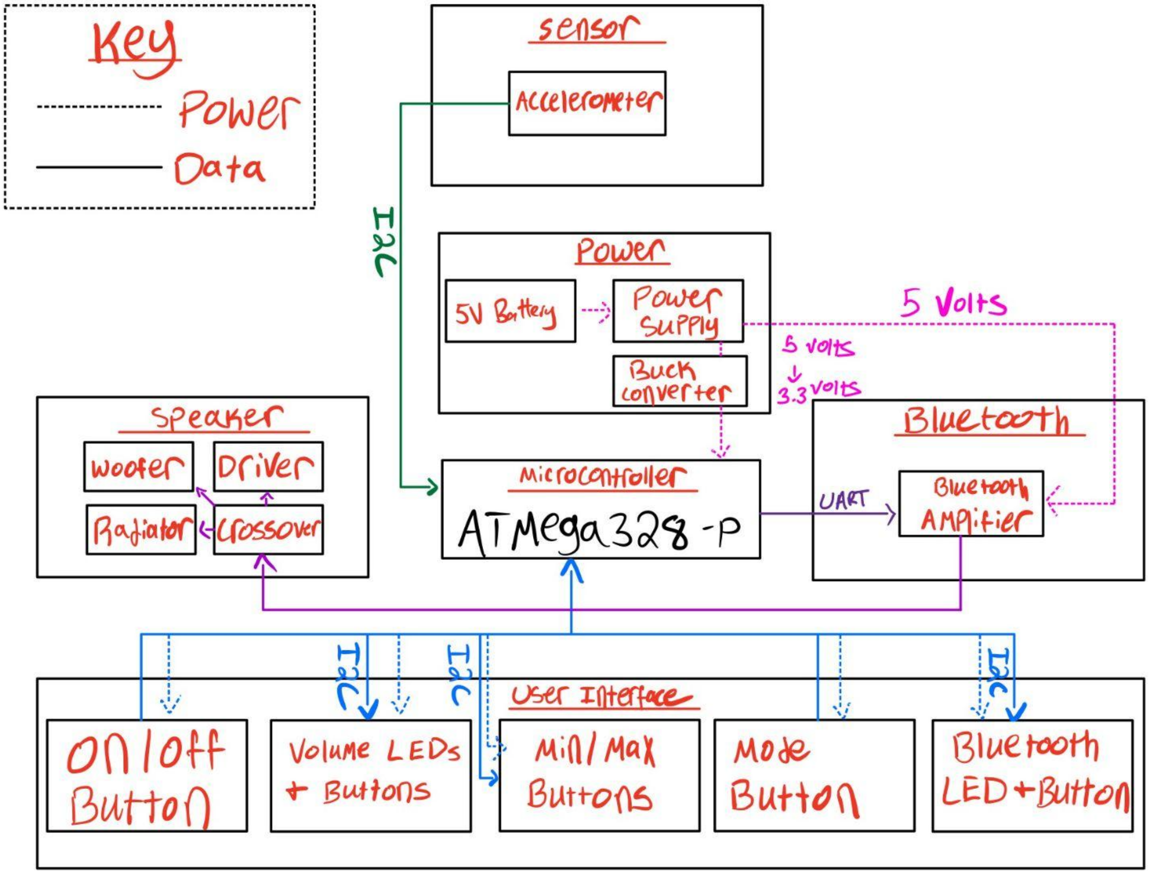

Figure 2: Block diagram for the subsystems in the speaker

Physical Design

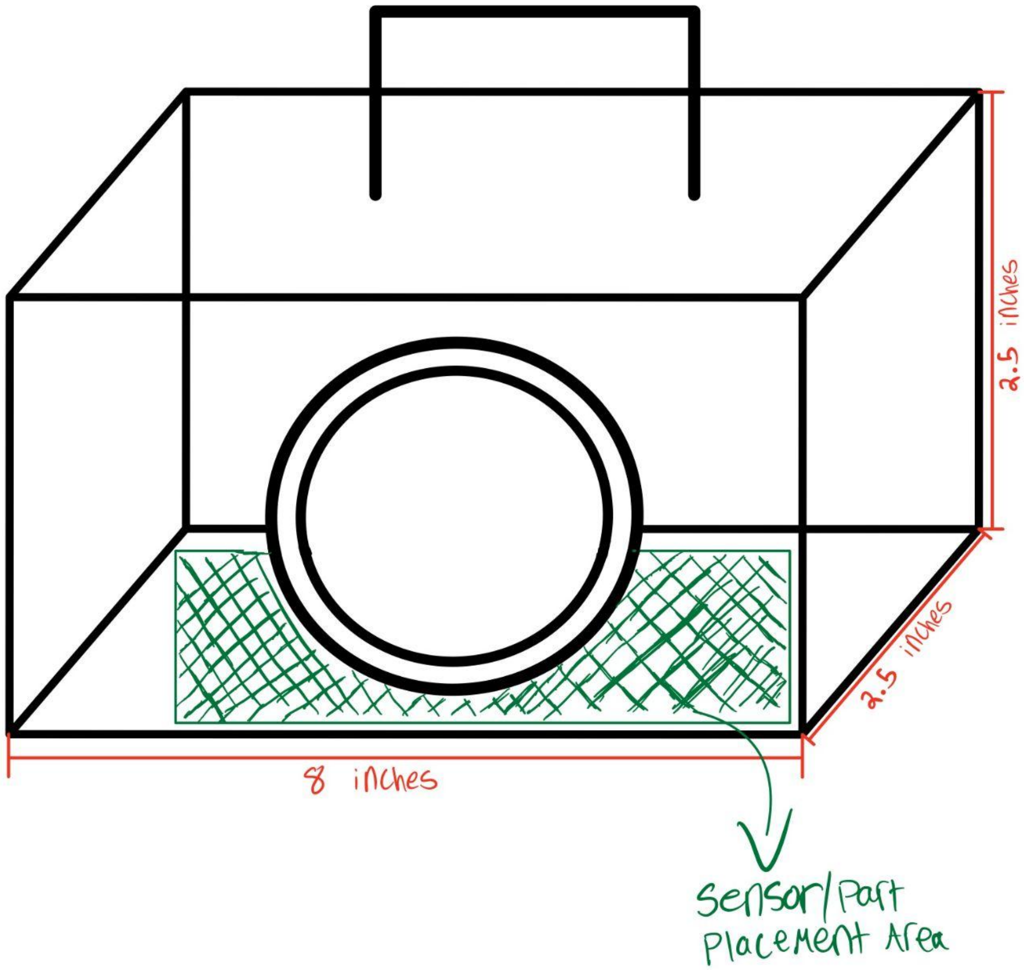

Figure 3: Physical diagram for the speaker dimensions

For the physical design of our speaker, we aim to model it similarly to many portable speakers on the market, which is the basis of the dimensions that we chose for now. For sensor placement, we left the bottom portion of our enclosure available for the sensors and other parts that will be contained within our speaker, and also are expecting to be able to take advantage of the back panel of the speaker to place internal parts as well.

Subsystem Overview & Requirements

Subsystem #1: Power

Overview: This part of our project will be key to making the remainder of our project operable. In order to power our speaker and change volume levels when in the "moving mode", we will need a battery to power it.

Requirements	Verification
Power supply needs to be able to steadily supply 3.3V ± 5% to the microcontroller.	Using a voltage regulator, we can make sure that there is a constant 3.3V supplied to the circuit. We can use an oscilloscope and multimeter to measure both current and voltage and check that it's in our desired range.
The speaker should be able to play music at 80 dB for 10 hours, which the specification for the Beats pill speaker [1]	We can use a multimeter to measure the power consumption at 80dB and then multiply it by the battery capacity to find the estimated battery life at 80dB. Another method of verification would be to let the speaker play at 80dB after fully charging the speaker and timing how long before the battery runs out of power.

Subsystem #2: Bluetooth Connection

Overview: Both the bluetooth module and bluetooth amplifier are essential for wireless communication between the speaker and a media device. Both the HC-05 bluetooth module and the TDA7492P amplifier board will be connected to the battery to receive power. The HC-05 module will then be directly connected to the microcontroller through the serial communication pins. The amplifier board's audio output will be connected to the speaker subsystem and the board will also be connected to the microcontroller using the I2C pins [2].

Requirements	Verification
Any device with bluetooth functionality should be able to connect to the speaker.	Manually connect any device that has bluetooth capabilities to the speaker to verify it's bluetooth compatibility.
The Bluetooth data transfer speed should be at least 2.1Mbps [3]	Use a bluetooth speed test app between a phone and the speaker to make sure the transfer speed is up to our standards. A bluetooth analyzer program on a computer can also be used to not only measure bluetooth transfer speed, but also interference and signal strength.

Subsystem #3: Sensor System

Overview: Arguably the most essential subsystem for our project, the point of the sensor is to track changes in speed within our speaker so that it can use that information to adjust the volume of our speaker automatically based on a formula that we create (this formula will create a consistent change in volume values that correspond with the changes in speed). We plan on using an accelerometer sensor for this, which means we must also account for the fact that the sensor will only give us information regarding the speaker's acceleration, meaning we need to convert that to speed so that our speaker can properly change the volume [4]. This system will be connected to the PCB in addition to the bluetooth amplifier so that there is a line of communication between our subsystems which will allow the PCB to make changes to the volume itself based on the information provided by the system.

Requirements	**Verification**
The accelerometer should be able to send data continuously to the microcontroller.	We will connect the accelerometer to the microcontroller and then connect the microcontroller to the computer using the serial port. We will then verify that the accelerometer is continuously sending data and is giving different values if we manually move the accelerometer around.
The microcontroller is able to accurately convert the acceleration readings to velocity.	We will use the microcontroller to compute velocity from acceleration using the equation $V = V_0 + at$. We will set t to be 10 ms, so we will convert the acceleration to velocity every 10 ms. We will verify the conversion by connecting the microcontroller to the computer and verifying that the velocity is being updated every t milliseconds and that the velocities are accurate.

Subsystem #4: Speaker System

Description: The physical build of the speaker itself is very important to our project, as the aesthetic appearance of our product will be directly correlated to its assumed value and durability. To build the speaker itself, we will need the bluetooth technology (see above), in addition to the physical parts of the speaker that produce sound. Given the components below and wood, we would be able to ask the machine shop to put the parts together in a way that could complete the physical part of the speaker. With the case of the speaker completed, we can add the remaining subsystems to an empty part of the case and make the necessary connections for the speaker.

Requirements	Verification
The max volume should be 85 dB. The minimum volume should be 60 dB, similar to the Beats pill speaker [1].	Use a decibel meter to measure the maximum and minimum volume that the speaker is capable of producing. Check that the upper bound is 85 dB and that the lower bound is 60 dB
The speaker should have an SNR of at least 60 dB	Measure the signal level by playing an audio test track and using a decibel meter. Then measure the background noise using the same meter to get the noise level. Then plug the values into the equation below to calculate the SNR. $SNR = 20 \times log(signal\ level \div noise\ level)$
The speaker should be able to play sounds at 10 different volume levels spaced out between 60 and 85 dB.	We will play a single buzzing sound from the speaker and use a decibel meter to ensure that there are discrete volume levels that are equally spaced out between the minimum and maximum volumes.

Subsystem #5: User Interface

Overview: The last module is what the user will see on the outside surface of the speaker, and would consist of buttons and LEDs. The buttons are used to take in user input, and the LEDs give the user feedback about the system. The interface would have a button for power, a button for toggling between driving/stationary modes, buttons for setting the minimum and maximum volume for driving mode, and a button to initiate the Bluetooth pairing. The interface would have LEDs that indicate volume level, battery percentage, and the current mode of the system.

Requirements	Verification
Each of the buttons should be debounced, so that the desired output from pressing a button only occurs when the button is fully pressed.	We will ensure debouncing using software. Our code will keep track of if the button is high or low, and keep track time between presses, and then decide whether the button press should be processed. We can verify this by connecting the buttons to an LED that will only turn on once per button press.
The 10 count LED strip should display the correct volume as the volume changes.	We will have code that maps speaker volume into a mapping of which LEDs should be on. We can verify that the LEDs display the correct volume by setting test volumes using the microcontroller and visually checking that the correct LEDs are on.

The LED to display battery level should show the correct color based off battery level (green 30-100%, yellow 10-30%, red 0-10%)	We will have code that maps a battery percentage to either red, green, or blue. We can test this by setting test battery percentages using the microcontroller and checking that the LED is the correct color.

Tolerance Analysis

One of the major concerns for this project is the rate and intensity that the volume changes based on speed change. For example, the volume change should not be overly sensitive to speed change, which would cause rapid fluctuations, leading to an annoying listening experience. To avoid this, we would implement a slight delay and take a moving average of samples before changing the volume. The moving average (time span of 3-5 seconds) would be useful in lowering the impact of outliers, if for some reason an accelerometer value is very inaccurate. We will also add a function to gradually change from one volume to another, as opposed to just jumping to the next level. The following two figures demonstrate how the moving average (window of 5 seconds) is able to gradually adjust to data and also avoid a major impact from outliers.

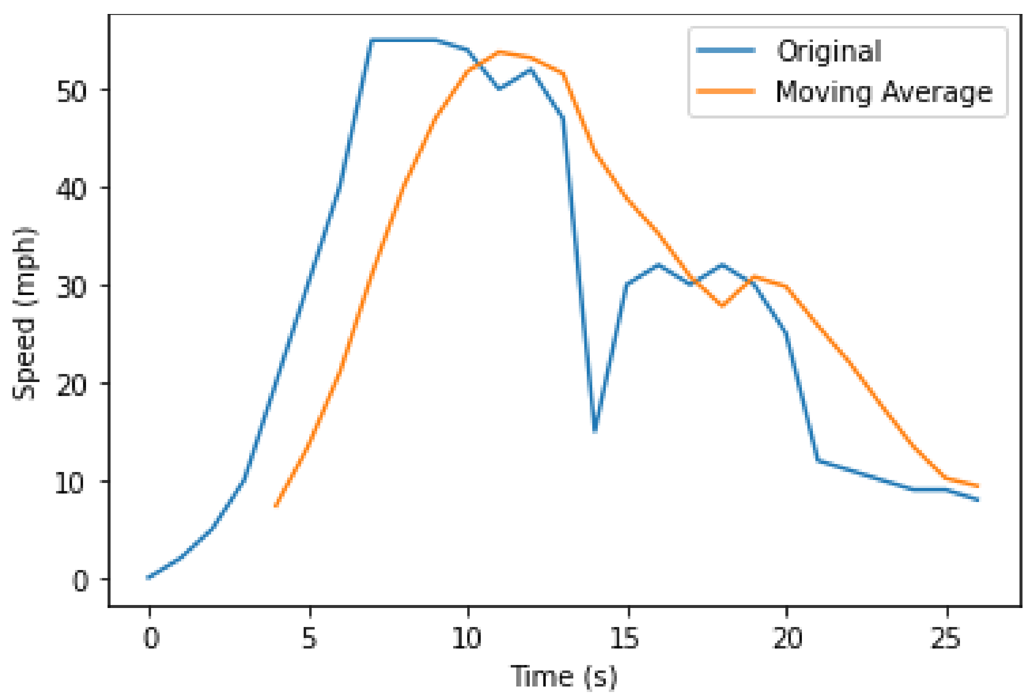

Figure 4: Moving average adjusting to the original data over time

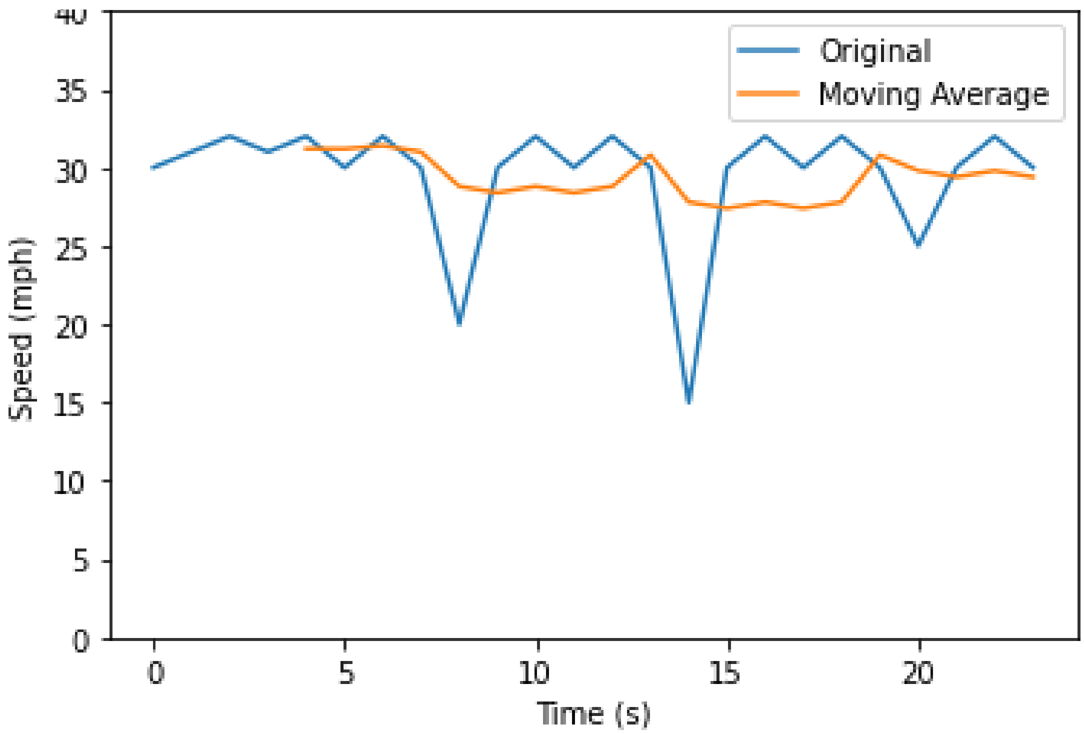

Figure 5: Moving average softening impact of outliers

Cost and Schedule

Cost Analysis

Description	Manufacturer	Quantity	Extended Price	Link
MPU6050 Accelerometer	HiLetGo	3	$9.99	Link
STM32F401RET7	ST	3	$31.35	Link
GRS 5PF-8 5-1/4" Paper Cone Foam Surround Woofer	GRS	1	$8.98	Link
GRS 1TD1-8 1" Dome Tweeter 8 Ohm	GRS	1	$6.98	Link
LED strip of 10	Sparkfun	3	$13.50	Link
Single LEDs	Digikey	10	$8.06	Link
Samsung U083L03SSK1 3" Poly Cone Passive Radiator	Samsung	1	$2.48	Link
Buttons	Digikey	10	$15.54	Link
Dayton Audio XO2W-3.5K 2-Way Speaker Crossover 3500 Hz	Dayton Audio	1	$28.98	Link
RN-52 Bluetooth Audio Module	Microchip	1	$20.29	Link
TPA3116D2 Bluetooth Amplifier	Texas Instruments	3	$10.14	Link

Figure 6: Cost analysis table for parts that need to be purchased

The cost of all the components from the components list above rounds out to $125.86. To work out the total labor cost we first start with the average salary of a computer engineering graduate from UIUC and perform some simple math to calculate the hourly rate:

$$\$105,352\ yearly\ \div\ 50\ weeks/year\ \div\ 40\ hours/\ week\ =\ \$52.676\ per\ hour$$

Now we need to account for how many employees we have, number of hours of work per week and number of weeks till the project is completed.

$$\$52.676\ per\ hour\ \times\ 20\ hours/week\ \times\ 10\ weeks\ \times\ 3\ employees\ =\ 31,605.6$$

The total labor cost is the sum of the components and total labor, which amounts to $31,761.89

Schedule

Week	Task	Task Lead
2/20/23 - 2/26/23	Design Document	All
	Ordering parts	
2/27/23 - 3/5/23	Design Review/Design Document Revisions	All
	PCB Board Design	Raj, Dhruv
3/6/23 - 3/12/23	Develop Bluetooth subsystem	Chirag, Dhruv
	Develop Power subsystem	Raj, Chirag
	Order PCB Board	All
3/13/23 - 3/19/23	**SPRING BREAK**	
3/20/23 - 3/26/23	Develop Sensor subsystem	Chirag, Dhruv
	Run testing requirements on Power and Bluetooth subsystem	All
	PCB Board development	Dhruv, Raj
	Develop UI subsystem and Speaker subsystem via machine shop	Raj, Chirag
3/27/23 - 4/5/23	Progress Reports	All
	Run testing requirements on UI, Speaker and Sensor subsystems	
	Finalize PCB Design (if revisions from previous deadline are needed)	
4/3/23 - 4/9/23	PCB Board Revision	All
4/10/23 - 4/16/23	Final PCB Board Revision/Order	All
	Testing/Minor bug fixes	Raj, Chirag
4/17/23 - 4/23/23	Testing and PCB Board Assembly	All
	Testing/Minor bug fixes	Raj, Dhruv
4/24/23 - 4/30/23	Final Demo/Mock Presentation	All
	Testing/Minor bug fixes	Dhruv, Chirag

5/1/23 - 5/7/23	Final Presentation/Paper	All

Figure 7: Scheduling table which shows an overview of tasks for the project

Discussion of Ethics and Safety

We believe that there are minimal ethical concerns and risks with this project. One potential concern is that the volume may be too loud after it is automatically adjusted. To combat this, we have highlighted that we would like the user to have the highest priority for controlling volume on the speaker. Another concern that may be a little far fetched is that if the speaker isn't in driving mode and the user is driving, they can be distracted from driving by trying to adjust the volume on the speaker, and potentially risking the safety of others with their distracted driving. However, this type of behavior from the user defeats one of the purposes of our product, which is to increase driver safety by making it easier to complete a task (changing the volume of the music in the car) that is traditionally considered to be a distraction. Thus, we feel that despite the potential risk that this creates, we are still abiding by the IEEE Code of Ethics [5], as our intent with the project is the responsible use of a product that we are creating to help the public mitigate a risk that exists even without our product.

References

[1] J. Pollicino, “Beats by Dre Pill Portable bluetooth speaker…,” *Engadget*, 16-Oct-2012. [Online]. Available: https://www.engadget.com/2012-10-16-beats-by-dre-pill-bluetooth-portable-speaker-ears-on.html#:~:text=An%20internal%20battery%20is%20said,via%20its%20Micro%2DUSB%20input. [Accessed: 09-Feb-2023].

[2] “How does a bluetooth amplifier work?,” *Auris, Inc.* [Online]. Available: https://theauris.com/blogs/blog/how-does-bluetooth-amplifier-work. [Accessed: 09-Feb-2023].

[3] J. Blom, “Bluetooth basics,” *SparkFun*. [Online]. Available: https://learn.sparkfun.com/tutorials/bluetooth-basics/common-versions. [Accessed: 09-Feb-2023].

[4] “How to measure acceleration?,” *Omega Engineering*, 14-Oct-2022. [Online]. Available: https://www.omega.com/en-us/resources/accelerometers. [Accessed: 09-Feb-2023].

[5] IEEE, “IEEE code of Ethics,” *IEEE*. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 09-Feb-2023].

[6] D. Moore, “How to measure audio quality,” *Phairs*, 26-Sep-2022. [Online]. Available: https://phairs.com/blogs/news/how-to-measure-audio-quality#:~:text=Signal%20to%20Noise%20Ratio&text=Usually%20the%20higher%20the%20decibel,for%20many%20discerning%20human%20ears. [Accessed: 21-Feb-2023].