ECE 445: SENIOR DESIGN LABORATORY

DESIGN DOCUMENT:

BRACELET AID FOR d/DEAF AND HARD OF HEARING PEOPLE

TEAM #59

AARUSHI BISWAS (abiswas7)

ANITYA KAPOOR (anityak2)

YASH GUPTA (yashg3)

TA: Saroj, Sarath
PROFESSOR: Fliflet, Arne

Table of Contents

Introduction

Problem

We are constantly hearing sounds around us that notify us of events occurring, such as doorbells, fire alarms, phone calls, alarms, or vehicle horns. These sounds are not enough to catch the attention of a D/deaf person and sometimes can be serious (emergency/fire alarms) and would require the instant attention of the person. In addition, there are several other small sounds produced by devices in our everyday lives such as washing machines, stoves, microwaves, ovens, etc. that cannot be identified by D/deaf people unless they are observing these machines constantly.

Many people in the D/deaf community combat some of these problems such as the doorbell by installing devices that will cause the light in a room to flicker. However, these devices are generally not installed in all rooms and will also obviously not be able to notify people if they are asleep. Another common solution is purchasing devices like smartwatches that can interact with their mobile phones to notify them of their surroundings, however, these smartwatches are usually expensive, do not fulfill all their needs, and require nightly charging cycles that diminish their usefulness in the face of the aforementioned issues.

Solution

A low-cost bracelet aid with the ability to convert sounds into haptic feedback in the form of vibrations will be able to give D/deaf people the independence of recognizing notification sounds around them. The bracelet will recognize some of these sounds and create different vibration patterns to catch the attention of the wearer as well as inform them of the cause of the notification. Additionally, there will be a visual component to the bracelet in the form of an OLED display which will provide visual cues in the form of emojis. The bracelet will also have buttons for the purpose of stopping the vibration and showing the battery on the OLED.

For instance, when the doorbell rings, the bracelet will pick up the doorbell sound after filtering out any other unnecessary background noise. On recognizing the doorbell sound, the bracelet will vibrate with the pattern associated with the sound in question which might be something like alternating between strong vibrations and pauses. The OLED display will also additionally show a house emoji to denote that the house doorbell is ringing.

Visual Aid

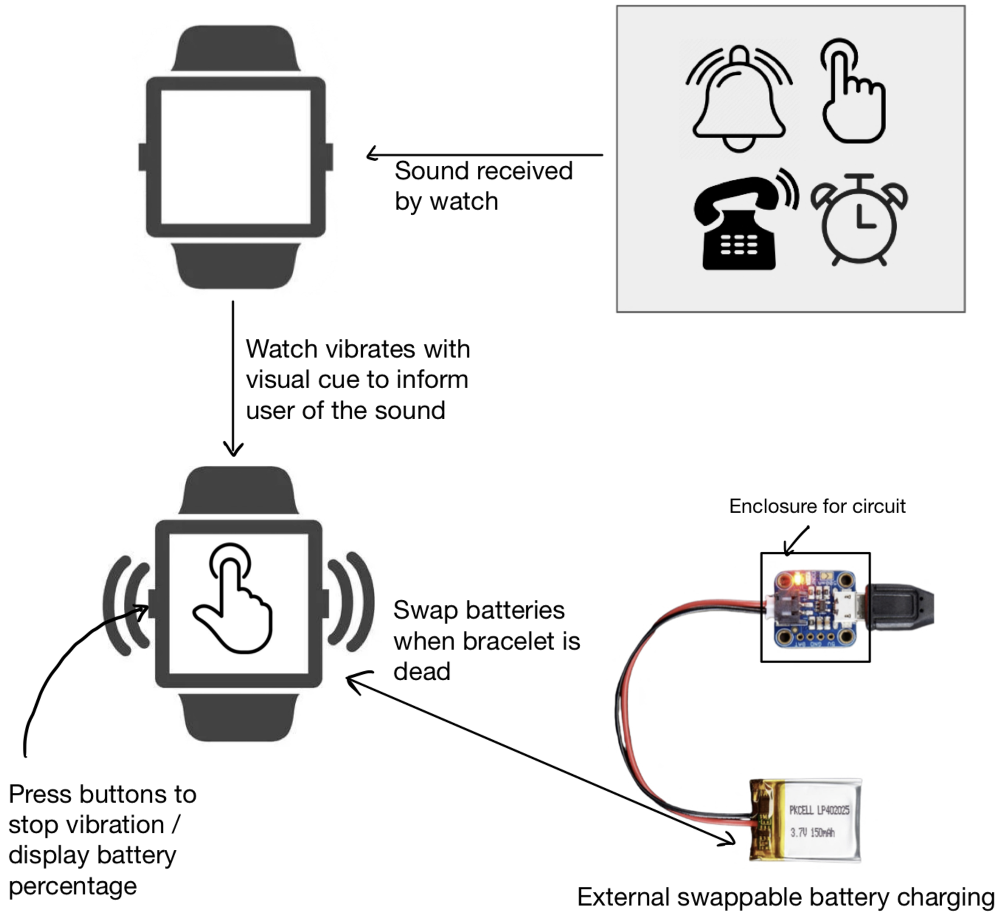

Figure 1: Visual Aid on how the bracelet works

High-Level Requirements

- The device should have a small form factor and should be light such that it can sit on a person's wrist without feeling bulky or overbearing, as the device will sit on their wrists for most of the day. It should weigh less than 70 grams for a successful product.
- The device should be able to recognize multiple notification sounds and create different vibration patterns that are recognizable and distinguishable by the user. It should be able to produce at least 10 distinguishable vibration patterns.
- The device should have a feedback time (i.e. time taken for the device to recognize crucial sounds and notify the wearer) of at most 10 seconds

Design

Block Diagram

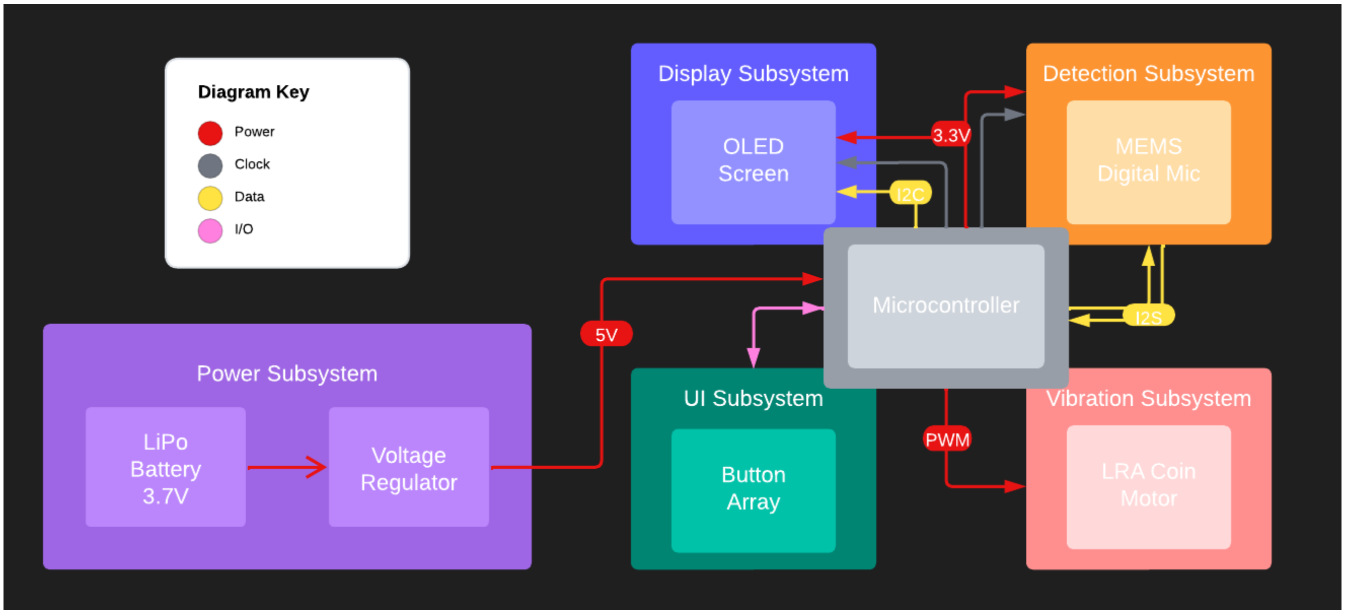

Figure 2: Block Diagram

Physical Design

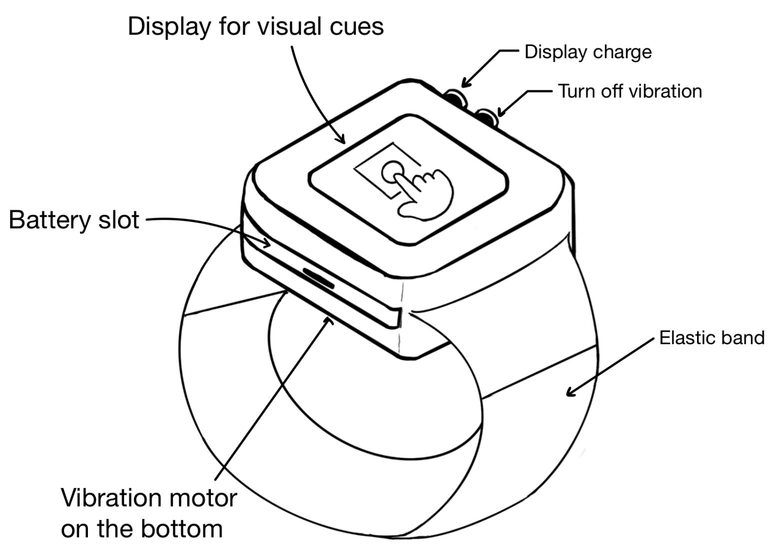

Figure 3: Figure 1: Bracelet Prototype

Power Subsystem

The power subsystem handles voltage regulation and makes swapping batteries easy and secure on the device. On the charging side the subsystem will have a simple USB to JST converter with protective charging circuit built into it so that the user may charge the additional battery provided in the kit while the primary battery is used for minimal downtime. The charging will be handled by a specific Li-Po battery charger, specifically the MCP73831T-2ACI/OT which has the capability of identifying when a 1S battery is done charging. We have also wired it up in our schematic to ensure that the maximum charge current provided is less than the rated current.

Since the chosen battery is rated 1.9Ah, it has a max charging current of 1.9A, however, is standard charging current is specified as 380mA. To ensure that the downtime of charging the battery is not too high, and to reduce charging time, we can safely choose a charging current of 500mA which is a commonly chosen parameter for 1S batteries. To ensure that the charger is set to charge at this current, we had to use a resistor of 2kOhms across the PROG and VSS pins on the charger. Also, to ensure compatibility with most devices, we added a USB port on the charger. This can be seen below with the schematic for the charger.

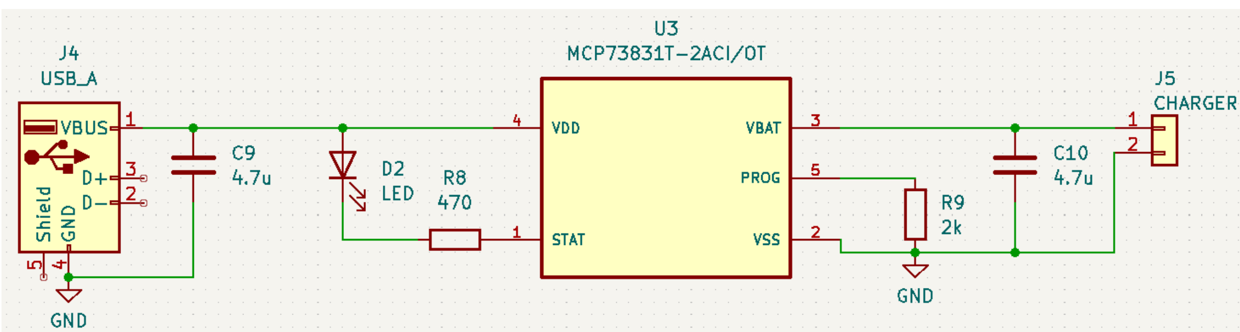

Figure 4: Charging Schematic

On the other hand, to connect to the main PCB, we will have to ensure that some of the required functionality is met. First off, to drive the microcontroller and other peripherals, we will have to ensure that there is a stable, minimal-noise voltage of 3.3V provided, and also have to include a charge guage. The first objective is met by using a Low Dropout Voltage Regulator. We decided to use the 3.3V variant of the SPX3819, that meets the requirements, with a dropout of less than 175mV with a current draw of 100mA. Also, we created a voltage divider circuit across the two terminals of the battery so that the ESP32 can guage the charge left. The VOLT label in the schematic below connects to the IO Pin 19 on the microcontroller.

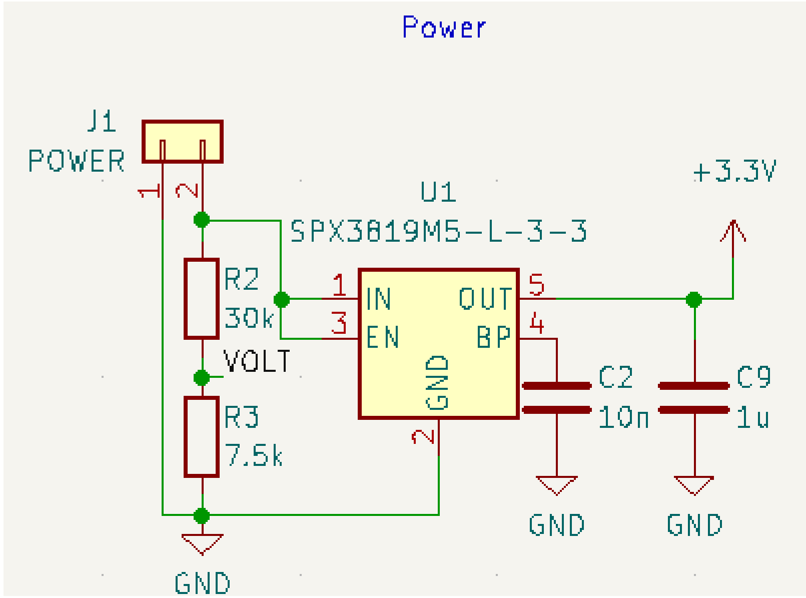

Figure 5: Power subsystem schematic

Requirements	Verification
The charging circuit should have general Li-Po battery protection and should ensure that the battery is not charged or discharged at a rate larger than 1C.	- Assemble the charging board - Connect a USB cable to a power source and connect the cable to the board - Connect one of the two discharged Li-Po batteries to the JST ports on the charging circuit and ensure that the LED turns on - Measure the voltage across the two terminals with an ammeter and verify that the constant current provided is 500mA
The microcontroller should be provided with a constant, uniform 3.3V with minimal noise and a tolerance of up to ±1%	- Assemble the bracelet with a complete vibration subsystem - Connect a charged battery to the device - Ensure that the bracelet is powered on, and measure the voltage between the 3V3 and GND - Verify for 1 minute that the voltage doesn't change by more than 33mV

It should be able to keep the device powered for at least 24 hours.	- Assemble the bracelet with a complete vibration subsystem - Connect a fully charged battery to the device - Ensure that the bracelet is powered on, and verify that the bracelet can be interacted with for at least 24 hours

Table 1: Requirements and Verification for Power Subsystem

Sound Detection Subsystem

The sound detection subsystem involves the MEMS digital microphone and the auxiliary circuitry to allow the microphone to detect a range of frequencies. The microcontroller will run FFTs when it detects sounds and check whether the peak frequencies match that of any of the predetermined sounds our device can detect. When a sound match is found the microcontroller will trigger the vibration motor sequence corresponding with the matched sound as well as display the corresponding symbol on the OLED display. The chosen microphone, the ICS 43434, interacts with the microontroller over I^{2}S and sends its information in either the left or the right channel of the output. Like other peripherals and devices, the microphone is also decoupled with a capacitor.

Requirements	Verification
The subsystem should be able to detect different sounds with a frequency range of at least 200 Hz to 15 kHz when placed in the enclosure	- Assemble the bracelet with a complete microphone subsystem - Program the device to detect 200Hz and 15kHz sounds - Produce a 200Hz with a laptop or computer and verify that the sound is detected by the bracelet when worn - Repeat the above with a 15kHz sound and verify detection
It should have a maximum current draw of 5mA during heavy use	- Assemble the bracelet with a complete microphone subsystem - Program the device to detect regular sounds as needed by the user

	- Connect an ammeter between Vcc of the system and the Vin pin of the subsystem - Verify that the current draw is never above 5mA regardless of the quantity or amplitude of background sounds present
It should take less than 10 seconds of notification to produce a successful sound detection	- Assemble the bracelet with a complete microphone subsystem - Program the device to detect regular sounds as needed by the user - Trigger one of the sounds on loop, at a distance of at least 10 feet and start a stopwatch - Wait for successful detection and stop the stopwatch as soon as the sound is detected - Repeat last two steps for 5 more of the programmable sounds added on the device

Table 2: Requirements and Verification for Sound Detection Subsystem

Vibration Subsystem

The vibration subsystem is responsible for providing haptic feedback to the user when a predetermined sound is detected by the microcontroller. With varying vibration amplitudes the vibration motor will be given signals by the microcontroller that will generate unique patterns for corresponding sounds detected by it.

The vibration subsystem includes a vibration motor driver IC by TI that interfaces with the microcontroller. The motor driver has a ROM built into it that stores small vibration patterns. The microcontroller communicates which vibration pattern is desired to be played via I^2C communication protocol to create longer, complex, and detectable vibrations. The following are the requirements for this subsystem.

Requirements	Verification
It should be able to produce a strong detectable vibration	- Assemble the bracelet with a complete vibration subsystem.

	- Wire up the motor to the motor driver circuit - Ensure that the bracelet is powered on, measure the voltage across the motor when playing a “strong click” to be 3.6V [1] - Ensure a detectable vibration is felt when motor is pressed against skin
It should be able to produce at least 10 unique vibration patterns	- Assemble the bracelet with a complete vibration subsystem. - Wire up the motor to the motor driver circuit - Run 10 different vibration combinations made up of the 123 individual vibration patterns. [1] - Survey a study group of 15 people to determine whether or not the can distinguish the 10 different vibration patterns
The subsystem should successfully produce a vibration within 10 seconds of when a sound is produced	- Assemble the bracelet with a complete microphone subsystem & vibration subsystem - Program the device to detect regular sounds as needed by the user - Trigger one of the sounds on loop, at a distance of at least 10 feet and start a stopwatch - Wait for a vibration to occur and stop the stopwatch as soon as the device vibrates - Repeat last two steps for 5 more of the programmable sounds added on the device

Table 3: Requirements and Verification for Vibration Subsystem

Display Subsystem

The digital display subsystem is responsible for providing visual feedback to the user when a predetermined sound is detected by the microcontroller. Each unique sound will have a unique corresponding symbol that will be displayed on the display. The microcontroller will communicate with the OLED display via I^2C communication protocol. The display will also display the current battery percentage (increments of 5) when the user presses a button. The user will be shown a visual representation of the sound detected by the microcontroller (Ex. international standard fire symbol). The following are the requirements for this subsystem:

Requirements	Verification
It should be able to clearly display symbols associated with detected sounds.	- Assemble the bracelet with a complete display subsystem. - Wire up the OLED display to the OLED driver circuit, and microcontroller. - Ensure when the symbol is quantized to 128x64 pixels is clearly distinguishable. - Survey a study group of 15 people to determine whether or not the can distinguish the 10 different symbols
Its peak current draw should be less than 15mA. [2]	- Ensure that none of the symbols we display are not going to use all 128x64 pixel - Ensure that the current draw does not exceed 15mA while displaying all 10/battery symbols by connecting voltmeter probes between Vin pad and VCC.

Table 4: Requirements and Verification for Display Subsystem

User Interaction Subsystem

The user interaction system contains a set of buttons that will be used to control the bracelet. Button 1 will display the battery percentage and Button 2 will stop the vibrations once the user is notified. This means that the first button will require the system to interact with the power subsystem and the second one will require interaction with the vibration and display subsystems. The following are the requirements for this subsystem:

Requirements	Verification
They should be easily accessible from the top of the watch facing the user	- The buttons will be soldered on to the top PCB of our layered PCB system - Ensure that the buttons have enough height

	clearance to clear the enclosure even when fully depressed - Ensure the display and the button are the only things exposed from the enclosure's top surface
They should be spaced far enough apart to ensure buttons aren't accidentally pressed	- The buttons should be atleast one button width (6.00 mm) away from the edge of the enclosure as well as the two buttons should be two button widths (12.00 mm) apart. [5]

Table 5: Requirements and Verification for User Interaction Subsystem

Tolerance Analysis

A critical portion of the entire design is the vibration aspect of the device, which is handled by a vibration motor. The vibration motor used, the VG1040003D, can produce up to 2.1Grms vibration acceleration, which is an expression of the intensity of the vibration. However, one major issue that our design might face is that a vibration might cause the motor to move off of its pressure tab, and stop functioning, or even that the vibration might cause contact issues with other peripherals. Therefore, we want to ensure that the maximum magnitude of amplitude movement is less than 0.05mm.

From the datasheet, we can see that the maximum vibration produced is about 2.1Grms, with a tolerance of ±30%, at a frequency of 170Hz [6]. Since the vibration acceleration is in rms, we can convert them to peak measurements by multiplying by the square root of two, and converting to metric by dividing by multiplying by 9.81 as follows:

Grms	**Acceleration Peak in metric**
2.1	27.74
2.73 (+30%)	37.86
1.47 (-30%)	20.38

Table 6: Grms to Peak Acceleration

Now from the standard harmonic motion equation found here [7]:

$$a_{peak} = \pm(2\pi f)^2 A$$

Thus, we get the following values for Amplitude magnitude:

Grms	**Magnitude of Amplitude in mm**
2.1	0.0243
2.73 (+30%)	**0.0332**
1.47 (-30%)	0.0178

Table 7: Grms to Magnitude of Amplitude in mm

As can be seen above, the maximum magnitude of amplitude displacement due to the vibration itself, is 0.0332 mm, which lies well within the tolerance included above, ensuring that there should not be any impact on the contact of components due to the vibration of the motor.

Cost and Schedule

Cost Analysis

- Labor

  The average hourly starting salary of a typical ECE major is $38. The total hours to complete the project apart from the planning and researching is ~10 hours per week for each person and we will be working for 10 weeks. Therefore, total number of hours worked = 10 x 10 = 100 hours.
  Therefore, for per person,
  Salary = $38 x 2.5 x 100 = $9,500

  For all three members of the group, the total salary comes out to be $28,500

  The enclosure for our device is estimated to take 10 hours by the machine shop. We can take the hourly average salary of the machine shop to be $36
  Therefore, total cost for machine shop = $360

- Parts

Part Description	Manufacturer	Digikey Part Number	Quantity	Cost
CONN HEADER R/A 2POS 2MM	JST Sales America Inc.	455-1719-ND	4	$0.68
CONN RCPT HSG 2POS 2.00MM	JST Sales America Inc.	455-1165-ND	3	$0.30
CONN HEADER VERT 3POS 3.96MM	TE Connectivity AMP Connectors	644749-3-ND	3	$1.29
CONN HEADER VERT 12POS 2.54MM	Molex	WM20588-ND	3	$4.32
CAP CER 10000PF 50V C0G 0805	TDK Corporation	445-7519-1-ND	4	$1.16
CAP CER 0.1UF 100V X7R 0805	KYOCERA AVX	478-5780-1-ND	10	$2.00
CAP CER 1UF 25V X7R 0805	KYOCERA AVX	478-10487-1-ND	15	$3.82
CAP CER 10UF 10V X7R 0805	KEMET	399-15694-1-ND	4	$3.76
RES 100K OHM 0.1% 1/8W 0805	Panasonic Electronic Components	P100KDACT-ND	4	$1.44
RES 30K OHM 1% 1/8W 0805	YAGEO	311-30.0KCRCT-ND	4	$0.40
RES 10K OHM 5% 1/8W 0805	YAGEO	311-10KARCT-ND	10	$0.28
RES 7.5K OHM 5% 1/8W 0805	YAGEO	311-7.5KARCT-ND	4	$0.40
RES SMD 1K OHM 0.1% 1/8W 0805	YAGEO	YAG1820CT-ND	4	$1.52
SMD MODULE, ESP32-C3FN4, IPEX AN	Espressif Systems	1965-ESP32-C3-MINI-1U-N4CT-ND	2	$4.18
BATT LITH POLY 1S1P 1900MAH 3.7V	Jauch Quartz	1908-LP103450JH+PCM+PTC+2WIRES70MM-ND	2	$34.66
VIBRATION LRA MOTOR 170HZ 2G	Vybronics Inc	1670-VG1040003D-ND	2	$6.34
MICROPHONE MEMS DIGITAL I2S OMNI	TDK InvenSense	1428-1066-1-ND	5	$15.65
IC REG LINEAR 3.3V 500MA SOT23-5	MaxLinear, Inc.	1016-1873-1-ND	2	$1.34
SWITCH TACTILE SPST-NO 0.05A 12V	E-Switch	EG4375CT-ND	5	$2.15
TRANS NPN 65V 0.1A SOT1123	onsemi	NST846BF3T5GOSCT-ND	3	$1.08
DIODE SCHOTTKY 20V 1A 0805	KYOCERA AVX	478-7800-1-ND	4	$1.44
128X64 LIGHT BLUE/YELLOW GRAPHIC	Focus LCDs	2632-O12864A-GBY-TW3-ND	1	$13.12
CAP CER 4.7UF 10V X7R 0805	KEMET	399-15708-1-ND	10	$3.93
CAP CER 0805 2.2UF 16V X7R 5%	KEMET	399-C0805C225J4REC7210CT-ND	4	$1.20
RES 4.7K OHM 5% 1/8W 0805	YAGEO	311-4.7KARCT-ND	10	$1.00
RES SMD 910K OHM 5% 1/2W 0805	Panasonic Electronic Components	P910KADCT-ND	3	$0.36
CONN HEADER VERT 4POS 2.54MM	Adam Tech	2057-PH1-04-UA-ND	3	$0.42
RES 2K OHM 5% 1/8W 0805	Stackpole Electronics Inc	RMCF0805JT2K00CT-ND	4	$0.40
RES SMD 470 OHM 5% 1/8W 0805	Vishay Dale	541-3025-1-ND	4	$0.64
IC BATT CNTL LI-ION 1CEL SOT23-5	Microchip Technology	MCP73831T-3ACI/OTCT-ND	2	$1.52
LED RED CLEAR 0805 SMD	Inolux	1830-1082-1-ND	2	$0.66
CONN RCPT TYPEA 4POS R/A	On Shore Technology Inc.	ED2989-ND	2	$0.96
IC MOTOR DRIVER 2V-5.5V 10VSSOP	Texas Instruments	296-38481-1-ND	2	$6.32

The cost of all the parts are coming out to be $118.74

- Sum Total

The sum total of our costs comes out to be $28,500 + $360+ $118.74 = $28,978.74

Weekly Schedule

Week	Tasks
February 13th - February 19th	For All: • Start choosing final components • Start designing the schematic for the PCB ○ Microcontroller + Vibration motor + Voltage regulator + Buttons

	● Start writing the design document
February 20th - February 26th	For All: ● Finalize schematic for PCB ○ Add external charger circuit and OLED display to the schematic ● Start working on the footprint for the PCB board ● Meet with the machine shop for schematic update ● Finish team contract For Anit and Yash: ● Finish the subsystem requirements and verification ● Finish the tolerance analysis For Aarushi ● Finish the cost analysis and weekly schedule ● Finish the physical design ● Order all necessary components
February 27th - March 5th	For All: ● Finish PCB design ● Meet instructors and TAs for design review and PCB board review ● Contact machine shop for updates on the enclosure ● Start working on the FFT for sound recognition
March 6th - March 12th	For All: ● Submit first round of PCB order ● Continue working on FFT ● Start working on programming the microcontroller
March 20th - March 26th	For All: ● Solder all components on the PCB ● Test the PCB ● Complete the FFT if not yet finished ● Contact machine shop to updates to enclosure dimensions / shape if required and for an update on the progress of the enclosure
March 27th - April 2nd	For All: ● Make revisions to the PCB if required ● Submit the second round of PCB design if required ● Continue working on programming the microcontroller ● Work on getting display to work ● Submit individual progress reports
April 3th - April 9th	For All: ● Solder new PCB if required and test the PCB ● Finish all software requirements for our device ● Work on getting motors to work by recognizing different sounds and correct display shows up

April 10th - April 16th	For All: ● Team contract fulfillment ● Test the device on study groups to ensure that vibrations and display patterns are distinguishable
April 17th - April 23th	● Mock Demo
April 24th - April 30th	● Final Demo
May 1st - May 4th	● Final presentation ● Final paper submission ● Lab checkout ● Lab notebook submission

Discussions of Ethics and Safety

Ethics

Our group followed the [9] IEEE Code of Ethics and the [8] ACM Code of Ethics to commit ourselves to the highest ethical standards possible which includes the following:

1. According to the IEEE Code of Ethics 1.1, we will promptly disclose any factors of our product which might cause harm to the user and will prioritize safety, health, and welfare of our customers while designing and building our product. This includes ensuring that we use safe and top quality material and components for our technology and disclose any safety hazards to our projects, more of which can be found under the ‘safety’ section.
2. According to the IEEE Code of Ethics 1.5 and ACM Code of Ethics 2.4, we will seek and accept any criticism about our technology and work on improving it. This includes meeting with our assigned TA and Mentor Jack Blevins regularly to keep them updated on the progress of our technology and get feedback on any possible improvements. We will also ensure that we credit and cite all possible sources and references used.
3. According to the IEEE Code of Ethics 1.6 and ACM code of Ethics 2.6, we will use this opportunity to develop our skills and experience. We will make certain that each of us has the proper certification required to take on a particular technological task. Each of the members completed the lab safety training before using the lab and underwent soldering practice and training before undertaking the task of soldering for our final technology. We also ensured to complete any other training as assigned by the course.

Safety

Safety concerns have been considered in the design of this proposal, illustrated in the following points:

1. Since we will be using a set of two, hot-swappable Li-Po batteries in this product, we will have to consider safety precautions for the user. This necessity for Li-Po battery safety stems from the issue of spontaneous combustion which can occur from excessive or rapid charging and discharging. To ensure that we do not face any issues related to this, we will ensure that we read through the datasheet for the battery carefully, and design our power subsystem around this issue. Further details on how we are mitigating safety concerns related to battery handling can be found in the battery lab safety manual in appendix A.
2. On a similar note, we will have to ensure that the electrical components in the device are properly enclosed and are not at a risk of short circuiting and causing battery issues. To combat this potential issue, we will work with the machine shop to ensure that none of the important and/or dangerous electrical components are exposed, especially the power subsystem.
3. Another smaller safety issue is regarding the charging circuit. This circuit will also have to be shielded and enclosed from the user and the surroundings, which is why we will ensure that the charging circuit also has an enclosure designed by the machine shop.

CITATIONS

1. “DRV2605 Haptic Driver for ERM and LRA With Built-In Library and Smart-Loop Architecture datasheet (Rev. E).” *Texas Instruments*, https://www.ti.com/lit/gpn/drv2605. Accessed 23 February 2023.

2. *SSD1306 (pdf)*, https://cdn-shop.adafruit.com/datasheets/SSD1306.pdf. Accessed 23 February 2023.

3. Services, Engineering IT Shared. “Course Overview.” *Course Overview :: ECE 445 - Senior Design Laboratory*, courses.engr.illinois.edu/ece445/.

4. Idgadvertising. “Battery Maintenance Safety Tips- U.S. Battery Mfg. Co.: The Leader in Deep Cycle Batteries.” *U.S. Battery Mfg. Co.*, Idgadvertising Https://Www.usbattery.com/Wp-Content/Uploads/2018/09/Header-Logo-Ret-300x149.Png, 8 Oct. 2018, www.usbattery.com/safe-handling-tips-battery-maintenance/.

5. “WP-Content: A Beginner's Guide to Wordpress' Most Important Directory.” *MalCare*, 27 Jan. 2023, www.malcare.com/blog/wp-content-uploads/.

6. “LRA Coin Vibration Motor - VG1040003D.” *Vybronics*, 19 Dec. 2022, www.vybronics.com/coin-vibration-motors/lra/v-g1040003d.

7. Vibration Therapeutic. “G-Force of Vibration Plate.” *G-Force of Vibration Plates [Definition & Calculation]*, Vibration Therapeutic, 22 Dec. 2021, www.vibrationtherapeutic.com/G-force-of-vibration-plate.html.

8. “ACM Code of Ethics and Professional Conduct.” *Association for Computing Machinery*, https://www.acm.org/code-of-ethics. Accessed 9 February 2023.

9. “IEEE Code of Ethics.” *IEEE CAS*, https://ieee-cas.org/about/ieee-code-ethics. Accessed 9 February 2023.

10. “Insight Into ESP32 Sleep Modes & Their Power Consumption.” *Last Minute Engineers -*, https://lastminuteengineers.com/esp32-sleep-modes-power-consumption/. Accessed 9 February 2023.

APPENDIX A

Battery Lab Safety Manual

In order to ensure maximal battery handling safety, all members are expected to:

1. Complete the Laboratory safety Training
2. Complete additional fire safety and fire extinguisher training
3. Have an in-depth knowledge about how the battery works by reading through its datasheets
4. Eliminate sources of sparks or flames while handling the battery [4]
5. Remove any jewelry or metal from one's person before handling the battery [4]
6. Keep the battery stored in a cool and dry place [4]
7. Dispose of dented batteries
8. Thoroughly read and understand ECE445's Battery Safety Practice Guide [3]. The members are more specifically expected to follow the following guidelines mentioned:
    a. We must ensure that a TA is present whenever batteries are being handled and have a TA supervise the first time the battery is used
    b. Ensure that the circuit and PCB are looked over by the TA before using the battery with it
    c. Cover terminals of the battery with insulated material for storage and ensure proper ventilation in the storage area
    d. Keep the battery datasheet and materials safety data sheet on hand when using the battery