RONArmor

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Abstract

The goal of this project, RONArmor, is to construct a safe, reusable, and affordable facial shield for daily use during COVID-19. It is an enhanced shield that does not restrict the user's voice like disposable surgical masks, and it alerts its users to maintain a safe social distance from those around them. It is comfortable, reusable, and versatile so that it can be environmentally friendly and flexible to consumers in all shapes and sizes. The product implements an alerting system that reinforces the CDC's social distancing guidelines to encourage safety and minimize stress. It also possesses audio amplification qualities in order to ensure improved communication. Therefore, users can feel properly protected and less stressed as well as easily communicate with others, all while being eco-friendly.

Contents

1. Introduction

Since the end of 2019, the world has been struck by vicious cycles of a global pandemic and non-stop quarantine where we are responsible not only for our own well-being, but also for the health and safety of those around us. Throughout this entire process, we have received three essential safety precautions: mask up, stay six feet apart, and wash or sanitize hands as often as possible.

COVID-19 has left the world scrambling for economic stability, social justice, vaccines, and face masks. Daily, frontline workers must gear up with the proper protective equipment, leading to a shortage of N95 masks throughout the United States [1]. As face masks have become a normalized and required necessity, enormous amounts of plastic waste have been generated throughout the world [2]. Furthermore, a common recurring issue associated with the enforcement of face coverings is difficulty with communication, specifically with the transmission and reception of speech. Companies like Razer and their Project Hazel have proposed solving this issue with a mask that possesses voice amplifying technology in addition to a UV Sterilizer charging case for repetitive use [3]. However, it remains conceptual as the product is yet to be officially introduced in the marketplace [4]. Moreover, the ample amount of high-tech and smart features will most likely require longer production time as well as higher cost. Both of these factors pose obstacles for people who are struggling to fulfill their essential duties on a daily basis. Our goal is to create an effective product that can combat these issues so that everyone can easily, affordably, and comfortably attempt to regain some normalcy in their everyday lives while ensuring the safety of themselves and their communities.

So we thought, "Why not design a safe, reusable, and affordable facial shield that reinforces the social distancing process and possesses communication-friendly features?" RONArmor will be a form-fitting, protective facial shield constructed with recyclable plastic that reinforces the safety of users by enforcing social distancing guidelines through sensors and ensuring improved and entertaining communication through audio amplification and modulation. Our challenge is to produce a product that will aid people in moving beyond a conventional mask to express themselves better and in a safer manner. While initially everyone struggled to keep up with the supply of masks and settled for whatever they could get their hands on, now we can design new masks that offer proper safety, freedom of expression, comfort and utility.

1.1. Modifications

In comparison to the original design mentioned in our design document, there were several adjustments to the final design of RONArmor. These changes are included in the high level requirements, physical design, and block diagram. Additional changes that affect the subsystems consist of utilizing four PIR sensors instead of eight, switching from frequency to volume modulation, and implementing the software and build with Arduino and C/C++ instead of MicroPython.

1.1.1. High Level Requirements

1. Audio is properly amplified and can be modulated between three volumes (whisper, conversational, raised).

2. Shield accurately assesses and notifies the user when someone is standing within a 6-6.5ft distance.
3. Components located near the face will avoid shorting, overheating, or exposing the user to dangerous amperage levels (~2mA).

The above are our final high level requirements. When compared to our initial requirements, the first requirement has been switched to a modulation of three pitches to three volumes and the second requirement has a detection range between 6-6.5ft instead of a mere six feet.

1.1.2. Physical Design

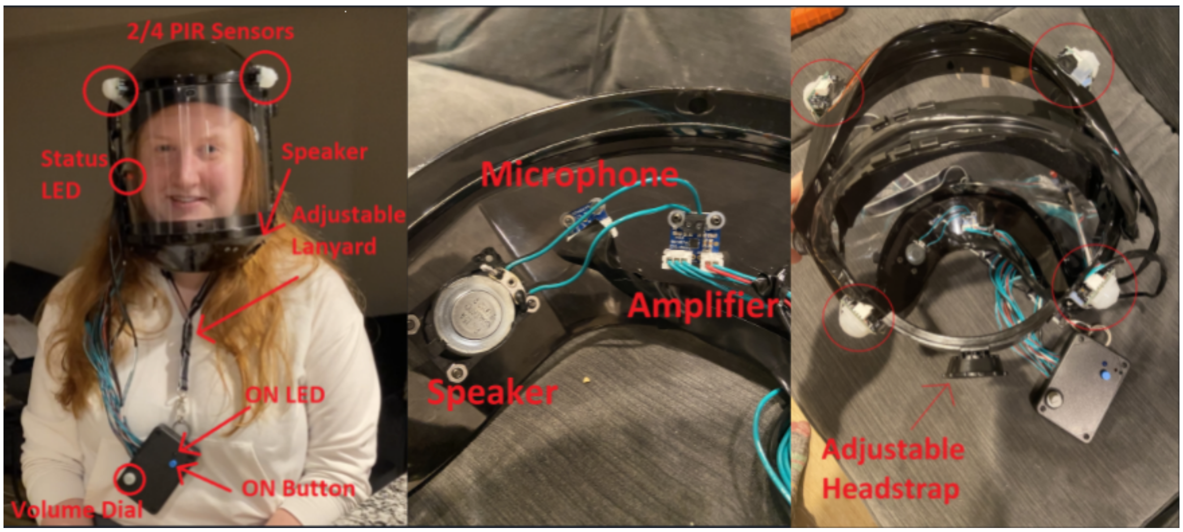


Figure 1: Final Physical Design

The physical design of RONArmor consists of a facial shield constructed of recyclable plastic with the intention of being environmentally friendly and transparent. The plastic shield extends past the face towards the back of the head. RONArmor is secured to the user's head with an adjustable head strap to accommodate various head shapes and sizes. Mounted to the bottom of the mask near the mouth are a microphone, amplifier, and speaker. The red warning LED is positioned at the right side of the shield within the user's peripheral vision. Four PIR sensors are then fixed onto the top of the shield at 45, 135, 225, and 315 degrees, one for each quadrant, 90 degrees apart from one another. Finally, an adjustable lanyard is attached to a thermally insulated battery case which keeps volatile elements away from the face. The ON/OFF button, blue ON LED, and the volume dial are found on this black battery case. This is to provide additional support and relieve the stress that is exerted on the wires between the shield and battery case. Refer to Figure 1 for visuals of the previously mentioned features.

While the shield still retains its clear and recyclable plastic features, it no longer has a silicon lining around the side and nor be form-fitting to the face. Instead, as mentioned earlier, the shield's structure extends all the way to the back of the head. This new physical design not only continues to protect vulnerable areas, but is also more comfortable, allows ease of breathing, and has a convex shape that provides self-amplifying features.

1.1.3. Block Diagram

RONArmor consists of five individual subsystems: power supply, control unit, voice functions, social distancing indicator, and face shield. Each subsystem is essential to the functionality of the final product and the flow of information and power between subsystems is shown in Figure 2.

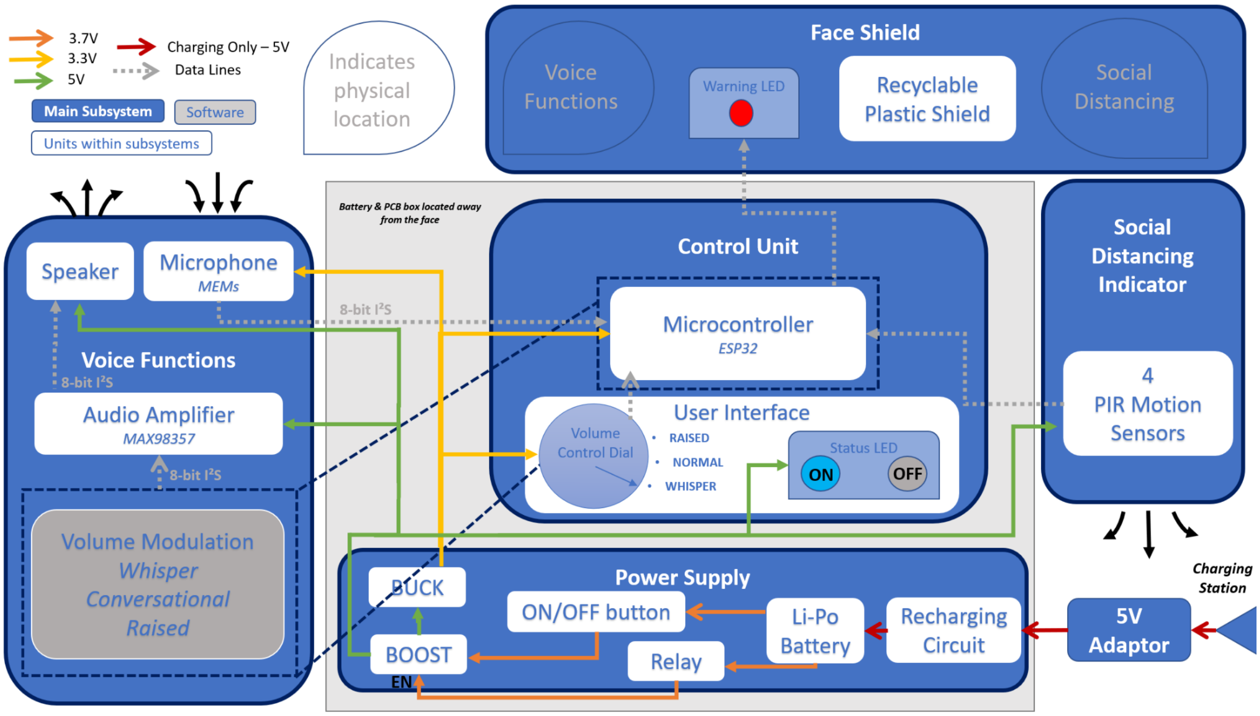


Figure 2: Block Diagram

The final block diagram has experienced a few changes from the original. Namely, the power supply now illustrates exactly what voltage is supplied to each of the main components within their respective subsystem. These voltage levels can be observed by the color coding of the arrows presented in the top left corner of Figure 2. The power supply block itself now displays a much more detailed outline of how each regulator is supplied and what it supplies, as well as how the unit is powered on and off. Apart from these modifications, the power supply subsystem is still responsible for providing the appropriate measures of voltage and current to each of the following subsystems. The step-up converter must be able to supply 5 V and sufficient current to the speaker-amplifier, four PIR sensors and buck regulator. The step-down converter similarly must supply 3.3 V and sufficient current to the microphone and microcontroller. More details on the current and power consumption of each major component are listed in Table 1 and 2 in section 2.1 Power Management and Storage. RONArmor provides power with a 3.7 V lithium-polymer battery with a maximum constant current of 2 A and a capacity of 4.4 Ahr.

The control unit uses the 5V output from the power supply subsystem through a blue LED to indicate to the user that the system is on. It is also responsible for reading in and transferring out the I²S protocol for audio in the voice functions subsystem, as well as taking in a high voltage signal from the volume control dial at one of three varying GPIO pins. Furthermore, the control unit must also provide communication between the four PIR sensors and the warning LED on the shield. The control unit's functions are largely tied to the functions of both the voice function and social distancing subsystems, which are elaborated on below.

Another major alteration was the transition from frequency modulation in the voice functions subsystem and the four position modulation control dial in the control unit subsystem to volume modulation and a three position volume control dial respectively. For more information on this design change, reference section 2.3 Voice Functions. Aside from the shift to volume modulation, the voice function subsystem still must take in an 8-bit I^2S audio input from an external source and relay it to the microcontroller. The subsystem must also be able to choose by how much the audio signal should be amplified based on the input from the volume control dial on the face shield. From there an amplifier must take in the 8-bit I^2S audio output from the microcontroller and deliver it to the 8Ω speaker.

Continuing, the block diagram also illustrates the alteration of the warning LED to display only one red LED instead of a junction of one red LED and one green LED. This revision is elaborated on more in section 2.4 Social Distancing. The warning LED is mounted on the face shield. However, it works in conjunction with the system of four PIR sensors. Each of the four PIR sensors is responsible for surveying 100 degrees of the user's surroundings for a total 360 degree coverage. If another person steps within a six to six-and-a-half foot radius of the user, the system of four PIR sensors is responsible for sending a high 3.3V signal to the microcontroller. If any of the four PIR sensors is triggered, the microcontroller will then turn on the warning LED.

Lastly, the final block diagram no longer states that the facial shield will include non-woven polypropylene and humidity resistant spray. For further explanation as to why, refer to section 2.5 Facial Shield. The control dial was moved from the facial shield to the control unit in order to cut down the weight of the shield and the number of wires from the PCB to the shield. The block diagram has been modified to show what other subsystems are physically located on the shield with a thin, transparent bubble pointing in the direction of the respective subsystem, as seen in Figure 1.

2. Design

2.1. Power Management and Storage

2.1.1. Design Description

The power of our final project is supplied by a 3.7 V lithium-polymer battery with a maximum constant current of 2 A and a capacity of 4.4 Ahr. When originally designing the flow of power through the system, the battery was going to be the direct input to both the boost and buck regulators. With testing and troubleshooting, though, we discovered that it was very difficult to sustain a reliable 3.3 V step-down from 3.7 V. For this reason, we reorganized the power subsystem so that the battery output was only directly connected to the 5 V boost input and the 5 V output was used to power the buck regulator.

The next two considerations were focused on providing enough power to the amplifier and speaker because they were the greatest consumers of the system. The original amplifier and speaker arrangement were designed to be powered by 5 V through a 4 Ω speaker. While this set up worked fine during isolated audio testing, when integration tests began, the battery could not support this setup. As an alternative, tests were performed with the amplifier being supplied with 3.3 V as opposed to 5 V. While this solved the integration problem by reducing the power consumption of the amplifier, the audio volume was greatly reduced. Since audio is a major function of RONArmor, we explored different ways to cut down the power consumption of the amplifier. The next option was to increase the resistance of the speaker. At 5 V to the amplifier through an 8 Ω speaker, the best audio volume was achieved while maintaining a functional integrated system.

Overall, battery capacity versus the size and weight of the battery used was our greatest challenge. Small batteries with large capacities were very expensive, and the aim was to make RONArmor affordable to the average person. For this reason, the final battery capacity used supported a minimum of three hours of function. As is, the product would only be useful for short trips such as grocery shopping or walking one’s dog. The goal, however, is to allow RONArmor to be used for the extent of a full work day (roughly eight hours at least). One alternative implementation to minimizing power that would be strongly considered moving forward would be to implement a hierarchical system within both the social distancing and the voice function subsystem. For the social distancing subsystem one solution would be to not have the PIR sensor detection always on, but instead to include an ultrasonic sensor that would alert the microcontroller when movement was detected and thus when PIR sensor detection should be activated. Similar for the voice function subsystem, power consumption could be reduced by not having the amplifier always on and instead including an energy sensor that tells the microcontroller when air pressure changes warrant the activation of the amplifier.

2.1.2. Design Details

The circuit implementation of the power subsystem can be viewed in Figure 3. The power subsystem’s main responsibility is to provide the appropriate voltage and current levels to each subsequent subsystem in the unit. The flow of the main power suppliers and consumption is shown in Figure 4. The unit does so with a 3.7 V rechargeable battery. For the user’s safety, a SN74LVC1G3157DBVR single pole, double throw (SPDT) relay was also used to isolate the main circuit from the recharging circuit when the 5 V source is present. The 3.7 V battery powers the relay, and the output of the relay acts as the enable to the 5 V boost regulator. The relay is closed in its resting position (when no 5 V is present). When 5 V is connected, the relay opens and the boost is disabled [#]. When the 5 V is connected, a MCP73831T-2ATI/OT recharging IC with overcharge control charges the battery to 4 V and then stops [#].

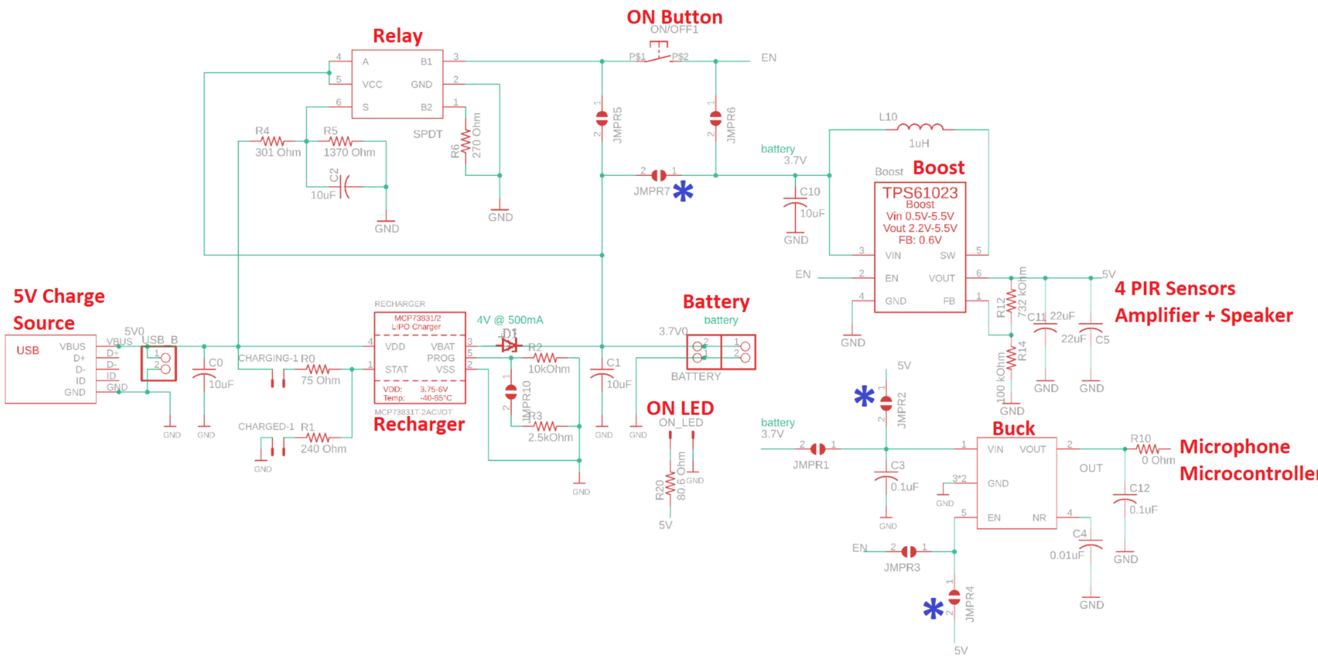


Figure 3

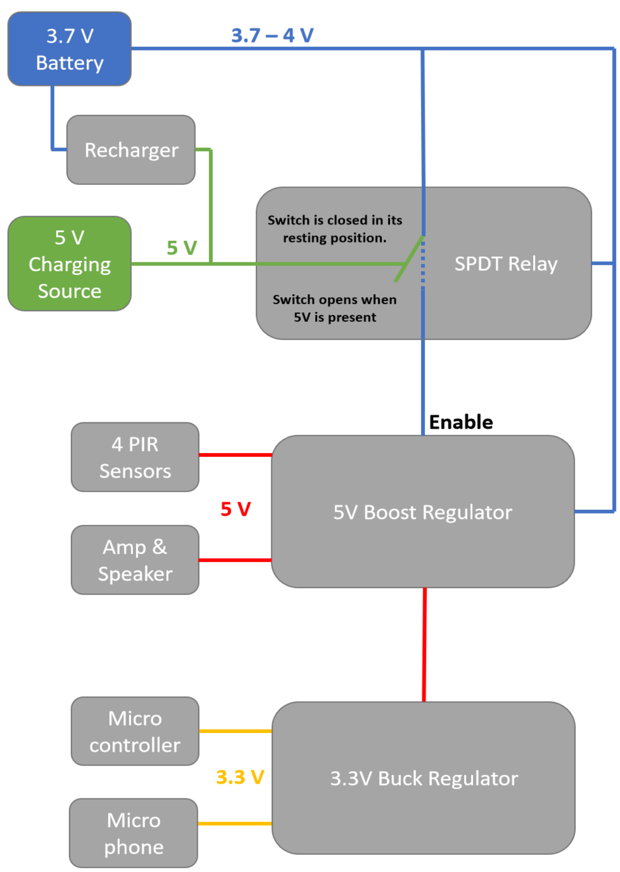


Figure 4: Power Subsystem Block Diagram

The battery is only directly connected to the 5 V boost regulator. For this reason, the regulator must be able to support the full current needs of all the subsystems. Texas Instructment's TPS61023 was perfect for the job as it has a current rating of 3 A [#]. The boost then supplies the four PIR sensors, the amplifier-speaker combo, and the 3.3 V buck. The exact values of current consumption for each of the components that the boost must support is displayed blow in Table 1 and 2. The buck is necessary because the microcontroller and microphone have an input voltage of 3.3 V maximum. Similarly, the 3.3 V buck regulator had to have the ability to supply enough current to both the microcontroller and the microphone. Texas Instrument's REG104GA-3.3/2K5 was utilized for this purpose because it could deliver 1 A [#]. The exact values of current consumption for each of the components that the regulator must support is displayed blow in Table 2. A total current consumption of 1,461.98 mA with a battery capacity of 4.4 Ahr yields a total battery life of about three hours.

5 V / 3 A Boost Current	
4 PIR Sensors	41.35 mA
Amplifier & Speaker	760.22 mA
3.3 V Buck Regulator	660.41 mA
Total Consumption	1,461.98 mA

Table 1

3.3 V / 1 A Boost Current	
Microcontroller	659.79 mA
Microphone	0.62 mA
Total Consumption	660.41 mA

Table 2

2.2. Control Unit

2.2.1. Design Description

This unit is responsible for processing the data from the sensors, determining the status of user interface LED, and handling the signal processing performed from microphone input to speaker output. An ESP32 microcontroller was used for this purpose. This microcontroller was used for its versatility with different sensors, internal DAC, which would be helpful for audio processing, compact size, and low price. In addition, ESP32 has a dual core processor which enables us to run the different subsystems on different cores, thus enabling Social Distancing and Audio Processing to run independently of each other. The ESP32 is available as a standalone module which makes it easy to incorporate into a custom board. Table 3 shows the general connections made to and from the control unit.

Connection from	Connection to	Purpose
3.3 V from Power Module	ESP32 Vin and Enable	To power the board using Vin and running it by keeping Enable high.
4 PIR sensors	ESP32	To receive data from the PIR sensors, for the social distancing indicator module.
ESP32	Warning LED	To indicate when a presence is detected within 6-6.5ft radius
Microphone	ESP32	To receive data captured by the microphone
ESP32	Amplifier	To transmit the processed microphone signals to the speaker for output.
Volume Dial	ESP32	To adjust the volume level

Table 3: Connections to and from the control unit

2.2.2. Design Details

Bootloading Circuit

To incorporate a standalone dev module instead of dev board, we used a USB to TTL programmer module. The circuit for this is shown in Figure 5. The TX and RX lines are the data lines used for programming the module. RX stands for Receiving and TX for Transmitting. Thus, it is essential while programming the board that the TX from the computer is connected to RX of the module for successful bootloading. The circuits on either side of the module emulate the BOOT and ENABLE button of a dev board.

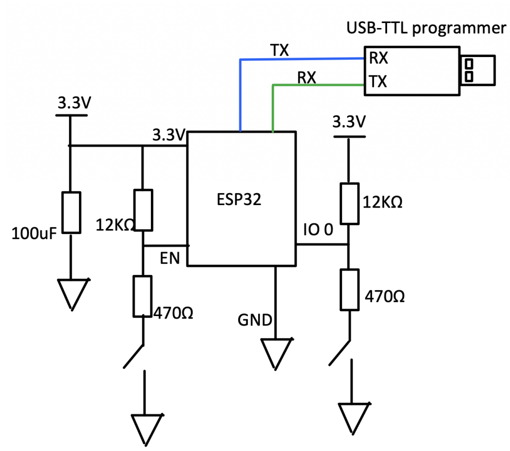


Figure 5: Bootloading circuit for the ESP32

Software

Initially we had decided to use Micropython to program the board. The decision was based on ease of use with signal processing functions. However, we shifted to conventional Arduino(C++) when Micropython's i2s driver failed to establish the connections needed for communication with the microphone and amplifier. Overall the software was responsible for receiving, processing and delivering signals and commands according to the user's inputs via the modulation control dial, the ON/OFF button, and the PIR sensors' signals.

a) *Algorithm for Social Distancing Indicator*
   The software uses an interrupt based approach to read the DIG OUT signals from the PIR sensors. An interrupt based approach increases efficiency by removing the constant polling, thus triggering a condition only when an event occurs. In our case, whenever a person enters within a 6ft distance of the user, the PIR sensor generates an interrupt which in turn turns on the warning LED.
b) *Algorithm for Voice functions:*
   The software establishes a connection with the Microphone and Amplifier via the I2S protocol which allows the DMA buffer within the ESP32 to receive and transmit audio data respectively. This data is then read using the 'i2s_read' function from the Espressif-IDF library. We use buffers to store this data and then process it for amplification. Once processed, it is sent to the amplifier by using the 'i2s_push_sample' function. The audio data is thus transmitted in real time.

2.3. Voice Functions

2.3.1. Design Description

This is one of the main characteristics of the project which utilizes voice amplification based on user input. This subsystem utilizes a microphone inside the face shield to capture voice. The signal is then sent to the microcontroller for processing. The processed audio data is sent to the digital audio amplifier which relays the analog sound to a speaker present on the face shield. The user is able to select a volume level from whisper, conversational, to loud (low, normal, high amplification respectively). Initially, we intended to use frequency modulation to change a user's voice; however after realizing the full scope of the complexity of frequency modulation, especially in real-time, we determined that it was more practical for both our design and the purpose of RONArmor to implement volume modulation instead so that the shield can be convenient in various quiet and loud environments. Prior to making this change, we tried using granular synthesis, phase vocoder, and pitch shifting in order to modulate voice. While we were able to generate a modulated sound, we were unable to sustain the duration of the original audio and ultimately decided to incorporate volume modulation instead.

2.3.2. Design Details

We used the SPH0645 breakout board (I2S digital microphone) and MAX98357 (I2S audio amplifier) [6]. Each of these operates on 3.3 V inputs and has low amperage of about 20 mA. Since these utilize only digital signals, we were able to test and monitor the desired nature of audio using the microcontroller. The interaction between the controller and these chips was done via Arduino code using specific libraries for the ESP32 board. The ESP32 microcontroller has good support for I2S protocol and by using the separate breakout boards we were able to ensure minimal loss in quality since the microcontroller natively supports only 8 bit stream while the breakout boards support 16 bit stream.

2.4. Social Distancing

2.4.1. Design Description

One of the main functionalities of our project is its ability to warn the user if there are people within a 6 to 6.5 ft radius. To do this, we utilize a total of four Passive Infrared (PIR) Sensors set at a sensitivity between 6 to 6.5 ft for detection, because of their nature of only triggering to living organisms. These sensitivity ranges are calibrated by using the testing circuit below in Figure 6. We send this data to our software in the microcontroller to establish whether the person detected is too close per the CDC's social distancing guidelines using logic. Signals are then sent to the red warning LED that indicate to the user whether social distancing guidelines have been breached.

Alternative approaches that were considered for the design of this subsystem include using eight PIR sensors with sensitivity ranges of 4ft and 6 ft and also by using 4 ultrasonic sensors and 4 PIR sensors that are vertically stacked upon one another. While we initially proposed the first consideration, we ultimately decided to not use it due to the redundancy and ineffectiveness of having PIR sensors at differing sensitivities and because of the magnitude of power that would be consumed by eight sensors. Our calculations and estimations for the detection ranges of this design consideration can be seen in Figure 7. Similarly, the second consideration was also not used due to the amount of power that would be consumed, the likelihood of an increased amount of false positives when using ultrasonic sensors that are sensitive to inanimate objects, and the difficulty of ensuring the PIR sensors are detecting the same people as the ultrasonic sensors.

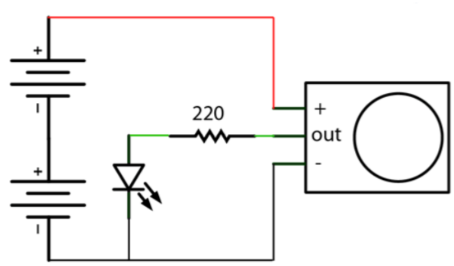
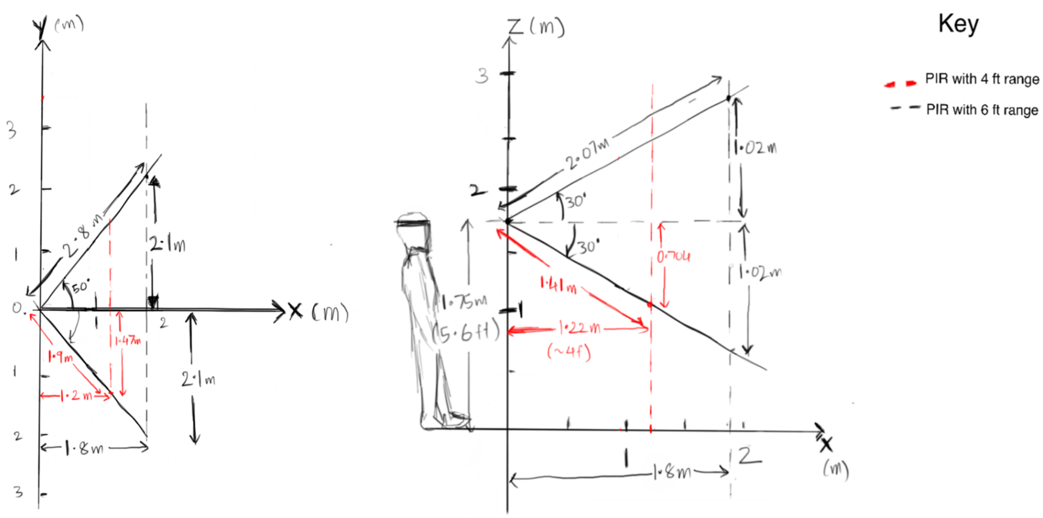


Figure 6: Verification circuit for PIR sensors [13]



Top View

Side view

Figure 7: Angles and Ranges for a two PIR sensor social distancing module.

2.4.2. Design Details

We intend to use the PIR sensor module controlled by the ESP32 microcontroller to ensure the social distancing aspect of our project. Each PIR sensor takes in 3.3 V and is controlled via the I/O pins on the microcontroller. We also use the PIR motion sensors by Adafruit. They each have an overlooking horizontal range of ~100-110 degrees and a vertical range of ~60-70 degrees as shown in Figure 7 [12]. Given the range of each sensor and our calculations from Figure 8, we have a total of four sensors in each quadrant, 90 degrees apart, in order to ensure a full coverage of 360 degrees and reduce unnecessary power consumption. Again, each of the sensors are calibrated to have a sensitivity range between 6 to 6.5 ft by using the testing circuit from Figure 6 and adjusting the trimpots of each sensor until they output a HIGH of 3.3V only when correctly triggered.

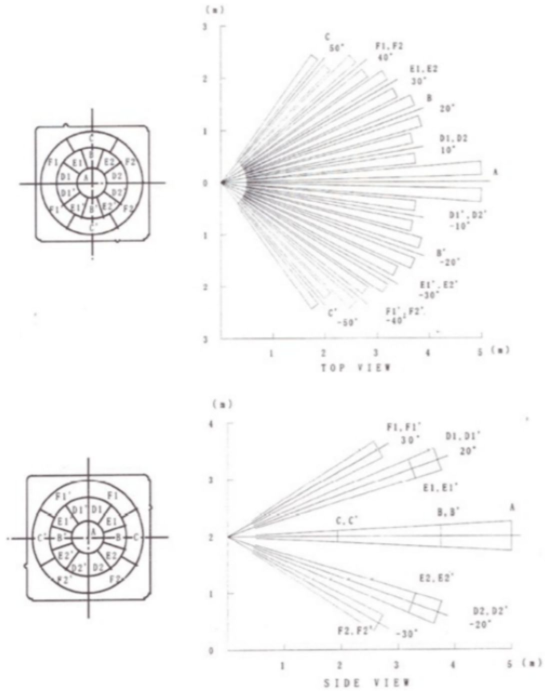


Figure 8: PIR Sensor’s different faceting/sub-lenses and their range of detection areas [12]

2.5. Facial Shield

2.5.1. Design Description

As for the physical shield of our project, we use clear, recyclable plastic for the shield that extends past the face and effectively covers the user’s eyes, nose, and mouth. It no longer has the initially proposed silicon padding nor be form-fitting. The reasons for these alterations are to increase comfort for the wearer and reduce the likelihood of fogging up the shield. Lastly, the inside is coated with a transparent humidity resistant spray.

2.5.2. Design Details

This subsystem consists of the ON button, the ON LED, warning LED, and the volume modulation dial. The frequency modulation dial has instead become the volume modulation dial due to the reasons stated earlier in the voice functions subsystem. The table below, Table 4, shows the general connections made to and from the facial shield unit.

Connection from	Connection to	Purpose
5V from the Boost	ON Button	To allow the unit to power up and down as a whole

3.7 V Lithium-polymer battery	ON LED	To show whether or not the facial shield is active
ESP32	Warning LED	To indicate when a presence is detected within 6-6.5ft radius
User	Volume Dial	To allow the user to have manipulate volume levels

Table 4:Connections to and from the Face Shield

The ON button allows the unit to power up and down as a whole. When the unit is successfully powered on, a green ON LED lights up to indicate to the user that the facial shield is active and fully operating.

The warning LED is dependent on the PIR sensors in the social distancing indicator subsystem. According to the signals received by the microcontroller from the PIR sensors, the embedded software delegates when the LED will light up.

The volume dial consists of three volume options: whisper, conversational, and raised. When the dial is turned to a specific volume setting, a signal is sent to the microcontroller for signal processing. Once the microcontroller receives the voice signal, it applies the appropriate amplification ratio to the volume before outputting the new audio via a 4 ohm speaker mounted on the facial shield.

3. Verification

Due to the modular nature of RONArmor, we used a module-based verification approach as it made sense for us to assume that if the higher level application worked, then the lower level must work as well. In the event of a module failure, we shifted to the lower level verification steps. Detailed description of the requirements and verification is included in Appendix A. Sections 3.1 through 3.5 elaborate on the verification process per subsystem.

3.1. Power Management and Storage

Success of Power Management and Storage is defined by each regulator and load receiving the voltage and current levels necessary for operation. Furthermore, the power subsystem is only considered successful if all wires are properly insulated and routed away from the user's face to ensure his or her safety.

3.2. Control Unit

The overall success of the Control Unit is verified by the operation of the product as a whole. If the Voice Functions and Social Distancing work after the code is uploaded onto the standalone module, then it verifies that the Control Unit is working.

3.3. Voice Functions

The major requirement for Voice Function is to hear whatever the words spoken by the user through the speaker. To test the data received by the microphone, we used the Serial Plotter in the Arduino IDE to visualize the signals. This is shown in Figure 9. To verify that these signals were outputting to the amplifier, we used the Serial monitor to read the HEX signals from the buffer right before pushing to the DMA buffer in the ESP32.

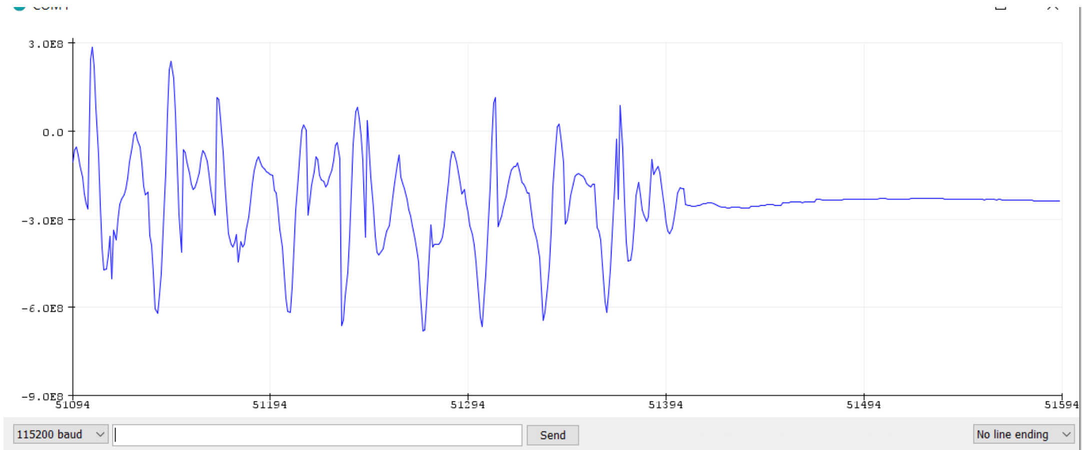


Figure 9: Serial Plotter Output for Microphone

The other requirement for the voice functions was to successfully amplify the signals. We used a multiplier based on the modulation dial input to change the volume and confirm by listening for definite change in volume.

3.4. Social Distancing

The biggest requirement to confirm the full functionality of the social distancing indicator is to have each PIR sensor set to the correct sensitivity range, 6-6.5 ft, and its DIGI.OUT is HIGH only whenever human motion is detected within this range. This requirement is verified in two steps. Initially, by connecting each PIR sensor to the PIR testing circuit along with a voltmeter and having someone pace less than 6ft, between 6-6.5ft, and beyond 6.5ft away and adjust the trimpot accordingly so that the voltmeter reads 3.3V only for the first two ranges. Finally, we confirmed that this subsystem works properly after integration by checking that the warning led is outputting correctly when a person actually wears the entire shield. The results of the verification are put into a confusion matrix as shown in Table 5.

	Positive	Negative	Total
True	44	24	68
False	18	14	32
Total	62	38	100

Table 5: Confusion Matrix to show True/False Positive/Negatives

The data in Table 5 was generated by testing about 25 test points per quadrant giving a total of 100 test points. Overall, the success rate i.e. total true positives and negatives is 68%. The positions of the testing points and their results are shown in Figure 10.

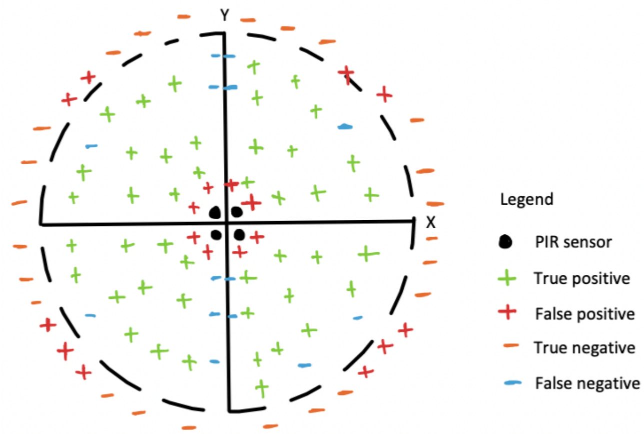


Figure 10: Verification Setup for Social Distancing Subsystem

3.5. Facial Shield

The success of the facial shield subsystem is dependent on the power management and storage, control unit, and social distancing subsystems. Thus, if the specified subsystems are functional, the ON button will power the entire system, the ON and warning LEDs will light up when necessary, and the volume dial will respond to the user's input accordingly. These indicate the successful implementation of the facial shield subsystem. Additionally, for safety reasons, we must also ensure that the entirety of the printed circuit board (PCB) and the power supply is not exposed or near the face. We verified this by positioning all the relative components inside the black, thermal box and checking that the enclosure can be completely closed with all components covered.

4. Costs

Our fixed development labor cost for each of the three members of our team is estimated to be about $43.80/hour based on the average starting salary of an ECE graduate from the University of Illinois [20]. Each team member will work on the project for approximately 10 hours a week for the entire duration of the semester - a total of 14 weeks.

$$3\ team\ members \times \frac{\$43.80}{hour} \times \frac{10\ hour}{week} \times 14 weeks \times 2.5 = \$45,990$$

Additional Expenditures are included in Table 6 and Table 7 below:

Part Number	Description	Manufacturer	Quantity	Unit Cost	Bulk Cost
ESP32	Dual-core microprocessor & development board	HiLetgo	1	$10.99	$10.99
3006	MAX98357A amplifier breakout board	Adafruit Industries LLC	1	$5.95	$5.95
3421	SPH0645LM4H microphone breakout board	Adafruit Industries LLC	1	$6.95	$6.95
PIR Motion Sensor module (BIS0001 decoder, RE200B PIR element, NL11NH fresnel lens)	Motion Sensor	Adafruit Industries LLC	4	$9.95	$39.80
MCP73831T-2ATI/OT	LiPolymer Recharger	Adafruit Industries LLC	1	$0.59	$1.18
296-48647-1-ND	3.3 V Linear Voltage Regulator	Texas Instruments	1	$0.98	$1.96
HJ-0502000W1-US	5V Adaptor/ Charger	Hanzhiqiang	1	$10.90	$10.90
1528-1834-ND	3.7 V Lithium-Polymer Battery	Adafruit Industries LLC	1	$19.95	$19.95
AS04008PO-2-LW152-WR-R	Speaker	PUI Audio, Inc.	1	$4.52	$4.52
TPS61023	5 V Switching Regulator	Texas Instruments	1	$1.13	$1.13

Total Electrical Parts Cost: $103.33

Table 6: Electrical Expenditures

Part Number	Description	Manufacturer	Quantity	Unit Cost	Bulk Cost
ANSI/ISEA Z87.1+	Facial Shield	McMaster-Carr	1	$38	$38
1594CBK	Thermally resistant box	Hammond Manufacturing	1	$10.60	$10.60
565PB-ND	On/Off button	NTE Electronics, Inc	1	$2.25	$2.25
NR01104ANG13-2H	Modulation Knob	NKK Switches	1	$11.68	$11.68
N/A	Lanyard	MJ fashion	1	$3.88	$3.88
N/A	Humidity Spray	Apple Brand	1	$16.49	$16.49

Total Electrical Parts Cost: $82.90

Table 7: Mechanical Expenditures

Grand Total

$$\$45,990 \ + \$103.33 \ + \ \$82.90 \ = \$46,176.23$$

5. Conclusion

5.1. Summary

Overall, we are satisfied with the outcome of our project and its successes. Each member of our team did their utmost to overcome any unforeseen circumstances we faced. We were able to have each individual subsystem function completely on its own but faced difficulties concerning the integration of the entire project. After integration, most of our subsystems remained relatively functional with the control unit receiving, processing, and sending signals, social distancing system alerting the user within the desired ranges and audio being amplified. However, we would like to improve the overall safety of our project to ensure the full protection of the user not only from viruses, but also from any of the electrical components of this project. Thus a reduction of wires and proper enclosures for them are vital future steps. We will expand more on our successes, failures, and future considerations in the following sections.

We also recognize that we gained valuable experience during the entire process of creating the final RONArmor deliverable. We learned how to make a compact PCB, the complexity of frequency modulation, and the extent of how portable devices are limited by power and cost. This experience was important to our growth in confidence as engineers.

5.2. Safety & Ethics

The main concern we are focused on as we begin to develop RonaAmor is the potential safety hazard that lithium-polymer batteries present. This hazard cannot be completely eliminated due to the necessity of a high energy density, portable power supply for our facial shield. Nevertheless, we are committed to upholding the IEEE standard of prioritizing, “the safety, health, and welfare of the public [by striving] to comply with ethical design and sustainable development practices” [21]. In doing so, we will center our attention on taking the necessary precautions to ensure the longevity of our facial masks and the safety of the community members who will be wearing them.

Lithium-polymer batteries have been known to cause fires, explosions, and other harmful accidents. Studies have shown that these accidents are largely caused by poor electrical designs such as short circuits, overcharging batteries, and exposure to temperatures beyond their thermal rating [22]. To reduce these risk factors, we will integrate an appropriate charge management controller into our power supply subsystem. A good contender for a power management IC (PMIC) is Microchip Technology’s MCP73831/2 linear charge management controller. Once this PMIC has reached its Charge Complete mode (meaning the average charge current has diminished below an established percentage of the programmed charge current), the MCP73831/2 will latch off the charge current to prevent overcharging the battery. Furthermore, this PMIC is also designed to suspend charge if the die temperature exceeds 150° C and will not resume charging until the die has cooled to 10° C [5].

Another precaution that RonaAmor takes to prevent the harm of its users is the isolation of the battery pack from the user’s face, neck, and head. Our design allows for the battery recharging circuit, the battery itself and much of the supplemental circuitry to be located inside a thermally protective box fashioned to clip onto the users’ clothing a safe distance away from the facial shield itself. In this way, we are both preventing electrical accidents as well as preparing for the worst-case scenario. Overall, all the engineers on this project are committed to the IEEE standard, “to seek, accept, and offer honest criticism of technical work [and] to acknowledge and correct errors” as we launch this new and exciting product that we anticipate will provide some relief in the midst of this global pandemic [21].

5.3. Successes & Difficulties Encountered

RONArmor has experienced its fair share of successes and failures. It was successful in that the PIR sensors properly trigger 68% of the time. While we would like to have increased this number if possible, it still demonstrates that the PIR sensors are relatively receiving and sending signals correctly, which fulfills one of our high level requirements. Other successes include the audio components amplifying the user's voice, the dual core implementation, and constructing a compact and wearable design.

Difficulties that we encountered included using the Micropython software implementation for our control unit due to the difficulty of installing the i2s driver/tools for our audio components and the implementation's lacking documentation. Again, this is what resulted in eventually using Arduino instead. The second struggle we faced was with frequency modulation. It turned out to be more complex than what we initially expected, especially when attempting to perform modulation in real-time. After attempting several times to use granular synthesis, phase vocoder, and pitch shifting, we were able to generate an imperfect modulated sound. Thus, we decided to integrate volume modulation instead as it was more practical for our project's purpose. This issue also led to our realization of the importance of thoroughly researching and understanding the full-scope of a project's features prior to trying to design and build it. We also struggled with volume modulation and were unable to adjust the volume levels using the dial. This is because. Finally, during our final demo, we had to confront the issue of a sudden bunch of loose wires for our components' connectors as the wires that were retrieved from ECEB were not the appropriate sizes for the crimps and connectors that we had used, but we were unable to access the building to exchange them.

5.4. Future Considerations

Future considerations and improvements that we have for this project are to implement better cable management by: centralizing all the GNDs and Vin wires together to reduce the number of wires, adjusting the sensitivity range of the PIR sensors to not detect the user's own motion, covering audio components in water-resistant enclosures, identifying more compact and powerful batteries with larger capacities, and decreasing the overall weight of the entire shield.

Lastly, as the safety of the user is extremely important for the success of this project, we will also make sure all wires, connectors, and any electrical components of the final product are fully enclosed, covered, and away from the face.

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Appendix

A. Requirements and Verification Tables

A1. Power Management and Storage

Requirements	Verification	Result
1.) Battery supplies 3.7-4V	1a.) Make sure button is in off position. 1b.) Use multimeter to measure voltage across battery connector terminals.	V_{bat} = 3.97 V
2.) Boost takes in battery voltage and outputs 5V ∓ 5%	2a.) Press power button to turn on RONArmor 2b.) Measure voltage across JUMPR 5 and verify that voltage is 3.7-4 V. 2c.) Measure voltage across JUMPR 4 and verify that voltage is 5 V ∓ 5%.	V_{JUMPR5} = 3.97 V V_{JUMPR4} = 4.99 V
3.) Buck takes in 5V and outputs 3.3V ∓ 5%	3a.) Make sure the button remains in the on position. 3b.) Measure voltage across JUMPR4 and verify that voltage is 5 V. 3c.) Measure voltage at via below buck and verify that voltage is 3.3 V ∓ 5%.	V_{JUMPR4} = 5.01 V V_{via} = 3.30 V
4.) Microcontroller and microphone takes in 3.3V	4a.) With button remaining in the on position, measure voltage from pin 3 on the microcontroller to GND. 4b.) Verify that pin 3 to GND is 3.3 V ∓ 5%. 4c.) Measure voltage across the first two pins on the left side of the microphone. 4d.) Verify that voltage is 3.3 V ∓ 5%.	$V_{pin\ 3}$ = 3.28 V $V_{microphone}$ = 3.28 V
5.) Amplifier and PIR sensors take in 5V	5a.) Measure voltage across the first two pints on the left side of amplifier/speaker 5b.) Verify that voltage is 5 V ∓ 5%	$V_{amp/speaker}$ = 5.00 V
6.) PIR sensors take in 5V	6a.) Measure voltage across the top and bottom pins on the PIR connectors. 6b.) Verify that voltage is 5 V ∓ 5%. 6c.) Repeat steps (6a) and (6b) for each of the three remaining PIR sensors.	V_{PIR1} = 4.99 V V_{PIR2} = 4.99 V V_{PIR3} = 4.98 V V_{PIR4} = 4.99 V

7.) Any load carrying greater than 2mA should be inaccessible to the user	7a.) Visually verify that wires connected to the amplifier/speaker are completely insulated and organized closely around the mask surface.	Success

A2. Control Unit

Requirements	Verification	Result
1.) ESP32 microcontroller is powered at 3.3 V as the I/O pins are not 5 V tolerant. I/O pins are needed to control the other components so it is crucial that 3.3 V is maintained.	1a.) Power the microcontroller with a voltage regulated lithium-polymer battery pack. 1b.) Connect the voltage inputs of the microcontroller to a voltmeter and confirm that a voltage reading of 3.3 V is being powered to the system.	Success
2.) Correct output is generated for the social distancing subsystem	2a.) Connect the four PIR sensors to their appropriate pins. Carry out the steps from the RV table for the social distancing indicator subsystem (Table A4). If successfully implemented, the warning LED should turn on when a person enters within 6ft radius.	Success
3.) Voice is successfully amplified and can be heard through the speaker	3a.) Follow the steps from the Voice Functions RV table (Table A3) to verify if the sound subsystem is working. On successful implementation, we should hear the user's amplified voice.	Partial Success

A3. Voice Functions

Requirements	Verification	Result
1.) Successful connection is established using the I2S protocol.	1a.) Connect the microphone and amplifier to the ESP32 correctly using the GPIOs required by the I2S protocol. 1b.) Upon successful connection, use the serial plotter and monitor to generate the signals received from the microphone. 1c.) Using the signal monitor, ensure that the amplified signals are getting written to the amplifier.	Success
2.) Speaker projects clear audio at either of the three optional volumes in real-time.	2a.) Set the voice modulation knob to "conversational" 2b.) Position yourself so that your mouth is approximately 3 cm from the bottom port of the MEMS device. 2c.) At your natural tone and volume, speak into the MEMs device. 2d.) Confirm that the volume of the voice projected through the speaker can be heard by someone else in a conversational setting. 2e.) Repeat steps 2b-2d with the volume modulation knob set to "whisper" and "raised", which are respectively quieter and louder than the "conversational" volume.	Partial Success

A4. Social Distancing

Requirements	Verification	Result
1.) Each sensor possesses an inherent latency of 2-5s after the sensor is triggered	1a.) Have someone stand within 6ft and wave their hands in their air 1b.) Count up to 5sec and confirm that the red LED is triggered 1c.) Repeat 2a and 2b at a distance beyond 6/6.5ft at which the LEDs should not be triggered	Success

2.) Microcontroller receives a high signal from the PIR sensors' DIG. OUT (3.3 V) based on the range set on each sensor. The PIR sensors need to set OUT to HIGH when a person is detected within 6 ft which is indicated by a lit red led.	2a.) Connect the microcontroller to a computer using a USB cable. Place the microcontroller on a breadboard for ease of connection. 2b.) Connect the sensors to the microcontroller by wiring them to the microcontroller's IO pins on the breadboard and power the sensors with a 5V DC input from a function generator. Leave the sensors idle for ~30 - 60 seconds for them to stabilize. 2c.) Place the breadboard at a height of 5.5 ft and have a human walk at a distance less than 6 ft, at 6/6.5 ft, and greater than 6/6.5ft within the range of the sensor (side view: ± 50 degrees, top view: ± 30 degrees assuming that the line of sight of the sensor is the central axis). 2d.) Use a voltmeter to confirm the 6 ft PIR sensor's output voltage to be 3.3 V for within 6/6.5 ft and 0 V for beyond. 2e.) Confirm that the red led is lit when someone is within 6ft of the user and not lit beyond 6/6.5 ft.	Success

<u>A5. Facial Shield</u>

Requirements	Verification	Result
1.) The frequency dial possesses a maximum response time of 1 s, but preferably within 100 µs [16].	1a.) Use an oscilloscope to track the response time and latency of the dial by speaking into the microphone with a roughly constant frequency. 1b.) Simultaneously record the time displayed in the oscilloscope and turn the frequency dial on the mask to "High". 1c.) Note the time at which the frequency displayed on the oscilloscope changes to a steady, higher frequency. 1d.) Ensure that the time difference between that of 1c and 1b is between 100 µs to 1 s.	

2.) The entirety of the printed circuit board and the power supply is no larger than the enclosure that can be clipped-on and away from the face.	1a.) Position the PCB as well as the battery inside of the enclosure and confirm that it will close and can be clipped at a safe distance away from the face.	