WEARABLE SMOKE/CO DETECTOR FOR HEARING IMPAIRED

By

Mohammad Adiprayogo

Mike Loftis

Final Report for ECE 445, Senior Design, Spring 2019

TA: Mengze Sha

01 May 2019

Project No. 57

Abstract

This project aims to create a wearable smoke and carbon monoxide detector designed for the hearing impaired. To accomplish this goal, we considered many different design concepts and the respective tradeoffs involved with each decision choice. This report begins with an introduction to our design and motivation to complete the project. Next, we dive into our design with a modular approach, supporting design choices made throughout. Results and verifications of functionality are then discussed, followed by product costs. The report wraps up with a conclusion and future plans if the project is to be continued.

Contents

1. Introduction

1.1 Purpose

The U.S. Fire Administration estimated a total of 1,319,500 building fires occurred in 2017, causing around 2,400 deaths [1]. In 2015, the CDC reported 393 deaths caused by unintentional non-fire related carbon-monoxide poisoning [2]. The Americans with Disabilities Act of 1990 requires new buildings to be equipped with high intensity strobe light smoke and carbon monoxide alarms to protect the hearing-impaired [3]. Buildings built prior to 1990 were expected to received upgrades to their alarm systems in adherence to the new standard. The responsibility of complying with fire safety building codes lies with the owner of the building, and the hearing impaired should not be at risk due to negligence.

In addition to the high-intensity alarm, products are sold that will vibrate to the frequency of a specified smoke alarm and are placed under a pillow to alert the user during sleep. This device is reliant on the chosen smoke alarm, and most are sold with the contingency of buying the alarm to go with the pillow pad. Wearable smoke detectors do exist, but with the intention of measuring cigarette smoke intake [4].

Our goal is to rid the hearing impaired of this burden. We have created a wrist-wearable device that will alert the wearer of smoke and/or carbon monoxide presence with a vibration. Our solution is the first of its kind in addressing a wearable smoke and carbon monoxide detector designed specifically for the hearing impaired.

1.2 Functions and Features

- External LED reflects battery life upon user request
- Alert the wearer of smoke via vibration motor and an orange LED
- Alert the wearer of carbon monoxide via vibration motor and a red LED
    - Concentration between 50 ppm and 150 ppm: red LED blinks at 5 Hz
    - Concentration between 150 ppm and 400 ppm: red LED blinks at 60 Hz
    - Concentration greater than 400 ppm: red LED is constantly illuminated
- External push buttons halt vibration motor
    - Push and hold ≤ 3 seconds: motor halts for 5 minutes
    - Push and hold > 3 seconds: motor halts for 1 hour

2 Design

2.1 Block Diagram

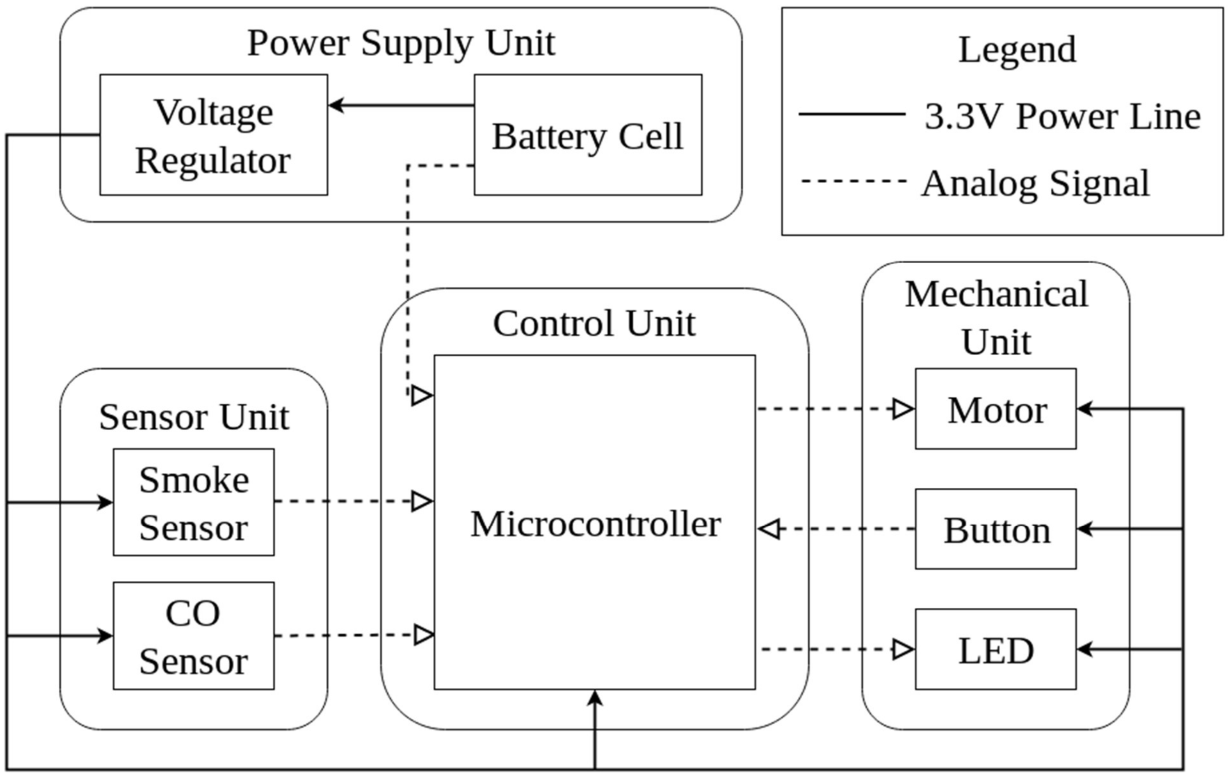

Figure 1 High Level Block Diagram

Shown in Figure 1, the device can be broken down into four distinct units: the power supply unit, the sensor unit, the control unit, and the mechanical unit. These four units were designed to be built and tested independently for modularity.

2.2 Block Description

2.2.1 Power Supply Unit

The Power Supply Unit will provide a constant 3.3 V ± 10% to power line. This unit will consist of a disposable coin cell battery and a 3.3 V step-up DC-DC converter.

Our battery cell is a single CR2477 lithium coin cell which will provide power for all device components. For our design, the battery cell is said to have sufficient remaining capacity if the output voltage lies between 3.3 V and 2.6 V. The 2.6 V cutoff is due to the discharge characteristics shown in Figure 2. Once the nominal voltage reaches 2.6 V, the decrease in output voltage rapidly increases, thus we deem 2.6 V the cutoff. Once this cutoff is reached, the device will communicate the need for a new battery to the user.

The voltage regulator will consist of a single 3.3 V step-up converter. A step-up converter was chosen for two reasons: (1) the range of the battery cell's nominal voltage and (2) the efficiency of the converter is superior to other regulating technologies.

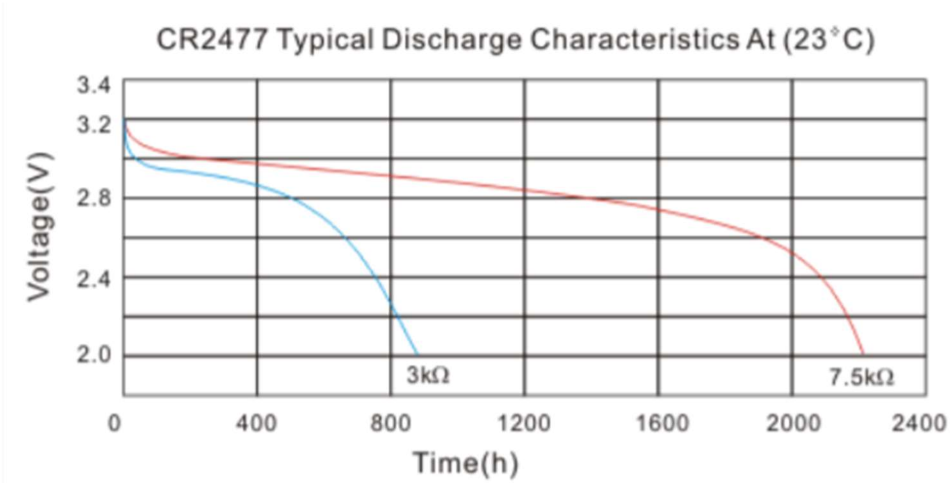

Figure 2 Discharge Characteristics of CR2477 [5]

2.2.2 Sensor Unit

The sensor unit consists of a smoke sensing unit and a carbon monoxide sensor. The two sensing units work in isolation and send readings to the microcontroller simultaneously. The microcontroller then uses the data and determines whether smoke and/or carbon monoxide is present.

The smoke sensing unit utilizes photoelectric technology over ionization. Photoelectric sensors have been shown to be much more effective and do not require a source of radiation that is needed in ionization sensors. Our smoke sensor consists of a white LED and phototransistor inside of a 3D printed chamber shown in Figure 3. The design of the chamber ensures that the phototransistor is sufficiently blocked from the LED light source under normal conditions. In Figure 3, the leads of the LED are placed into the holes at the bottom of the figure and the LED is pointed into the chamber, whereas the phototransistor leads are placed in the top right-hand corner of the chamber. In the presence of smoke, photons emitting from the LED are scattered, some of which will be detected by the phototransistor resulting in an output current greater than the baseline current seen under normal conditions.

Carbon monoxide is monitored using an electrochemical sensor. We elected to go with this technology over biomimetic and semiconductor technologies, because electrochemical gas sensors require no input power since they are effectively a small fuel cell. This decision allowed us to save significant battery life, a very important aspect of creating a wearable device. The electrochemical sensor produces an output current that is linearly related to the concentration of carbon monoxide in parts per million, this current is used as an analog input into the microcontroller.

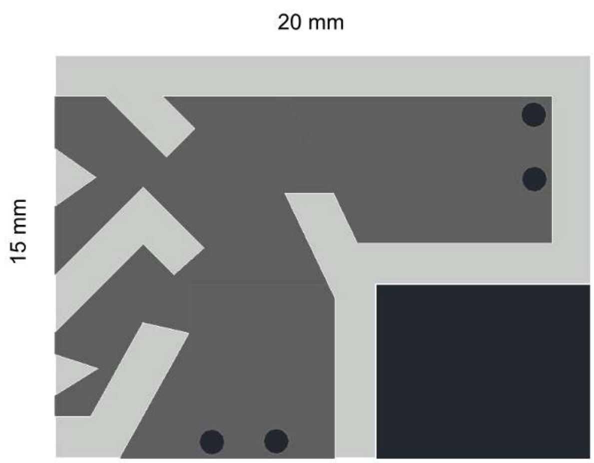

Figure 3 AutoCAD Drawing of Photoelectric Chamber

2.2.3 Mechanical Unit

The mechanical unit includes all our components used to communicate with the wearer. Two push buttons allow the user to interact with the device and three LEDs are used as indicators to effectively create a two-way communication channel between the wearer and the device. A vibration motor is the chosen mechanism for alerting the wearer of potentially dangerous changes in the surrounding environment. The functionality of each individual component at any moment in time is discussed in Section 2.2.4.

Tactile switches were used as the chosen push buttons for their mechanical simplicity. This simplicity gave rise to an unforeseen problem, bouncing. Occasionally in testing, when the button was pushed, we would observe an unexpected result in the physical system that did not occur in simulation. We determined that this was due to bouncing effects; to rid of this problem, we instituted a debouncing circuit shown in Figure 4. The tactile switch operates as an active low switch. This allows the 100 nF capacitor to charge while the button is not being pressed. Pressing the button discharges the capacitor according to Equation (1), where τ represents the time constant of the RC circuit.

$$\tau = RC = (47 * 10^3)(100 * 10^{-9}) \tag{1}$$

$$\tau = 4.7\ ms$$

After the push button has been released, the capacitor is considered to be recharged after about five time constants have passed. This results in a 25 ms timeframe in which the user must wait to guarantee successful communication with the device. Our design does not require quick consecutive button pushes that would cause issues with this debouncing implementation; therefore, we have effectively solved the problem.

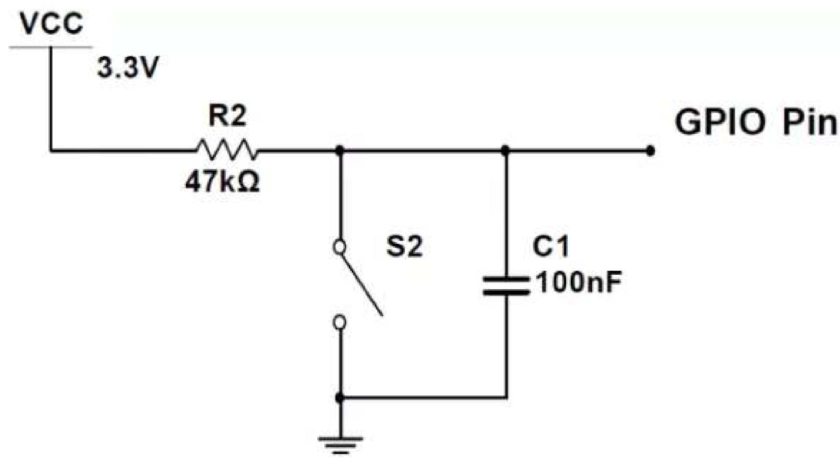

Figure 4 Debouncing Circuit

According to the ATmega328P datasheet, each I/O pin can endure a maximum current of around 40 mA [6]. This is problematic for our design since the vibration motor's rated current is known to be 60 mA [7]. To solve this issue, we decided to use an NPN BJT to control the motor actuation. As shown in Figure 5, the BJT acts as a digital switch between the motor and reference ground.

When the I/O pin is logically low, the BJT will be turned off stopping any current from flowing through the motor. Conversely, when the I/O pin is logically high, the BJT will be turned on allowing current to pass through the motor. Using the motor and BJT specification from their datasheet [7, 8], 3.5 kΩ resistor was chosen to bridge the I/O pin and the base pin of the BJT to ensure that the motor will run at roughly 60 mA.

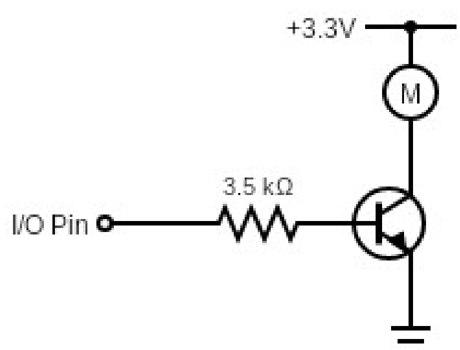

Figure 5 Motor-BJT Mechanism

2.2.4 Control Unit

The Control Unit will consist of a microcontroller. The microcontroller will take input from the battery bank, the push buttons, the two sensing units.

ATmega328P-AU will be used as the product's microcontroller. This microcontroller was chosen because it is small, consumes low power, has enough I/O pins to support our project needs, and can be programmed using Arduino IDE.

To be able to perform our intended functions, the microcontroller will be programmed by following the state machine shown in Figure 6. By default, the microcontroller will start in the normal state (no smoke or carbon monoxide) and move to danger state when a sensor reading exceeds a predetermined threshold. Depending on the user input, the microcontroller will then move to snooze state or halt state.

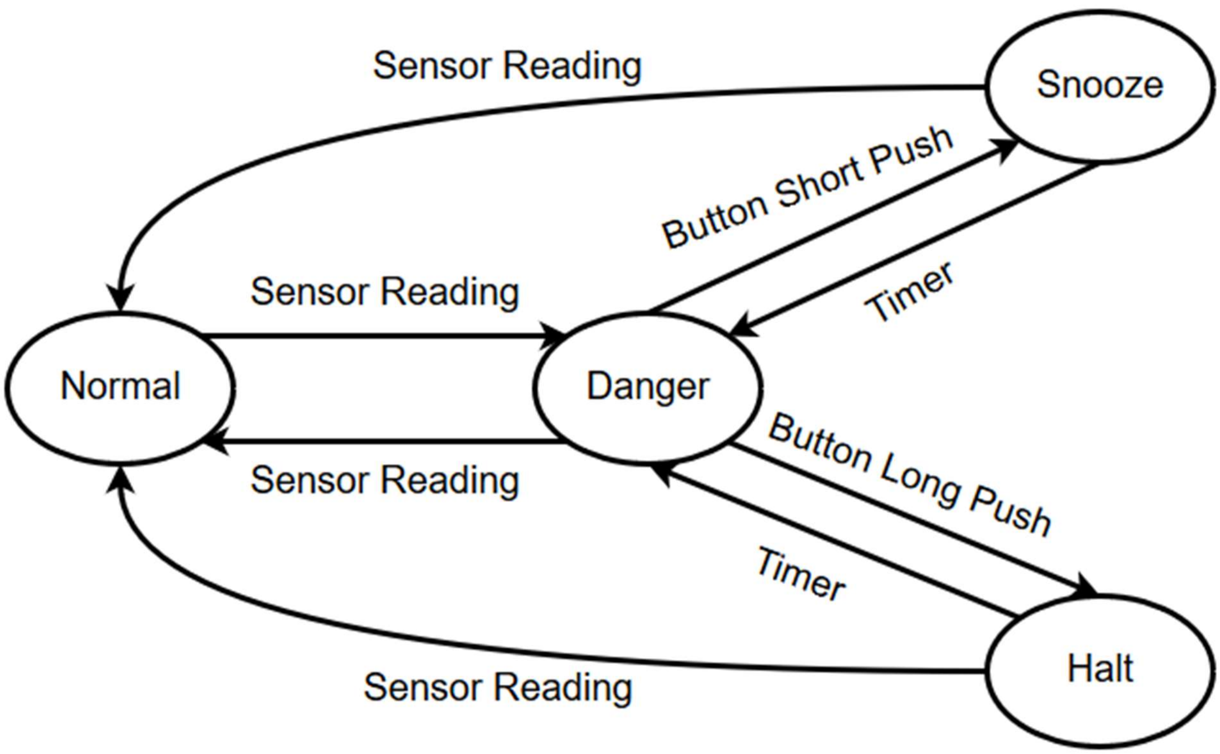

Figure 6 State Machine

In the normal state, the microcontroller will take user input (from an external push button) and perform specified action. One button is used to show current battery level: RGB LED will be green if the battery cell's output voltage remains above 2.6 V, and red if the cell's output voltage falls below 2.6 V. Another button is used to turn on the motor which serves to test whether the motor is functional.

In the danger state, the microcontroller will turn on the motor and the Danger Level Display LEDs to reflect the environment. All the push buttons will now be converted into motor halting buttons. If the button is pressed for less than three seconds, the microcontroller will move to the snooze state. If the button is pressed for more than three seconds, the RGB LED will illuminate blue and the microcontroller will transition into the halt state.

In the snooze state, the Danger Level Display LEDs will communicate the environmental conditions as in danger state, but the motor will no longer be vibrating. In this state, pressing a push button will have no effect. After five minutes, the microcontroller will move back to the danger state.

The halt state will essentially perform the same tasks as the snooze state. The only difference being the motor halting time lasts for one hour as opposed to five minutes.

If carbon monoxide is detected, the microcontroller will blink the red LED at different frequency depending on the concentration of carbon monoxide. Between 50 ppm and 150 ppm, the red LED will blink at a frequency of 5 Hz. Between 150 ppm and 400 ppm, the red LED will blink at a frequency of 5 60. Above 400 ppm, the red LED will no longer blink and continuously illuminate.

When smoke is present, the microcontroller will turn on the orange LED until there is no more smoke; the orange LED does not blink at different frequencies, it is always on if smoke is detected.

3. Design Verification

3.1 Smoke Sensor

The smoke sensor required significant testing to validate our proposed design. We needed to determine the optimal LED current limiting resistor, R1, shown in Figure 7, and simply prove that the design was capable of effectively sensing smoke presence (smoke was emulated with use of a Vape). Available resistors were tested while the LED and phototransistor were housed inside of the 3D printed chamber in Figure 3 to get the most accurate results. Table 1 shows that a 1 kΩ resistor is the optimal value to limit current on the LED, effectively limiting the amount of light seen by the phototransistor. If the resistor R1 was increased to the next available value of 3.3 kΩ, the microcontroller could not differentiate between no smoke and smoky conditions, as the output voltages were too close together. Under normal conditions (no smoke present), the white LED used in the smoke sensor consumes more power than any other component, thus we elected the resistor value which resulted in the most power saved.

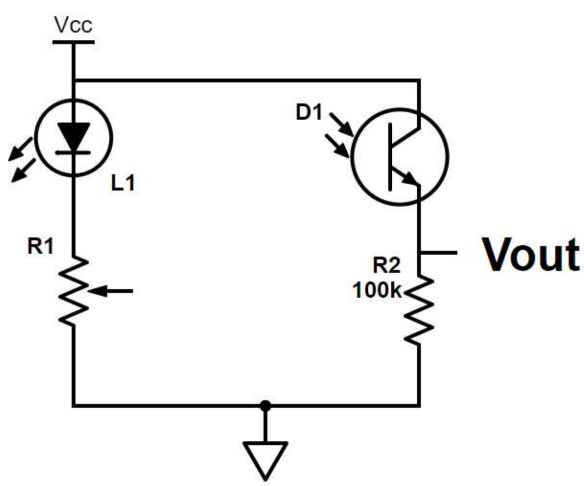

Figure 7 Smoke Sensor Testing Circuit

Table 1 Smoke Sensor Testing Results

Resistance (Ω)	Output Voltage No Smoke (V)	Output Voltage with Smoke (V)
100	2.521	2.980
220	2.228	2.977
330	1.200	2.974
470	0.891	2.610
1000	0.636	1.916
3300	0.088	0.091

3.2 Carbon Monoxide Sensor

The carbon monoxide sensor needed to be tested to validate the linear relationship between carbon monoxide concentration and output current (output voltage across a 100 kΩ resistor was used to measure the output current). The testing set up is shown in Figure 8, the electrochemical carbon monoxide sensor is placed right above the purchased detector to achieve the most accurate results. The detector is equipped with a display screen that is used to monitor the concentration inside of the testing set up. A cigarette is lit and placed on the ash tray shown in the left-hand side photo. After the cigarette is lit, the cardboard box shown in the right-hand side photo is placed over the top of the entire testing arrangement and the output voltage of the detector is measured using an ADALM1000, while the carbon monoxide concentration is monitored using the detector. Figure 9 shows the repeatability of the testing methodology. To our surprise, the set up worked considerably well. Unfortunately, the purchased detector was unable to accurately measure carbon monoxide concentrations higher than 100 ppm, this is the reason why none of the data points exceed 100 ppm.

We still wanted the functionality of increasing the red LED blinking frequency at higher carbon monoxide concentrations, but this feature would need to be simulated. Figure 10 shows that none of the obtained data points are outside of the bounds determined by the minimum and maximum allowable output voltages determined by Equation (3) provided in the sensor's datasheet.

$$I_{out} = 0.023 \pm 0.008 \text{ µA / ppm} \quad (3)$$

Validating Equation (3) allowed us to feel confident in simulating higher concentrations with a power supply used to emulate the sensor output at those unachievable concentrations.

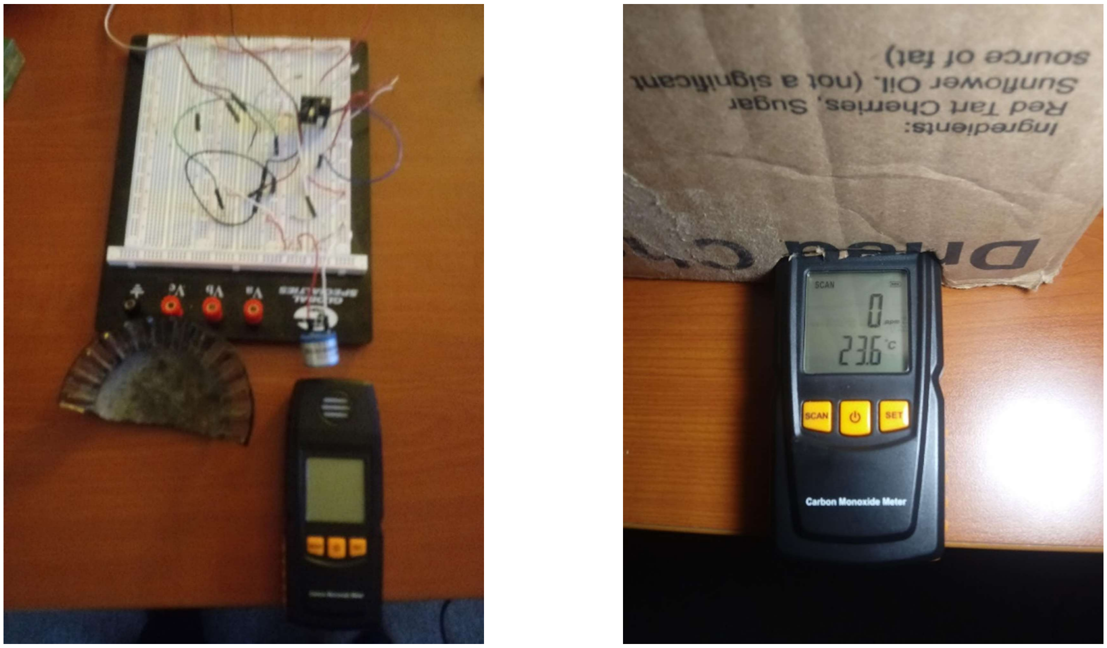

Figure 8 Carbon Monoxide Testing

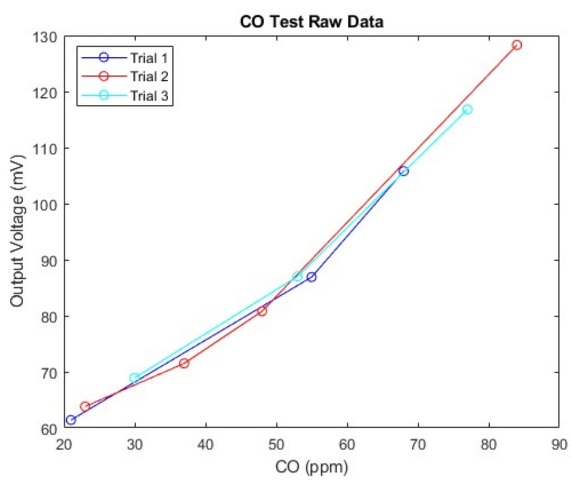

Figure 9 Raw Data from Carbon Monoxide Testing

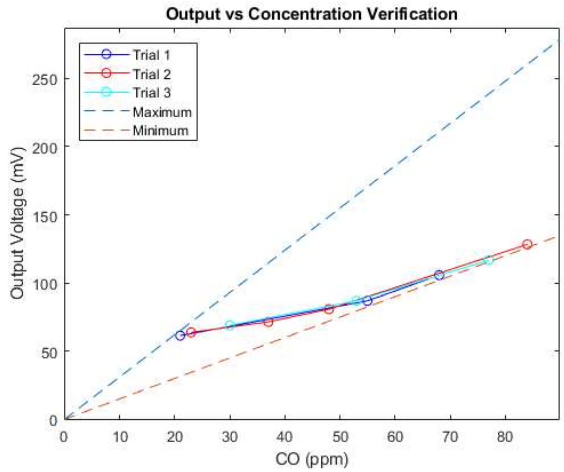

Figure 10 Output Current vs Concentration Verification Data

The control system set points of 50, 150, and 400 ppm (see Section 2.2.4) were chosen as the effects of carbon monoxide on the human body begin to drastically change at these levels. At around 50 ppm, humans are expected to experience mild headaches if exposure lasts longer than eight hours. The first noticeable affects beyond headaches occur around 150 ppm resulting in nausea and dizziness. The final set point is chosen at 400 ppm, with exposure time of about 3 hours this level of concentration can be life threatening [9].

4. Costs & Schedule

4.1 Parts

Table 2 shows the actual cost incurred by us in construction of the prototype and the how the costs are reduced if the product was to enter mass production.

Table 2 Part Costs

Part	Quantity	Manufacturer	Bulk Purchase Cost ($)	Actual Cost ($)
Electrochemical CO Sensor	1	Winsen	2.00	2.00
Phototransistor	1	Everlight Electronics	0.33	1.12
White LED	1	Optek Technology	0.10	0.15
Red LED	1	Wurth Electronics	0.10	0.15
Yellow LED	1	Wurth Electronics	0.10	0.15
RGB LED	1	Kingbright	0.94	2.05
Vibration Motor	1	SparkFun	2.15	2.15
Lithium Coin Cell Battery	1	Panasonic	1.23	2.26
Battery Retainer	1	Memory Protection Devices	1.18	2.02
Tactile Switch	2	TE Connectivity	0.16	0.20
Step-Up DC/DC Converter	1	Texas Instruments	2.26	4.89
ATmega328p	1	Microchip	1.62	1.95
3D Filament	6g	Generic	0.14	0.14
2-Layer PCB	1	PCBWay	0.50	0.50
NPN BJT	1	ON Semiconductor	0.03	0.14
22 µF Capacitor	1	Generic	0.01	0.10
100 pF Capacitor	2	Generic	0.02	0.20
4.7 µH Inductor	1	Generic	0.01	0.10
8-pin Connector	1	Generic	0.62	1.24
1 kΩ Resistor	4	Generic	0.04	0.40
3.5 kΩ Resistor	1	Generic	0.01	0.10
10 kΩ Resistor	2	Generic	0.02	0.20
47 kΩ Resistor	2	Generic	0.02	0.20
100 kΩ Resistor	2	Generic	0.02	0.20
200 kΩ Resistor	1	Generic	0.01	0.10
Total			13.62	22.07

4.2 Labor

Total labor cost is calculated using Equation (3) and tabulated in Table 3.

$$Labor\ Cost = 3 * Hourly\ Rate * Total\ Hours = 3 * 30 * 200 \quad (3)$$

$$Labor\ Cost = \$36{,}000$$

Table 3 Estimated Labor Cost

Name	Hourly Rate ($)	Total Hours	Total Cost ($)
Mohammad Adiprayogo	30.00	200	18,000.00
Mike Loftis	30.00	200	18,000.00
Total			36,000.00

4.3 Combined Cost

Table 4 shows the total estimated cost resulting from the addition of total costs in Table 3 and total actual cost of Table 2.

Table 4 Estimated Total Cost

Section	Cost ($)
Parts	22.07
Labor	36,000.00
Total	36,022.07

4.4 Schedule

Activities	Week									
	2/19	2/25	3/4	3/11	3/18	3/25	4/1	4/8	4/15	4/22
Component Ordering	[red]	[red]								
Testing of motor/LEDs		[blue]	[blue]							
Testing of Smoke Sensor		[green]	[green]							
Testing of CO Sensor		[green]	[green]							
Control System Testing		[blue]	[blue]							
PCB Design			[blue]	[blue]						
Design of Casing				[green]	[green]					
3D Printing						[green]				
Soldering							[red]			
All Inclusive Design Review								[red]	[red]	[red]
Presentation Preparation						[red]	[red]	[red]	[red]	[red]

Task Done By:

[red] All

[blue] Mohammad Adiprayogo

[green] Mike Loftis

5. Conclusion

5.1 Accomplishments

Ultimately, all major goals of the project were accomplished. The device can alert the wearer of smoke and/or carbon monoxide with use of a vibration motor and externally mounted LEDs, and all the interfacing features work as intended. All in all, the project was a success.

5.2 Uncertainties

One lingering uncertainty is ensuring operation at higher concentrations of carbon monoxide. If access to a fume hood was permitted, this uncertainty would be easily cleared up.

Second is the current robustness of the control system. If an input to the microcontroller is around a given set point the device will limbo between states due to noise. We could improve on this problem by taking multiple inputs to the microcontroller prior to outputting anything. For example, if the user requests battery life information, the microcontroller would be instructed to take a series of voltage readings and take the lowest reading as the accepted reading and display the battery life based on the accepted reading.

5.3 Ethical considerations

One of the most obvious safety considerations was made in choosing the proper sensors for smoke. An ionization detector contains a small amount of radiation, the exposure is much less than that of background radiation [10]. Still, no amount is radiation exposure is better than a small amount of exposure. Any potential risks associated with working around radioactive material has also been avoided with this design choice. This reflects IEEE Code of Ethics #1 which states: to ensure health and safety, factors that pose significant risk to the public will be disclosed, ethics and sustainability will be considered throughout the design process [11].

Since our device will be designed to be wearable, it will be making direct skin contact with the user, this poses obvious health risks in the event of a malfunction. Adherence to standard practices and extensive testing of equipment reliability is essential to ensure public health and safety. IEEE Code of Ethics #5 requires individuals to disclose all limitations [11]. Transparency throughout the design process is paramount for guaranteeing public safety, we must be forthcoming with any device limitations.

Our device will be designed to operate under raining conditions, thus the protective casing must effectively shield the inner components from rainfall. Failing in this regard effects not only the reliability of the components, but also poses a health risk due to the potential short-circuit conditions created from rain passing through the protective casing. This again speaks to IEEE #1 [11].

The sensitive nature of wearables will require us to be one-hundred percent honest with observed data. Any data obscuring would be putting the public at risk. Honesty in data presentation and estimates based upon the underlying data speaks to IEEE Code of Ethics #3 [11] and should be respected throughout the design process.

5.4 Future work

An obvious problem with the current design is the usage of disposable battery. Instead, we could change the battery into a rechargeable lithium ion cell. This will make the design more robust as there will be less holes and crevices for water, dust, and other unwanted particles to reach our circuit as well as making the device much more reusable.

Building upon the need for shedding water, a Polytetrafluoroethylene (PTFE) membrane could be fabricated to assist with our water repelling needs. PTFE can be fabricated in a way that allows target gases to pass through it, while maintaining the important property of repelling water [12]. This membrane would be placed over the grating seen on the exterior of the housing.

The size of the device is also quite large to be considered a wearable device. This is mainly caused by the large space occupied by the two sensor technologies. One way to remedy this problem would be to house the sensing units separately from the rest of the device. The user interfacing features and control unit would still be designed for a wearable, but the sensors would be contained in their own isolated chambers. The sensor units could be made in the form of a keychain or belt loop attachment where the size constraint isn't as concerning. With this change, the wearable unit would be much thinner and more comfortable to wear.

Another step forward from this idea is to integrate our device with smartphones and other smart electronic devices. This would be a better approach than creating a wearable unit on its own as smartphones are becoming more and more common. To further improve upon this, the sensor units could output messages through radio waves that could alert all surrounding devices, as opposed to communicating with a single user. This way, the sensor will not only alert the wearer but also the immediate surrounding population.

References

[1] U.S. Fire Administration, 'U.S. Fire Statistics', 2017. [Online]. Available: https://www.usfa.fema.gov/data/statistics/#tab-1. [Accessed: 2/5/2019].

[2] Center for Disease Control and Prevention, '*QuickStats*: Number of Deaths Resulting from Unintentional Carbon Monoxide Poisoning, by Month and Year — National Vital Statistics System, United States, 2010–2015', 2017. [Online]. Available: https://www.cdc.gov/mmwr/volumes/66/wr/mm6608a9.htm. [Accessed: 2/5/2019].

[3] United States Department of Justice Civil Rights Division, '2010 ADA Standards for Accessible Design', 2010. [Online] Available: https://www.ada.gov/2010ADAstandards_index.htm. [Accessed: 2/6/2019].

[4] ScienceBlog, 'Wearable Secondhand Smoke Sensor Built At Dartmouth', 2013. [Online]. Available: https://scienceblog.com/61462/wearable-secondhand-smoke-sensor-built-at-dartmouth/. [Accessed: 2/7/2019].

[5] Farnell, 'Specification for Lithium Battery', [Online], http://www.farnell.com/datasheets/1496886.pdf. [Accessed: 2/21/2019].

[6] Microchip, 'megaAVR Data Sheet', [Online], http://ww1.microchip.com/downloads/en/DeviceDoc/ATmega48A-PA-88A-PA-168A-PA-328-P-DS-DS40002061A.pdf. [Accessed: 4/30/2019].

[7] Seeed Technology, '1027 Specification', [Online], https://media.digikey.com/pdf/Data%20Sheets/Seeed%20Technology/1027_Spec.pdf. [Accessed: 4/30/2019].

[8] On Semiconductor, 'BC846ALT1G Series', [Online], https://www.onsemi.com/pub/Collateral/BC846ALT1-D.PDF. [Accessed: 4/30/2019].

[9] Centers for Disease Control and Prevention, 'Carbon Monoxide', 2014, [Online], https://www.cdc.gov/niosh/idlh/630080.html. [Accessed: 2/7/2019].

[10] Facilities Toolbox, 'Will smoke detectors cause radiation poisoning?', 2018. [Online]. Available: https://www.fs.fed.us/eng/toolbox/haz/haz25.htm. [Accessed: 2/7/2019].

[11] Institute of Electrical and Electronics Engineers, 'IEEE Code of Ethics', 2018. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 2/7/2019].

[12] Curbell Plastics, 'Low friction engineering plastic with outstanding chemical, high temp, and weathering resistance', 2019. [Online]. Available: https://www.curbellplastics.com/Research-Solutions/Materials/PTFE. [Accessed: 4/30/2019].

Appendix A Requirement and Verification Table

Table 5 System Requirements and Verifications

Component	Requirement	Verification	Verification status (Y or N)
Battery	Nominal voltage is 3 V ± 10%	Output voltage will be checked using a voltmeter. Voltage reading must fall within 3 V ± 10%	Y
Battery	Total Capacity > 1500 mAh	10 mA current will be drawn from the battery for ~50 hours. The voltage will then be read and compared to the datasheet. Output voltage after ~50 hours are expected to be 2.8 V ± 5%	Y
Battery	Dimensions of each battery cell must be smaller than 25 mm x 25 mm x 10 mm	Dimensions will be measured using ruler and must be smaller than 25 mm x 25 mm x 10 mm	Y
Voltage Regulator	Must be able to output 3.3 V ± 5% from input 2.5 V - 3.5 V	Output voltage will be checked using a voltmeter. Voltage reading must fall within 3.3 V ± 5%	Y
Voltage Regulator	Must have efficiency > 80%	Input and output power will be compared by measuring the input and output voltage and current. The output power is expected to be above 80% of the input power	Y
Phototransistor	Phototransistor must be responsive to visible light spectrum (~400 nm to ~700 nm)	A blue, red, and white LED light will be shined onto the sensor. If it produces current above 2.5 µA, light is detected	Y
Phototransistor	Phototransistor operates in switch mode to avoid current draw seen in linear region	Monitor output with current probe to ensure only dark current (determined by device ~0.5mAm is seen under normal operating conditions	Y
White LED	LED forward voltage < 3.3 V	3.3 V ± 5% will illuminate the LED	Y
Smoke Sensing Unit	Smoke Sensor unit responds to the presence of smoke	Smoke will be simulated with use of a Vape, the current output of the phototransistor will be measured to ensure output current > 2.5 µA	Y

Carbon Monoxide Sensor	Diameter of less than 25 mm, length of less than 20 mm	Measure with micrometer to ensure diameter of less than 25 mm and length of less than 20 mm	Y
Carbon Monoxide Sensing Unit	Respond to CO levels of at least 50 ppm as noted by CDC	Use CO detector to determine concentration and use ammeter to verify change in current of 0.023 ± 0.008 µA	Y
Microcontroller	Vcc voltage must be 3.3 V ± 5%	Voltage ranging from 3.0 V - 3.5 V with increment of ~0.1 V will be passed onto Vcc	Y
Microcontroller	Be able to respond to > 5 inputs simultaneously	5 on/off signals will be passed onto the microcontroller at the same time. The signal will then be passed to an array of LEDs to determine whether the microcontroller received the original signal.	Y
Vibration Motor	Operates with applied voltage of 3.3 V ± 5%	Motor will be tested with applied voltage ranging from 3.0 V - 3.5 V	Y
Vibration Motor	Less than 75 mA current draw	Motor current draw will be tested at 3.0 V - 3.5 V to ensure less than 75 mA will be drawn under operating conditions	Y
Vibration Motor	Less than 5mm thickness	Measure thickness with micrometer to ensure thickness of less than 5mm	Y
RGB LED	Capable of illumination of both green, blue, and red light	3.3 V applied across the pins corresponding to green and blue light, 2 V applied across the pins corresponding to red light	Y
RGB LED	Less than 30 mA current draw	Current drawn by LED to be measured with ammeter to ensure less than 30 mA current	Y
Orange LED	Capable of illumination of orange light	2 V applied across the pins to observe the illumination of orange light	Y
Orange LED	Less than 30 mA current draw	Current drawn by LED to be measured with ammeter to ensure less than 30 mA current	Y
Red LED	Capable of illumination of red light	2 V applied across the pins to observe the illumination of orange light	Y
Red LED	Less than 30 mA current draw	Current drawn by LED to be measured with ammeter to ensure less than 30 mA current	Y

Push Button	Force applied to external button pushes down tactile switch	Tactile switch will open circuit consisting of 3 VDC supply, $1\ k\Omega$ resistor, and ground; button push will close circuit, current will be measured through the $1\ k\Omega$ resistor expected to be around 3 mA	Y
Push Button	External button must be smaller than 10 mm x 10 mm	Measure dimensions of 3D printed external push button to ensure dimensions of less than 10 mm x 10 mm	Y