Wearable Smoke/CO Detector for Hearing Impaired

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1 Introduction

1.1 Objective

The U.S. Fire Administration [1] estimated a total of 1,319,500 building fires occurred in the year 2017, these fires caused around 2,400 deaths for the year. In 2015, the CDC [2] reported 393 deaths caused by unintentional non-fire related carbon-monoxide poisoning. Current smoke and carbon-monoxide detectors designed for the hearing impaired alert them of the presence of either with a high intensity strobe light in addition to the sound alarm. The Americans with Disabilities Act of 1990 requires new buildings to be equipped with high intensity strobe alarms [3], buildings that were built prior to 1990 were expected to upgrade their alarm systems in adherence to the new standard. The responsibility of adherement lies with the owner of the building, and the hearing impaired should not be at risk due to negligence.

Our goal is to rid the hearing impaired of this burden almost entirely. We will create a device designed to be worn on the wrist that will alert the wearer of the presence of smoke and carbon monoxide with a vibration.

1.2 Background

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 of course is reliant on the chosen smoke alarm, 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 solution is the first of its kind in addressing a wearable smoke and carbon monoxide detector designed specifically for the hard of hearing.

1.3 High-Level Requirements

- Device will alert the user in the presence of smoke and/or carbon monoxide in excess of 50 ppm
- External LED will reflect battery life upon user request
- External push button will halt the vibration motor

2 Design

2.1 Block Diagram

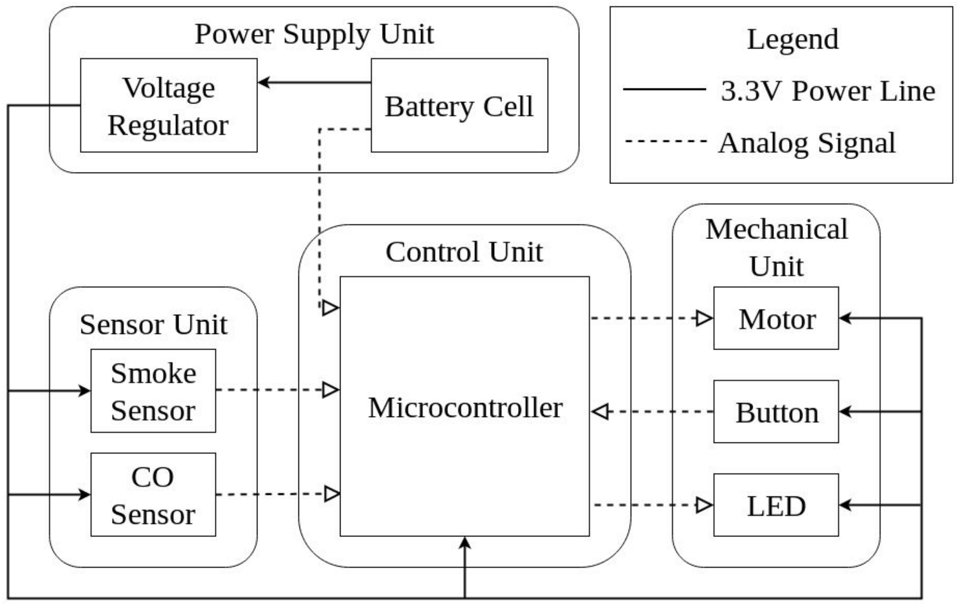

Figure 1: High Level Block Diagram

2.2 Physical Design

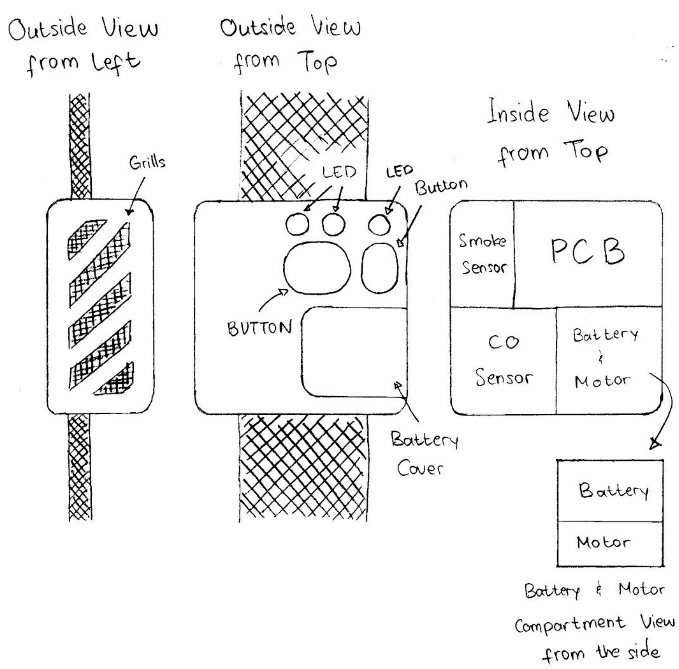

Figure 2: Physical Design of the Product

2.3 Block Design

2.3.1 Power Supply Unit

The Power Supply Unit will provide a constant 3.3V±10% to power line. This unit will consist of the battery bank that house disposable coin batteries and a voltage regulator that will be made of a 3.3V step-up DC-DC converter. Microcontroller will take an input directly from the battery bank to monitor the capacity of the battery.

2.3.1.a Battery Bank

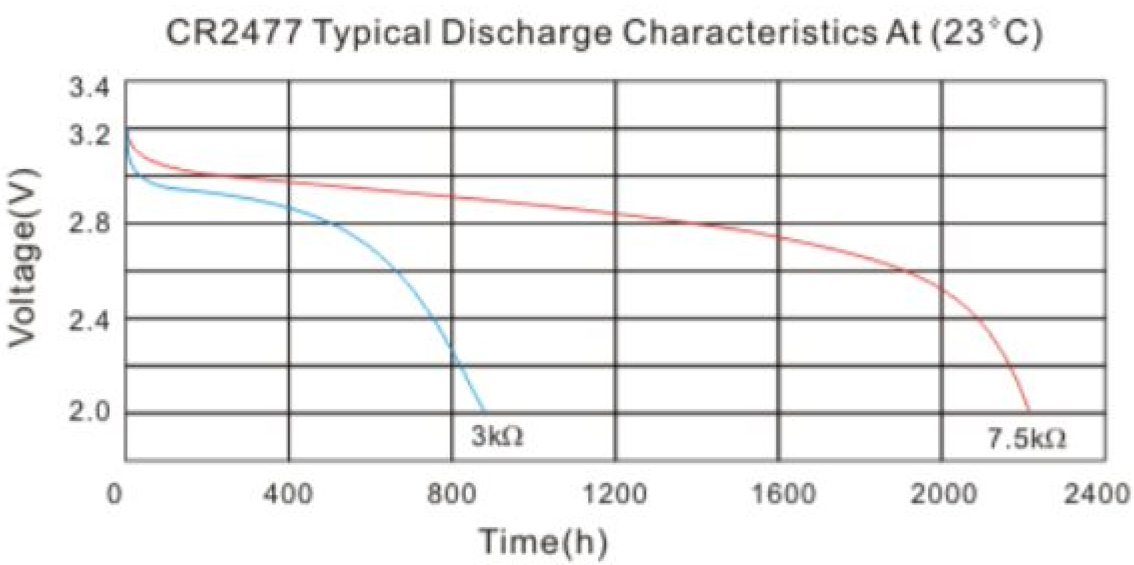

Figure 3. Discharge Characteristics of cr2477 - 850mAh [8]

The battery cell provides power for all components in the device. The battery cell will house two coin cell batteries of type CR2477. For the purpose of the design, the battery cell is estimated to have an output voltage between 3.2V and 2.6V. As can be seen from figure 3 above, below 2.6V the battery cell starts to discharge at a faster rate. Due to this reason, we decide that the battery is "dead" and must be changed once the output voltage is below 2.6V.

Requirement	Verification
1. Nominal voltage is 3V±10%	1. Output voltage will be checked using a voltmeter. Voltage reading must fall within 3V±10%.
2. Total Capacity >1500mAh	2. 10mA current will be drawn from the battery for ~50 hours. The voltage will then be read and compared to the

3. Dimensions of each battery cell must be smaller than 25mm x 25mm x 10mm	datasheet [8]. Output voltage after ~50 hours are expected to be 2.8V±5% 3. Dimensions will be measured using ruler and must be smaller than 25mm x 25mm x 10mm

2.3.1.b Voltage Regulator

The voltage regulator will consist of a single 3.3V step-up DC-DC converter. A step-up converter was chosen instead of other type of voltage regulator due the nature of the battery cell which have an output voltage ranging from 2.6V up to 3.2V. This decision was also supported by two reasons concerning our design choices: all the components in the design only use 3.3V or lower voltages and putting two coin cell batteries in parallel rather than in series will double the capacity thus doubling the products lifetime.

Requirement	**Verification**
1. Must be able to output 3.3V±5% from input 2.5V until 3.5V 2. Must have efficiency >80%	1. Output voltage will be checked using a voltmeter. Voltage reading must fall within 3.3V±5%. 2. 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.

2.3.2 Sensor Unit

The Sensor Unit will consist of a smoke sensor and a carbon monoxide sensor. The sensors will works in parallel with one another and are expected to be able to send readings to the microcontroller at the same time. The microcontroller will then use the data and determine whether smoke and/or carbon monoxide is present.

2.3.2.a Smoke Sensor

The smoke sensor will consist of an LED and phototransistor inside of a black 3D printed chamber. The phototransistor will be sufficiently blocked from the LED under normal conditions. In the presence of smoke, the photons from the LED will be scattered, some of which will be detected by the phototransistor that will produce a current beyond the dark current seen under normal operating conditions.

Requirement	**Verification**
1. Phototransistor must be responsive to visible light spectrum (~400nm to ~700nm)	1. A blue, red, and white LED light will be shined onto the sensor. If it produce current above 2.5µA, light is detected
2. LED forward voltage <3.3V	2. 3.3V ±5% will illuminate the LED
3. Smoke Sensor unit responds to the presence of smoke	3. Fog will be generated with dry ice and boiled water, the current output of the phototransistor will be measured to ensure output current > 2.5µA
4. Phototransistor operates in switch mode to avoid current draw seen in linear region	4. Monitor output with current probe to ensure only dark current (determined by device ~0.5mAm [12] is seen under normal operating conditions

2.3.2.b Carbon Monoxide Sensor

Carbon Monoxide levels will be monitored by an electrochemical sensor. If the carbon monoxide concentration reaches dangerous levels, the electrochemical sensor will produce an output current, effectively notifying the microcontroller.

Requirement	**Verification**
1. Respond to CO levels of at least 50 ppm as noted by CDC [9]	1. Use CO detector to determine concentration and use ammeter to verify change in current of 0.023±0.008 µA [9]
2. Diameter of less than 25mm, length of less than 20mm	2. Measure with micrometer to ensure diameter of less than 25mm and length of less than 20mm

2.3.3 Control Unit

The Control Unit will consist of a Microcontroller. The microcontroller will take input from the battery bank, the buttons, the smoke sensors, and the carbon monoxide sensors. If the microcontroller determines smoke and/or carbon monoxide is present based on readings of the smoke and carbon monoxide sensors, the microcontroller will send signals to the motor to start vibrating and alert the user. If the user push the stop button, the microcontroller will send signals to the motor to stop vibrating. If the user push the battery life button, the microcontroller will use the output voltage readings from the battery bank, determine the state of the battery capacity, and then send signal to the RGB LED about the current capacity.

2.3.3.a Microcontroller

ATMega328PB will be used as the product's microcontroller. This microcontroller was chosen because both the 5V and the 3V will work fine for the purpose of our product: both works under DC condition and have enough I/O pins to satisfy all the components. The availability of the 3V version is also one of the reasons behind our decision of making the power line 3.3V.

Requirement	Verification
1. Vcc voltage must be 3.3V±5%	1. Voltage ranging from 3.0V - 3.5V with increment of ~0.1V will be passed onto Vcc
2. Be able to respond to >5 inputs simultaneously	2. 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.

2.3.4 Mechanical Unit

The Mechanical Unit will consist of a motor, an RGB LED, an orange LED, a red LED and two buttons. All LEDs and the motor will receive signal from the microcontroller as to whether they should vibrate/light up or vice versa. The two buttons will take input from the user which will then be passed onto the microcontroller. One button will serve as the vibration button. If user pressed this button under normal condition (no smoke or carbon monoxide), the microcontroller will send signal to the motor to start vibrating until the button is released. This will serve as a test whether or not the vibration motor is working. When carbon monoxide or smoke is present and the motor has started vibrating, this button will serve as a stop button that will stop the vibration after the button has been pressed for a period of time determined by the length of time the button is held for. The RGB LED will partly serve as an indicator for the length of delay sent to the vibration motor. The other button will serve as the battery indicator. When this button is pressed, the red and green lights from the RGB LED will light up and inform the user about the battery capacity. A separate red LED will flash on and off in the presence of carbon monoxide, the frequency of flashing will correspond to the level of concentration. An orange LED will serve to differentiate between smoke and carbon monoxide, if the smoke sensor detects smoke, the orange LED will begin to flash.

Requirement	Verification
1. The battery motor halting button will illuminate blue from the RGB LED if it is pressed down and held for longer than 5±0.5 seconds	1. One of the tactile switches will be used to close the circuit input to the microcontroller, which will output to the pins corresponding to the blue LED, after a software determined 5s delay
2. Pressing and holding the motor halting button for longer than 5±0.5 seconds will halt motor vibration for 1 hour ±5 minutes	2. One of the tactile switches will be used to close the circuit input to the microcontroller, which will send a software determined 1 hour delay to the motor terminals. Voltage across the motor will be measured for 1 hour and 10 minutes to ensure the proper delay and, continued motor functionality after the delay has ended. A stopwatch will be used to measure the 5±0.5 seconds required to hold down the button
3. Pressing and holding the motor halting button for less than 5±0.5 seconds will halt the motor vibration for 10±1 minutes	3. One of the tactile switches will be used to close the circuit input to the microcontroller, which will send a software determined 10 minute delay to the motor terminals. Voltage across the motor will be measured for 15 minutes to ensure the proper delay and, continued motor functionality after the delay has ended.

2.3.4.a Motor

A 3V coin cell vibration motor will be actuated to alert the wearer in the presence of smoke and/or carbon monoxide. This vibration motor was chosen to accommodate the size of our product as well minimizing overall power consumption.

Requirement	Verification
1. Operates with applied voltage of	1. Motor will be tested with applied voltage

3.3V±5% 2. Less than 75mA current draw 3. Less than 5mm thickness	ranging from 3.0V - 3.5V 2. Motor current draw will be tested at 3.0V - 3.5V to ensure less than 75 mA will be drawn under operating conditions 3. Measure thickness with micrometer to ensure thickness of less than 5mm

2.3.4.b RGB LED

An RGB LED will inform the user whether the device is on and provide information on remaining battery capacity. The LED will illuminate if the user requests remaining battery life, green will represent battery life of above 20%, whereas red will represent battery life of under 20%. The blue pins of the LED will illuminate if the motor vibration button is pressed and held for longer than 5±0.5 seconds to indicate a sufficient press and hold to send a lengthened motor delay signal.

Requirement	Verification
1. Capable of illuminating red, green, and light 2. Less than 30mA current draw	1. 3.3V±5% applied across the pins corresponding to green and blue light, 2V±5% applied across the pins corresponding to red light 2. Current drawn by the LED will be measured with an ammeter to ensure less than 30mA current

2.3.4.c Danger Level Display LED - CO

A red LED will be mounted to the exterior of the device displaying the level of danger in terms of carbon monoxide concentration. The LED will blink faster and faster as the concentration of carbon monoxide is increased between 50 and 800 ppm. Once 800 ppm is exceeded, the light will remain constantly illuminated until the concentration level drops.

Requirement	Verification
1. Capable of illuminating red light	1. 2V±5% applied across the LED will cause the illumination of red light

2. Less than 25mA current draw	2. Current drawn by the LED will be measured with an ammeter to ensure less than 25mA current

2.3.4.c Danger Level Display LED - Smoke

An orange LED will be mounted to the exterior of the device to differentiate between the cause of motor vibration. The illumination of the orange LED will correspond to the presence of smoke.

Requirement	Verification
1. Capable of illuminating orange light 2. Less than 25mA current draw	1. 2V ±5% applied across the LED will cause the illumination of orange light 2. Current drawn by the LED will be measured with an ammeter to ensure less than 25mA current

2.3.4.d Buttons/Switches

Two external 3D printed buttons are mounted onto the exterior of the device for user interaction. One button will be for user to stop motor vibration in case of false alarm, the other will be for user to check remaining battery life. At the end of the button mechanism will be tactile switches which normally will open the circuit between the voltage regulator and a microcontroller pin. Pushing of an external button will push down the corresponding tactile switch acting as input to the microcontroller

Requirement	Verification
1. Force applied to external button pushes down tactile switch 2. External button must be smaller than 10mm x 10mm	1. Tactile switch will open circuit consisting of 3V DC supply, 1kΩ resistor, and ground; button push will close circuit, current will be measured through the 1kΩ resistor expected to be around 3mA 2. Measure dimensions of 3D printed external push button to ensure dimensions of less than 10mm x 10mm

2.4 Tolerance Analysis

We consider the lifetime of our battery to be the biggest constraint of our project. To be considered functional, the device must have a significant battery life. Given the limitation that the size of our device needs to be small, we must weight the costs and benefits associated with different battery configurations within our system.

Our projected battery capacity is 2000mAh, determined by connecting two 1000mAh batteries in parallel. Parallel connection is additive in terms of capacity, and has no effect on voltage. The largest consumer of power under normal operating conditions (no smoke or CO present, no user input) is the Smoke Sensor Unit, with the LED drawing about 20mA of current. If the LED was to continuously operate in the active region, with the oversimplification of being the only component drawing from the battery, our total battery life, t, would only be 100 hours, shown in Equation 1.

$$t = \frac{capacity}{current} \quad (1)$$

$$t = \frac{2000mAh}{20mA} = 100h$$

A battery life of only 100 hours is not sufficient for the nature of our device. To combat this issue, the microcontroller will send a signal pulse to illuminate the LED for 0.1 seconds every 10 seconds, resulting in the LED illuminating for $\frac{1}{100}$ of the time it was prior to the design decision. This design decision will surely decrease our response time, but for the application at hand, a theoretical maximum response time of 10 seconds is relatively insignificant. This decision vastly improves our battery life oversimplification.

$$t_{new} = \frac{2000mAh}{20mA * \frac{1}{100}} = 10,000h \quad (2)$$

The resulting additional battery life far outweighs the loss in response time. Under normal operation, the only components consuming power will be the LED, the voltage regulator, and the microcontroller. The voltage regulator and microcontroller are listed at drawing 60µA [10] and 0.24mA [11] respectively. Adding for the additional overall consumption can be seen in Equation 3.

$$t_{total} = \frac{2000mAh}{20mA * \frac{1}{100} + 0.24mA + 0.06mA} = 4,000h \quad (3)$$

The projected battery life comes out to be 4,000 hours which equates to roughly five and a half months, at this point the battery will only output 2V and is deemed unusable as per the datasheet [8].

Our defined voltage to signify the near end of battery life (red LED illumination) is chosen at 2.6V, this choice is made through analysis of Figure 1. A voltage of 2.6V marks roughly the end of the linear region, and begins the point of accelerated drop off. The quiescent current vs input voltage curve (Figure 4), shows that under the 3.3V operation, at around 2.6V the curve begins to exit the linear region (it is roughly constant at the rated 60μA prior to this inflexion point). As the voltage drop continues, the quiescent current continues to increase further draining from the battery capacity. The wearer will be alerted at this point as the remaining capacity will diminish rather sharply, but capacity still remains allowing continued use of the device for a short period of time.

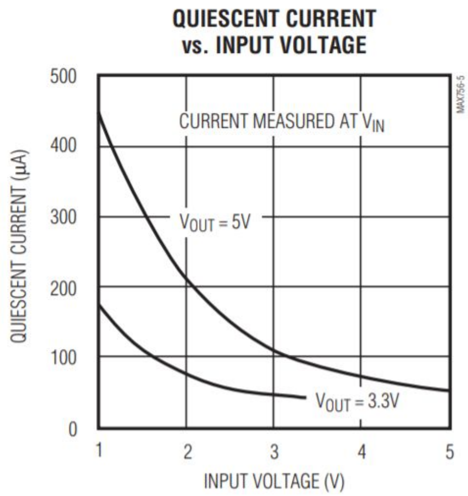

Figure 4: Voltage Regulator Quiescent Current vs. Input Voltage

3 Cost and Schedule

3.1 Cost

Cost of Labor: $(\$30/hr) * (10hr/week) * (10\ weeks) * (2\ persons) * (1.5\ overhead) = \$9,000$

Component	Quantity per Device	Cost per Unit ($)	Bulk Cost per Unit ($)
Electrochemical CO Sensor (Alibaba)	1	2.00	2.00
Phototransistor (Mouser/Digikey)	1	1.12	0.327
White LED (Mouser/Digikey)	1	0.15	0.104
Red LED (Mouser/Digikey)	1	0.15	0.104
Orange LED (Mouser/Digikey)	1	0.15	0.104
RGB LED (Mouser/Digikey)	1	2.05	0.936
Vibration Motor (Digikey)	1	2.732	2.15
Lithium Coin Cell Battery (Amazon)	2	2.85	2.28
Tactile Switches (Mouser/Digikey)	2	0.10	0.082
3.3V/5V Step-Up DC-DC Converter (Mouser)	1	4.89	2.26
Microcontroller (Mouser/Digikey)	1	1.95	1.62
3D Filament (Mouser)	6g	0.143	0.139
2-Layer PCB (PCBWay)	1	0.50	0.767
Total		18.49	12.67

Table 1: Component Costs

3.2 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

Table 2: Tasks and Schedule of Members

Task Done By:

red	All
blue	Mohammad Adiprayogo
green	Mike Loftis

4 Safety & Ethics

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 [6]. 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 [7].

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 [7]. Transparency throughout the design process is paramount to informing others of any devices shortcomings.

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 [7].

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 [7], and should be respected throughout the design process.

5 References

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