UV Sensor and Alert System for Skin Protection

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Contents

1 Introduction

1.1 Problem

Skin aging, damage and cancer are common problems for many, with one in five Americans developing skin cancer in their lifetime [1]. The leading cause of skin cancer is excessive exposure to ultraviolet (UV) light [2]. Often, it is difficult to assess how much UV exposure one has accumulated and when protection is needed. Therefore, skin damage is a risk for everyone; however, it is more prevalent for those who spend significant time outside for work or leisure activities.

1.2 Solution

The sensors and wristbands that currently exist only provide feedback through color indicators but are unclear on exposure time [3]. Our solution is to create a wristband that tracks UV intensity and exposure duration. Additionally, the device alerts the user to take preventative measures against skin damage, such as applying sunscreen or seeking shade. With our device, users can ensure their time in the sun is safe without manually tracking sun exposure. Ultimately, the goal of the device is to decrease the short-term risk of sunburn and long-term risk of skin cancer.

1.3 Visual Aid

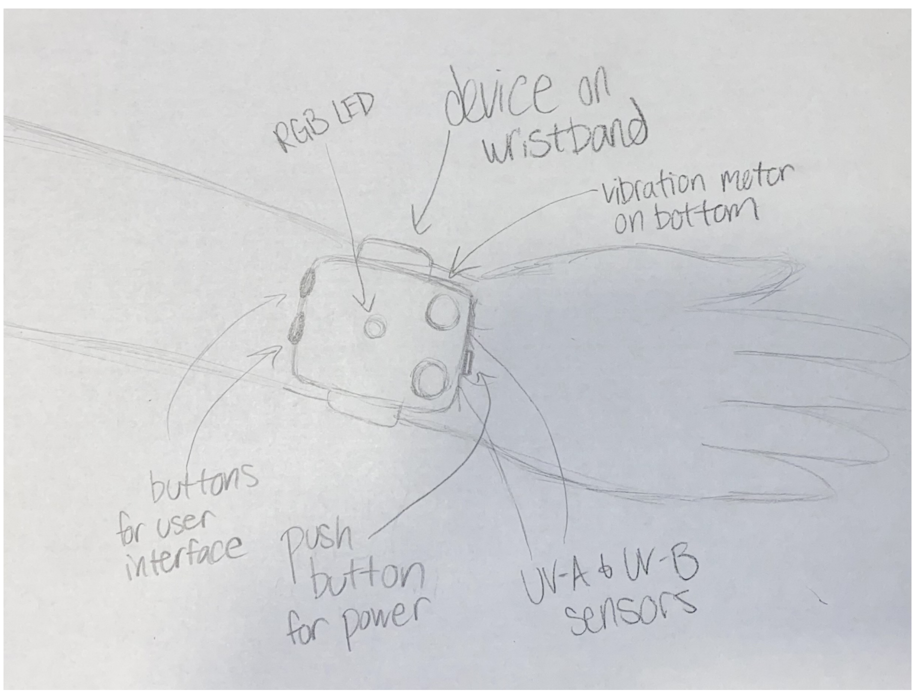

Figure 1: Drawing of Ideal UV Wristband

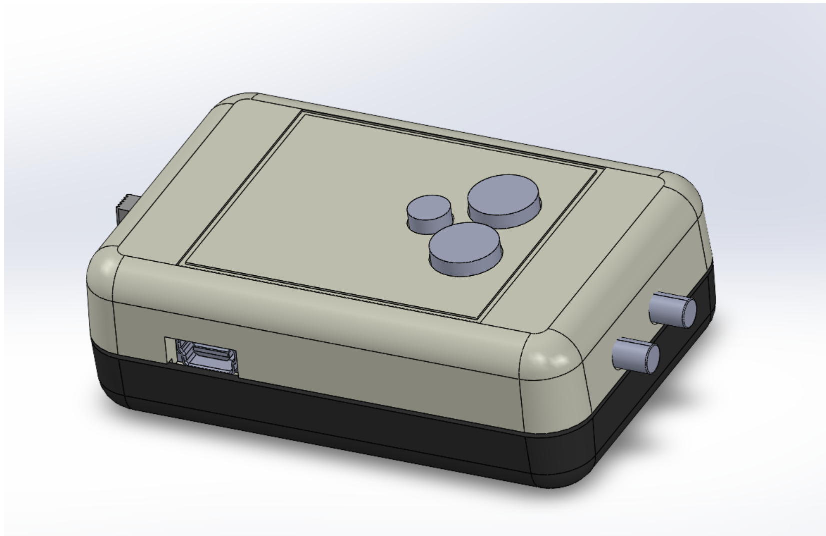

Figure 2: 3D Model of UV Wristband

1.4 High-Level Requirements List

Battery Life

Requirement: The watch must last at least 16 hours on a single charge.

UV Exposure Time and Intensity Accuracy

Requirement: The UV sensors monitor intensity in mW/cm^2 of UV exposure throughout the day at a rate of one sample per minute.

Input and Output to and from User

Requirement: Our device gives feedback to the user via a vibration motor to warn of extended exposure, and our device receives feedback from the user via a button to personalize the alert system based on skin type and sunscreen application.

2 Design

2.1 Block Diagram

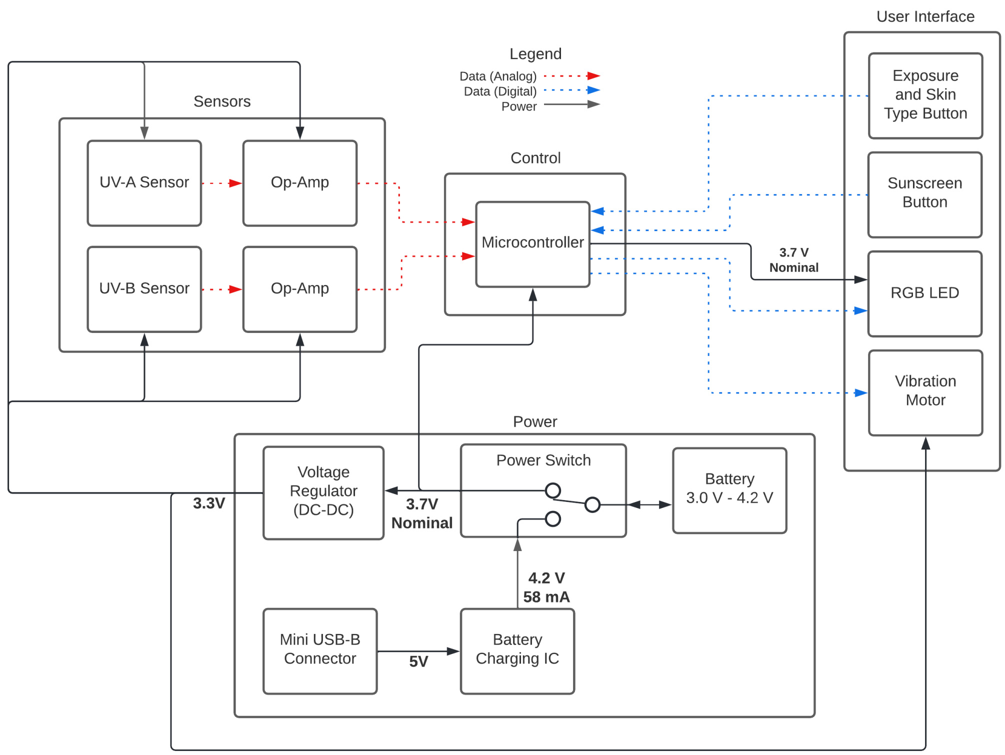

Figure 3: Block Diagram for UV Wristband

2.2 Subsystem Overview

2.2.1 Sensors

UV Sensors

The UV Sensors used in our device consists of one UV-A sensor and one UV-B sensor, which have peak intensities within the distinct wavelengths of UV light. Since UV-A and UV-B light have different safety effects, we want to track these separately to accurately warn users.

We have decided to use sensors with built-in amplifiers. This makes it easier when measuring the response of the UV light intensity, since photodiodes on their own respond in nanoamps to typical UV light from sunlight. The part number for the UV-A sensor is GUVA-T21GH and the UV-B sensor is GUVB-T21GH.

The UV sensors will be used to calculate the UV index. The UV-B sensor alone can be used to calculate the UV index within 10% error [4]. The UV-A sensor can be incorporated to make this calculation even more accurate [5]. However, in our preliminary design, we will focus on the UV-B sensor reading. Once verification of the sensors and overall design is completed, we will attempt to factor in the extra data from the UV-A sensor to increase the accuracy of the device.

The sensors will be powered with the 3.3 V output from the Power Subsystem's voltage regulator, and output to the operational amplifiers within the Sensor Subsystem.

In order to test and verify UV sensor functionality, we will be using UV LEDs. The part number for the UV-A and UV-B LEDs are MTE3661N1-UV and CUD8MN1A, respectively. Both of these lights have rated optical outputs in mW. This output is directly related to input current, which can then be used to calculate intensity of light at a distance in mW/cm^2. The procedure for verification is in Table 1 and 2.

Table 1: UV-A Sensor Requirements and Verification

Requirements	**Verification**
1. Measure UV-A intensity with wavelengths ranging from 320-370 nm, and output voltage corresponding to input intensity (±10%).	1. Plug in UV-A testing circuit by plugging in power supply to VCC and ground of the testing circuit. 2. Set the voltage of the power supply to 7V and current to 20 mA. 3. Using a distance measuring device, such as a tape measure, set the testing circuit's UV LED output directly inline with device at a distance of 1.0 m. 4. Using an oscilloscope, probe the UVA test point on the UV device. 5. Measure the voltage output at this point and confirm that the output voltage is 0.82 V (±10%).

Table 2: UV-B Sensor Requirements and Verification

Requirements	Verification
1. Measure UV-B intensity with wavelengths below 320 nm, and output voltage corresponding to input intensity (±10%).	1. Plug in UV-B testing circuit by plugging in power supply to VCC and ground of the testing circuit. 2. Set the voltage of the power supply to 5V and current to 75 mA. 3. Using a distance measuring device, such as a tape measure, set the testing circuit's UV LED output directly directly inline with device at a distance of 0.5 m. 4. Using an oscilloscope, probe the UVB test point on the UV device. 5. Measure the voltage output at this point and confirm that the output voltage is 2.96 V (±10%).

Operational Amplifier

The operational amplifier is the NCS21802DMR2G. It was chosen for its low offset drift, low quiescent current, availability, and dual-channel configuration.

Although the microcontroller has a ten bit ADC, the output of the UV sensors will typically be from 0 mV to 80 mV under sunlight [6]. Thus, in order to amplify these signals to a measurable range from 0 V to 3.3 V, this op-amp is implemented. A further discussion of the op-amp is in Section 2.6.2.

The op-amp will interface with the UV sensors as inputs and output to the Microcontroller Subsystem. Both inputs and outputs will be analog signals. The op-amp will also be powered by the 3.3 V voltage regulator output from the Power Subsystem.

Table 3: Op-amp Sensor Requirements and Verification

Requirements	Verification
1. Op-amp must amplify voltages between 0 mV and 80 mV to 0 V and 3.3 V (±5%).	1. Connect VCC of power supply to VCC of op-amp, and ground of power supply to ground of op-amp. 2. Connect a voltage source, such as a power supply, between ground and the positive terminal of the op-amp. 3. Connect an oscilloscope to the output of the op-amp and to ground. 4. Sweep the input of the voltage source from 0 mW to 80 mW. 5. Measure the output voltage and verify that the output sweeps from 0 V to 3.3 V (±5%).

2.2.2 Control

Microcontroller

The microcontroller for our device is the ATMega4808. It was chosen because of its peripherials, low power consumption, and part availability. It contains a ten bit analog-to-digital (ADC) converter, internal real-time clock, 48 kB of RAM, and several low power modes.

The microcontroller measures analog voltages from the Sensor Subsystem. The microcontroller also interfaces with the User Interface Subsystem through its digital I/O pins to read button states, illuminate the RGB LED (through its PWM capable pins), and turn on the vibration motor. These inputs and outputs are processed according to Figure 8.

The ATMega4808 contains an internal real-time clock. It is clocked by an external 32.768 kHz crystal oscillator to maintain accurate timekeeping of our device. Without the crystal oscillator, the device would be keeping time through its internal RC oscillator, which can have up to (±10%) variability depending on temperature [7]. As a result, we are using an external crystal oscillator with part number 32.768K12.5P2/DT38, which has an error rate of 20 parts per million (ppm) [8], which equates to roughly 1.728 seconds per day [9].

The ATMega4808 is powered by the Lithium Ion battery running at 3.7 V nominally. The interface of the device is shown in Figure 4 and Table 4.

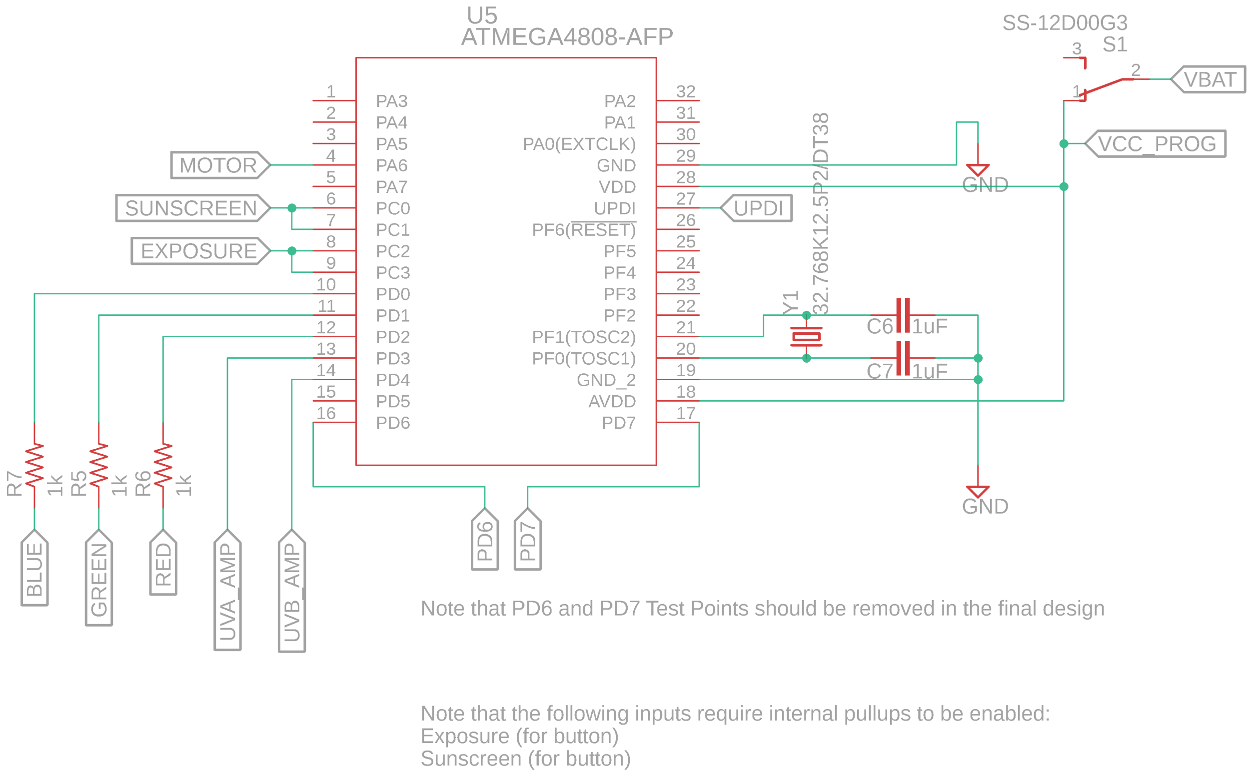

Figure 4: ATMega4808 Schematic

Table 4: Pin connections between ATMega4808 and other components

Pin	Function	Connection
4	PA6, digital GPIO pin	to motor
6	PC0, digital GPIO pin for reading state	to sunscreen button
7	PC1, digital GPIO pin for external interrupt	to sunscreen button
8	PC2, digital GPIO pin for reading state	to exposure button
9	PC3, digital GPIO pin for external interrupt	to exposure button
10, 11, 12	PD0/PD1/PD2, PWM digital GPIO pin	to RGB LED
13	AIN 3, analog pin	to UV-A sensor
14	AIN4, analog pin	to UV-B sensor
19, 29	AVDD/VDD, power pins	to battery
18, 28	GND/GND2, ground	to battery
20	TOSC1, external oscillator	to crystal oscillator
21	TOSC2, external oscillator	to crystal oscillator
27	UPDI, programming pin	to programming header

Table 5: Microcontroller Requirements and Verifications

Requirements	Verification
1. The microntroller must have a power-saving mode to limit current consumption to at most 1mA.	1. Connect an ammeter between positive terminal of battery and VCC of the microcontroller. 2. Turn on the device. Wait five seconds after startup to ensure the device enters its low power mode. 3. Measure the current drawn by the microcontroller using the ammeter. 4. Verify that the current measured is at most 1mA.
2. The microcontroller must have at least two ADC's with a resolution of 0.01 V or smaller.	1. Program microcontroller with the Development Mode Code. 2. Connect a power supply to the UVB test point and ground. 3. Turn on the device. The LED should be on. 4. Turn on the power supply. Set the voltage to 0.05 V. Note the color of the LED. 5. Set the voltage of the power supply to 0.06 V. 6. Verify that the color of the LED changed.
3. The microcontroller must be able to wake from a power-saving mode within one second of an external interrupt signal.	1. Obtain a timer. An acceptable timer includes a chronograph, a digital stopwatch, or a stopwatch app. 2. Connect an ammeter between the positive terminal of the battery and VCC of the microcontroller. 3. Turn on the device. Wait for the device to enter a power-saving mode (verified through Requirement 1). This will appear as a sudden low current draw in the ammeter. 4. Simultaneously, press the exposure button and start the timer. 5. Verify that the RGB LED illuminates within one second.
4. The microcontroller must be able to keep track of time within $\pm 5\%$.	1. Obtain a timer. An acceptable timer includes a chronograph, a digital stopwatch, or a stopwatch app. 2. Connect an ammeter between the positive terminal of the battery and VCC of the microcontroller. 3. Turn on the device. Wait for the device to enter a power-saving mode (verified through Requirement 1). 4. Start the timer as soon as device enters the low power mode. This will appear as a sudden low current draw in the ammeter. 5. Stop the timer as soon as the device enters its active mode (around ten seconds after entering low power mode). This will appear as a sudden higher current draw in the ammeter. 6. Verify the time measured is within ($\pm 10\%$) of ten seconds.

2.2.3 Power

Battery and Voltage Regulator

The battery used for this device is an ASR00007 by TinyCircuits. The cells used in the battery itself are the TY552325. The Lithium-Ion polymer battery has a nominal output voltage of 3.7 V[1] and a maximum output current of 290 mA. The total capacity of the battery is 290 mAh or alternatively 1.07 Wh. The discharge cut-off voltage is at 3.0 V. This battery comes equipped with a protection circuit that protects against: Over-Charge, Over-Discharge, Over-Current, and Short-Circuits. Additionally, a fuse of 290 mA had been added which is much higher than the expected current draw but well under the battery maximum current to protect the battery. Additionally the battery comes with a JST-SH 1.00 mm pitch connector which protects the battery from being connected in reverse polarity.

The main considerations taken when choosing this battery was size, capacity, and stock availability. With an initial conversation with the machine shop it was decided that the housing of the device would be limited to around 30 mm. With this limited size, the device's battery chemistry was limited to Lithium-Ion and Lithium-Ion polymer batteries due their relatively high energy density. Additionally, other considerations taken into account were: preexisting protection circuit, preexisting charging circuit, and the ease of connecting and disconnecting the battery.

Our device has a linear voltage regulator, an LP3988IMFX-3.3/NOPB. It is rated for a maximum input voltage of 6 V, a fixed output of 3.3 V, a dropout voltage of 150 mV,[2] and a maximum output current of 150 mA. The fixed output voltage keeps all electronics at a steady V_{cc}. The regulator stops operating at a battery voltage of 3.42 mV, but the benefits of a clean output power and smaller circuit footprint[3] make the linear regulator the optimal choice for our design.

The decision for a linear voltage regulator comes from two key metrics: fixed output voltage and low-noise. Since the Lithium-Ion battery will supply a variable voltage of 3.0 V to 4.2 V, a resistor voltage divider is incapable of keeping a constant 3.3 V output. Filtering voltage ripple from a switching converter would require extra circuit complexity or an additional linear voltage regulator after the switching regulator. In order to keep efficiency high and the circuit footprint small, using a linear voltage regulator by itself is the optimal choice.

[1] The maximum output voltage is 4.2 V.
[2] With an output current of 150 mA
[3] Compared to a switching regulator

Table 6: Battery and Voltage Regulator Requirements and Verification

<table>
<tr><th>Requirements</th><th>Verification</th></tr>
<tr><td>1. Sustain a peak current of at least 110 mA for at least two seconds.</td><td>1. Connect the voltage regulator output in series to a known load to draw 110 mA.
(a) If possible use an electronic load to draw 110 mA.
(b) Alternatively connect a 37 Ω load.
2. Without an electronic load measure current with an current meter connected in series with the voltage regulator output.
(a) Connect the current meter to the jumper at the voltage regulator output.
3. Measure time by utilizing a stopwatch. Verify that the current drawn is 110 mA for at least two seconds.
(a) Acceptable stopwatches include a chronograph, a digital stopwatch, or a stopwatch app.</td></tr>
<tr><td>2. Sustain an output voltage of 3.3 V ±5%</td><td>1. Connect the output of the voltage regulator to a series of resistors. independently.
(a) 33 Ω
(b) 330 Ω
(c) 3300 Ω
2. Probe the output of the voltage regulator with an oscilloscope.
(a) The positive reference probe should be placed on the output jumper of the voltage regulator.
(b) The negative reference probe should be placed on the ground reference point.</td></tr>
</table>

Battery Charging and Power Switch

The battery charging is handled by an XC6801A42XPR-G. With a maximum input voltage of 30 V and input current of 1.5 A, this device can be charged with many generic chargers for electronic devices. The charger used for the device is a USB wall charger with an output of 5 V and 1 A DC. The charger is connected to the device using a mini USB-B 2172034-1 connector. The main consideration in picking the charging integrated circuit came from the ability of outputting first a constant current then a constant voltage as the battery neared full charge. This was requested by the battery data sheet.

The power switch is the M2012TXW41-DA. It is a single-pole, double-throw (SPDT) slider switch. The slider is mounted on the side of the device, allowing the user to easily turn the device on and off. This switch ensures that the device is turned off and not measuring UV exposure when the user is not using the device, which increases power efficiency. The switch interfaces within the Power Subsystem, specifically between the battery and voltage regulator. An important design decision was made here to ensure the device could not be both operating and charging at the same time by way of the SPDT switch, allowing only one system to be operational.

Table 7: Power Switch Requirement and Verification

Requirements	**Verification**
1. Power switch switches system state within one second.	1. Power on device and connect oscilloscope at VBAT test point. 2. Flip power switch and measure voltage, monitoring for at least five seconds. 3. Check if all power is cut off within one second of switch flip. 4. Repeat process with device powered off and flipping power switch on.
2. The charging integrated circuit outputs 4.2 V ± 5% at a current of at least 50 mA and at most 200 mA	1. Connect device to the wall through the mini USB-B connector to a power source. 2. Use an oscilloscope to measure output voltage. (a) The positive reference probe can be placed on the charging output test point. (b) The negative reference probe can be placed on the ground reference test point. 3. Measure output current by connecting the two pins of the output jumper in series with a current meter.

2.2.4 User Interface

Vibration Motor

The vibration motor alerts the user when he or she have been exposed to UV light for an extended period of time. Similar to vibration motors in smartphones or smartwatches, the vibration motor is the VZ6SC0B0060081.

Because the microcontroller pin cannot drive the motor directly, a MOSFET is used as a switch to turn the motor on and off. The motor can then be directly powered by the output of the linear voltage regulator. The connections between the MOSFET and motor is shown in Figure 5. A pull-down resistor is used to ensure the gate of the MOSFET is not left floating.

The MOSFET interfaces with the Control Subsystem through a digital signal, and the motor interfaces with the MOSFET and the Power Subsystem.

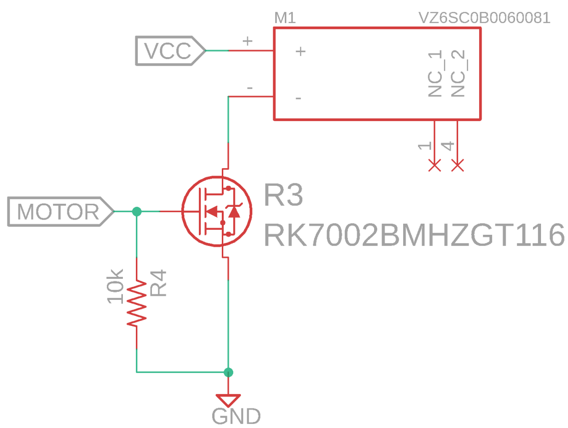

Figure 5: MOSFET and Vibration Motor Connections

Table 8: Vibration Motor Requirements and Verification

Requirements	Verification
1. When UV index reaches threshold for safety, vibration motor runs for five seconds, repeating every minute for up to five minutes.	1. Obtain a timer. An acceptable timer includes a chronograph, a digital stopwatch, or a stopwatch app. 2. Plug in UV-B testing circuit by plugging in power supply to VCC and ground of the testing circuit. 3. Set the voltage of the power supply to 7 V and current to 75 mA. 4. Using a distance measuring device, such as a tape measure, set the testing circuit's UV LED output directly inline with device at a distance of 0.5 m. 5. Wait for device to send notification to user of over exposure. As soon as motor begins vibrating, start timer. 6. Stop timer once motor stop vibrating. 7. Repeat steps 5. and 6. four more times every minute.

RGB LED

The RGB LED is the NTE30156. The RGB LED allows the user to see the current UV intensity as detected by the device. The colors shown indicates current UV index, such as green for UV index of two or less, yellow for UV index three to five, and so on, according to the Environmental Protection Agency's scale of UV Index [10]. The RGB LED interfaces with the Control Subsystem through three digital pins (one for each red, green, and blue), which are configured as PWM outputs to display each color.

Table 9: RGB LED Requirements and Verification

Requirements	Verification
1. RGB light outputs current UV index within one second of button press.	1. Obtain a timer. An acceptable timer includes a chronograph, a digital stopwatch, or a stopwatch app. 2. Turn on the device. 3. Simultaneously, start the timer and press the exposure button once for less than three seconds. 4. Stop the timer as soon as the RGB LED turns on. 5. Verify that the time is less than one second. If the action happens too fast for starting and stopping the timer, the requirement has also been verified.
1. RGB light remains on for five seconds ±10% when the exposure button is pressed.	1. Obtain a timer. An acceptable timer includes a chronograph, a digital stopwatch, or a stopwatch app. 2. Turn on the device. 3. Press the exposure button once for less than three seconds. 4. Start the timer as soon as the RGB LED turns on. 5. Stop the timer as soon as the RGB LED turns off. 6. Verify that the timer reads five seconds ±10%.
1. The RGB LED shows the current skin type when in the Skin Type Mode.	1. Turn on the device. 2. Press the exposure button for more than three seconds. The device will enter Skin Type Mode after a 0.5 second vibration. 3. Observe the LED color. Verify the color of the LED matches the Skin Type setting as seen in 11. 4. Press the sunscreen button. Verify that the color increases according to Table 11. Continue pressing until the LED is purple. 5. Press the exposure button. Verify that the color decreases according to Table 11. Continue pressing until the LED is red.

Sunscreen Button

The button is the 2-1825027-0. The button is mounted on the side of the device, allowing the user to input into the device that he or she has put on sunscreen, which resets the device exposure timer. The LED lights up blue to let the user know that their response has been recorded. The button interfaces with the Control Subsystem through a digital signal.

Table 10: Sunscreen Button Requirements and Verification

Requirements	Verification
1. Pressing the button resets exposure time to zero within one second.	1. Obtain a timer. An acceptable timer includes a chronograph, a digital stopwatch, or a stopwatch app. 2. Turn on the device. 3. Press the sunscreen button. 4. Verify the blue light turns on within one second. This signifies an exposure timer reset.
1. Button should be debounced and only register one high input per press.	1. Attach an oscilloscope to the Sunscreen pin of the ATMega4808 and to ground. 2. Turn on the device. 3. Press the sunscreen button. 4. Verify on the oscilloscope that there is no mechanical jumping when the button is pressed. The oscilloscope should show an exponential curve from 0 V to VCC.

Exposure and Skin Type Button

The button is the 2-1825027-0. The button is mounted on the side of the device. The button usage is twofold. If the button is pressed for a short duration (less than three seconds), the user queries the device for the current UV Index, which is reflected on the RGB LED. For a long duration press (more than three seconds), the device enters the Skin Type Mode (the vibration motor runs 0.5 seconds as feedback for entering this mode) and waits for further presses from the user to set their skin type.

Once in the Skin Type Mode, the sunscreen button (located physically on the upper side of the device), allows the user to increment their skin type according to the Fitzpatrick Scale [11]. The exposure and skin type button (located physically on the lower side of the device) allows the user to decrement their skin type. Along with this, the LED reflects the color corresponding to the defined skin types in Table 11 [12]. Once the user has set their skin type, he or she can exit the Skin Type Mode by again holding the exposure and skin type button for more than three seconds. To notify the user of the exit from this mode, the vibration motor runs for 0.5 seconds again.

The button interfaces with the Control Subsystem through a digital signal.

Table 11: Skin Type Color Reference Table (Fitzpatrick Scale) [13]

Skin Type	Description	Color
I	very light skin, often freckles, fair or red hair, blue or gray eyes never tans, burns Maximum exposure time before burning: 10 min	Red
II	light skin, often freckles, blonde or brown hair, any eye color hardly tans Maximum exposure time before burning: 20 min	Orange
III	light or light brown skin, rarely freckles, dark blonde or brown hair, gray or brown eyes tans easily Maximum exposure time before burning: 30 min	Yellow
IV	light brown or olive skin, no freckles, dark brown hair, brown eyes tans easily Maximum exposure time before burning: 50 min	Green
V	dark brown skin, no freckles, dark brown or black hair, dark brown eyes rarely burns Maximum exposure time before burning: 60+ min	Blue
VI	dark brown or black skin, no freckles, black hair, dark brown eyes rarely burns Maximum exposure time before burning: 60+ min	Purple

Table 12: Exposure and Skin Type Button Requirements and Verification

Requirements	Verification
1. Pressing the button for less than three seconds (short press) must display the UV Index on the RGB LED within one second.	1. Obtain a timer. An acceptable timer includes a chronograph, a digital stopwatch, or a stopwatch app. 2. Turn on the device. 3. Press the exposure button once for less than three seconds. 4. Verify the RGB light turns on within one second.
1. Pressing the button for more than three seconds (long press) must cause the device to enter Skin Type Mode within four seconds of the initial button press.	1. Obtain a timer. An acceptable timer includes a chronograph, a digital stopwatch, or a stopwatch app. 2. Turn on the device. 3. Simultaneously, start the timer and press and hold the exposure button for more than three seconds. 4. Once a vibration is felt from the vibration motor, stop the timer. 5. Verify that the vibration occured within four seconds of initially pressing the button. 6. Press and hold the exposure button for more than three seconds. 7. Verify that another vibration is felt.
1. Button should be debounced and only register one high input per press.	1. Attach an oscilloscope to the Exposure pin of the ATMega4808 and to ground. 2. Turn on the device. 3. Press the exposure button once for less than three seconds. 4. Verify on the oscilloscope that there is no mechanical jumping when the button is pressed. The oscilloscope should show an exponential curve from 0 V to VCC.

2.3 Circuit Schematic

Figure 6 is the complete circuit schematic, containing all components and subsystems. Additionally, the microcontroller programming header is located on the left, along with mounting holes and test points.

Figure 7 shows version one of our PCB layout. The ground plane on both the top and bottom of the PCB is hidden for clarity.

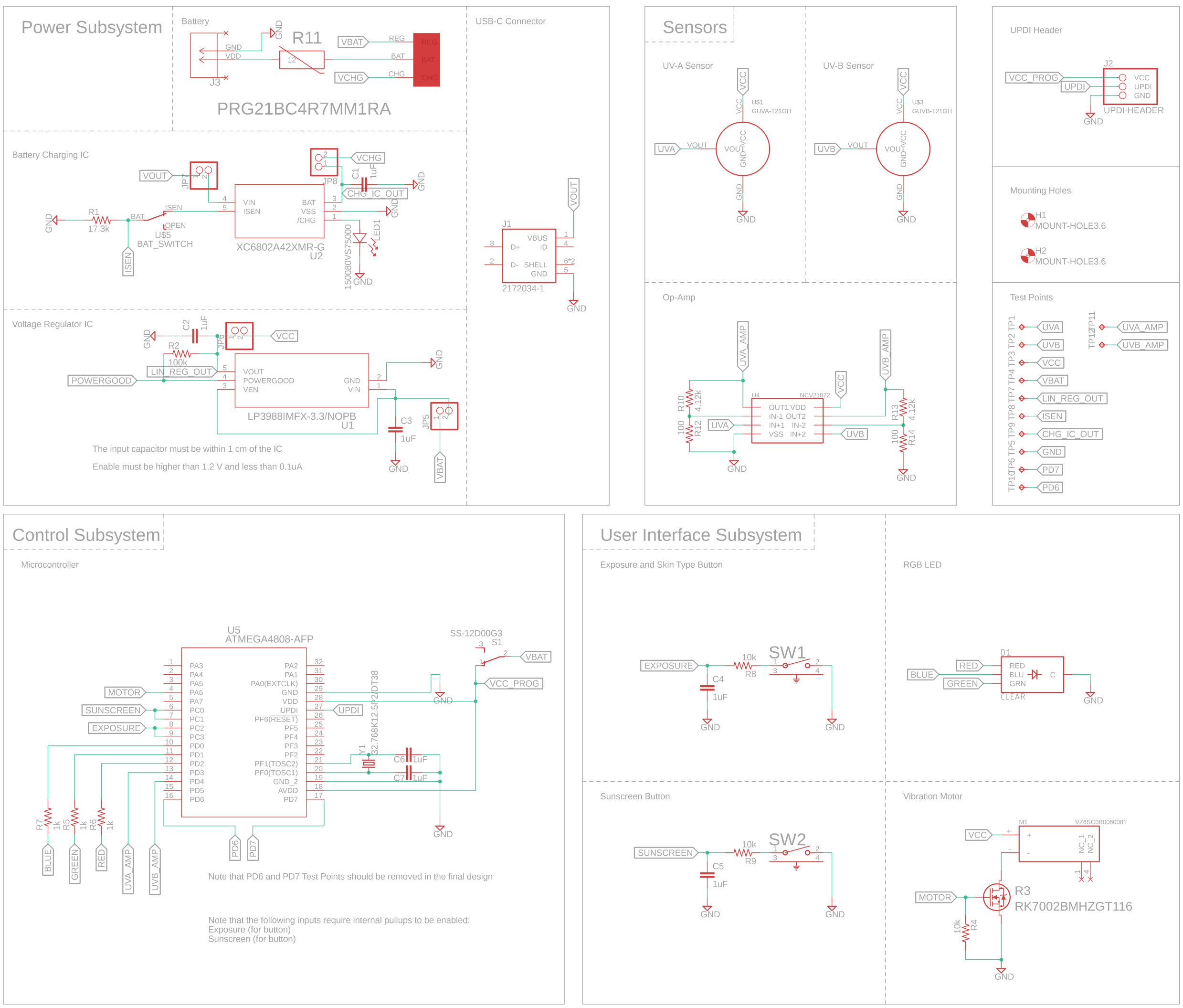

Figure 6: Circuit Schematic

2.4 PCB Layout

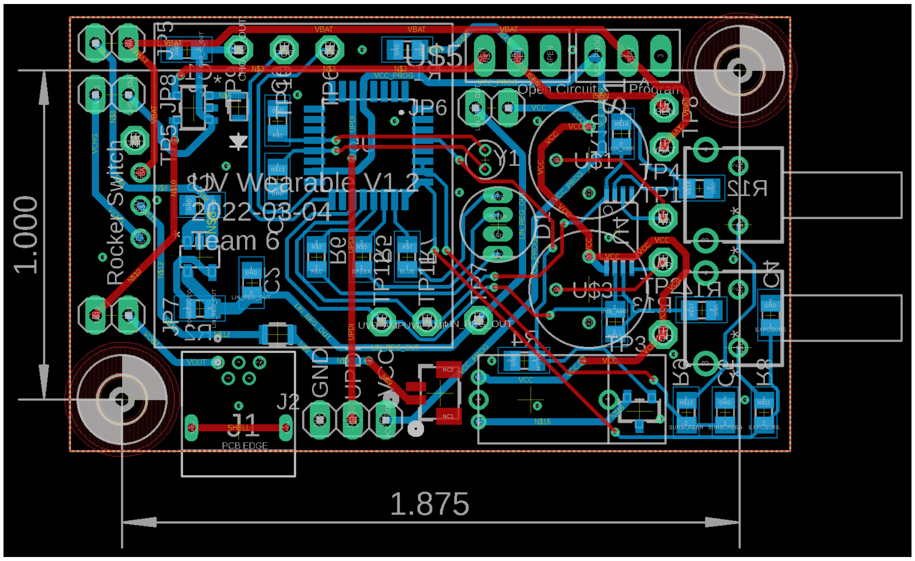

Figure 7: PCB Layout Version 1

2.5 Software Flowchart

The software flowchart is shown in Figure 8. The software of this device contains three modes: Low Power Mode, Active Mode, and Skin Type Mode. In the Low Power Mode, the microcontroller operates in a sleep state, and transitions into the Active Mode with an interrupt from the microcontroller's internal real-time clock or from the exposure or sunscreen button being pressed. Once transitioned into the Active Mode, the device reads the inputs from the sensors and the buttons and processes those inputs, as shown in Figure 8 under "Read Sensors and Button Inputs."

In the Active Mode, the first check is for the exposure button. If the exposure button has been pressed for less than three seconds, the RGB LED illuminates with the current exposure. If the exposure button has been pressed for more than three seconds, the device enters the Skin Type Mode. In the Skin Type Mode, the RGB LED illuminates with the current skin type setting, as defined in Table 11. The user can press the sunscreen and exposure button to increase and decrease the current skin type setting, respectively. This value is stored in the microcontroller's EEPROM and is read from at device startup. The user can exit the Skin Type Mode by pressing the exposure button for more than three seconds, and the device returns to its Active State.

Next, the device reads the sunscreen button. If the sunscreen button has been pressed, the device resets the exposure time accordingly. If the sunscreen button has not been pressed, the device measures the current UV index, takes the maximum of the past minute's measurements (to account for changes in the sensor's orientation), and determines if the current UV index is harmful to the skin. If so, the timer for exposure is incremented by the difference in the current time and previously stored time. Next, if the user's exposure time is over their maximum exposure time, the device alerts the user through a five second vibration. Finally, the device enters the Low Power Mode and configures itself to wake in ten seconds for the next measurement.

If the exposure time is over the maximum exposure for the set skin type, the device notifies the user by vibrating the motor for five seconds. This happens every minute for five minutes. If the user does not respond to this notification (either though putting on sunscreen and pressing the sunscreen button or getting out of harmful UV light) after five minutes, the device assumes the user is no longer wearing the device and stops the notification to prevent unnecessary battery drain.

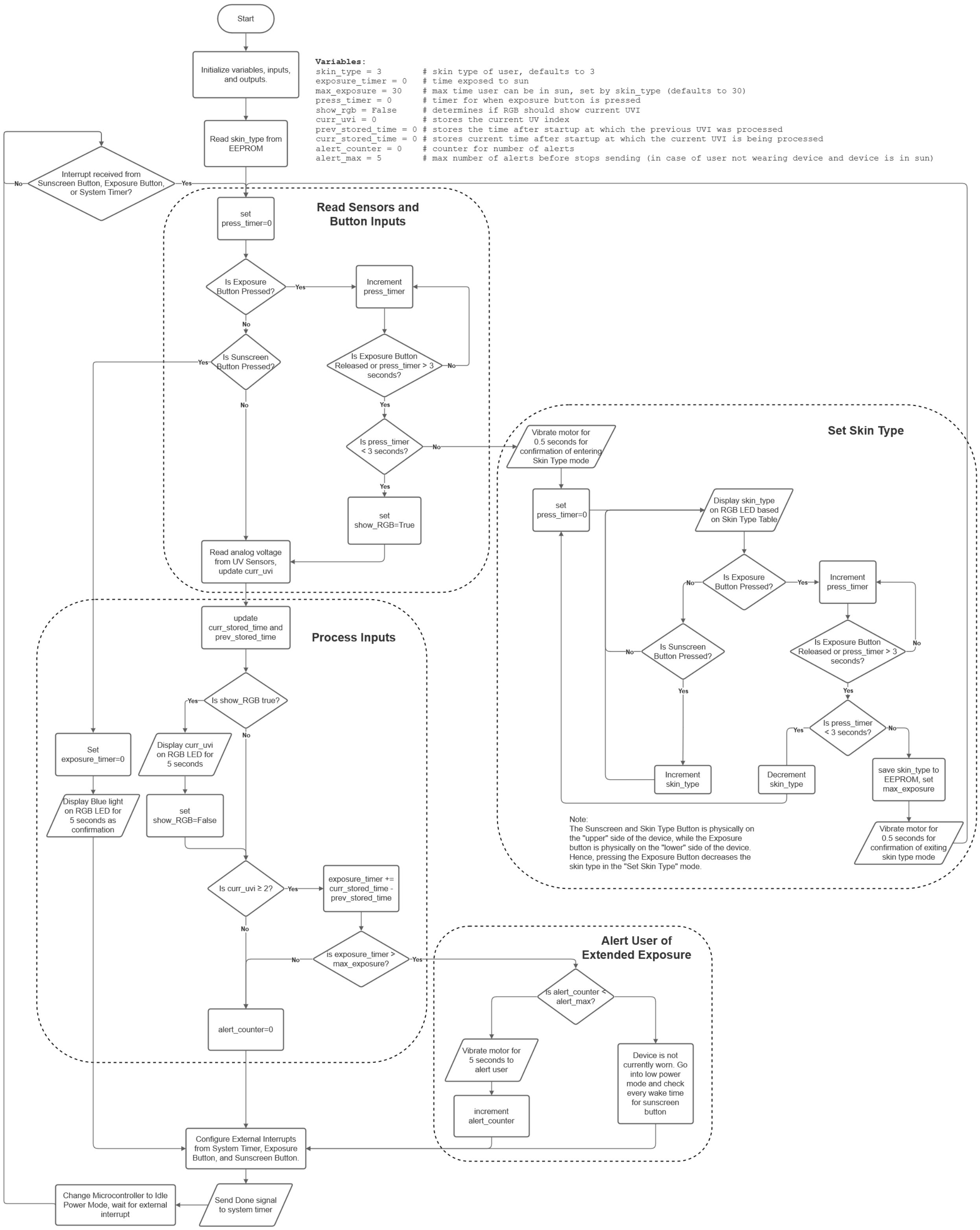

Figure 8: Software Flowchart

2.6 Tolerance Analysis

2.6.1 Battery Life

As a wearable device, the main constraint is battery life. We can mathematically analyze the expected minimum and maximum battery life. The device has three mode: Active Mode, Low Power Mode, and Skin Type Mode. During the Low Power Mode, all unnecessary functions of the microcontroller are turned off. Specifically, the only active components are the microcontroller (in a low power state with only the real-time clock running), the op-amp, and the sensors. During the Active Mode and Skin Type Mode, the microcontroller functions with all necessary components turned on to read sensor values, illuminate the LED, and vibrate the motor.

To increase battery life, we perform an analysis running the system at 5 V or 3.6 V (since all of our components have the capability of doing either). This analysis of battery life can be found in Table 13 and Table 14, running all components at 5 V and at 3.6 V, respectively. To calculate battery life, we implement Equation (1), where T is the total battery life in hours, $I_{components}$ is the total current draw from our device's components[4] (not including the microcontroller) in mA, I_{MCU} is the current draw from the microcontroller in mA, and C is the battery capacity in mWh. We must separate the current of the components and the microcontroller, since the microcontroller is connected directly to the battery and the rest of the components are connected to the linear voltage regulator.

$$T = \frac{C}{(I_{components} * V_{cc}) + (I_{MCU} * V_{bat})} \tag{1}$$

Then, we factor in the efficiency of our linear voltage regulator, which can be found by using Equation (2) [14].

$$Efficiency = \frac{V_{out}}{V_{in}} \tag{2}$$

Taking $V_{out} = 3.3\ V$ and $V_{in} = 3.7\ V$, [5] we find that the efficiency of our linear voltage regulator is 89.2%. By using Equation 3, we can find the power drawn from the battery, which is listed in Table 14.

$$P_{at\ battery} = \frac{P_{components}}{Efficiency} + P_{MCU} \tag{3}$$

Notably, running the entire system at $V_{cc} = 3.6V$ gives us a notable boost in battery life (almost 40% increased battery life), considering the device spends most of its time in the Low Power Mode. Even not running in the Active (MCU + Sensors) mode, there is still an increase in battery life (56 hours versus 37 hours). Finally, the time the device spends in the "Active (Everything On)" mode is very little, as the LED and Motor are on for less than five seconds for each notification. Overall, we expect to see a battery life surpassing our high level goal of at least sixteen hours.

[4] with the op-amp outputting an expected .4 mA per op-amp, for two op-amps, at a UV index of 5

[5] We assume that the battery runs at its nominal voltage of 3.7 V. However, the battery voltage varies depending on its discharge capacity from 3.0 V to 4.2 V [15]. However, because the battery spends most of its discharge cycle near or around 3.7 V, we assume this voltage in our efficiency calculation.

Table 13: Current Draw Analysis, $V_{cc} = 5V$ and $V_{cc} = 3.6V$, $C = 1073mWh$

	Current Draw (mA)						
at 5 V @ 15MHZ	**MCU**	**LED**	**Motor**	**Op-amp**	**UVA**	**UVB**	**Total Current except MCU (mA)**
Active (everything on)	6.40	20.00	70.00	0.82	0.05	0.05	90.92
Active (sensors only)	6.40	0.00	0.00	0.82	0.05	0.05	0.92
Low Power Mode	0.0024	0.00	0.00	0.82	0.05	0.05	0.92
	Current Draw (mA)						
at 3.6 V @ 15MHZ	**MCU**	**LED**	**Motor**	**Op-amp**	**UVA**	**UVB**	**Total Current except MCU (mA)**
Active (everything on)	4.20	20.00	70.00	0.82	0.05	0.05	90.92
Active (sensors only)	4.20	0.00	0.00	0.82	0.05	0.05	0.92
Low Power Mode	0.0013	0.00	0.00	0.82	0.05	0.05	0.92

Analysis of Current Draw at 5 V and 3.6 V using current draw of the Microcontroller running at 15MHz in its Active and Standby Power States [7], RGB LED [16], Vibration Motor [17], Op-amp [18], UV-A Sensor [19], and UV-B Sensor [6]

Table 14: Total Battery Life Analysis, $V_{cc} = 5V$ and $V_{cc} = 3.3V$, $C = 1073mWh$

at 5 V @ 15MHZ	**Total Power of MCU (mW)**	**Total Power Except MCU (mW)**	**Total Power after Regulator (mW)**	**Total Runtime (Hours)**
Active (everything on)	23.68	454.60	533.38	2.01
Active (sensors only)	23.68	4.60	28.84	37.21
Low Power Mode	0.0089	4.60	5.17	207.69

at 3.6 V @ 15MHZ	**Total Power of MCU (mW)**	**Total Power Except MCU (mW)**	**Total Power after Regulator (mW)**	**Total Runtime (Hours)**
Active (everything on)	15.54	327.31	382.53	2.81
Active (sensors only)	15.54	3.31	19.25	55.73
Low Power Mode	0.0048	3.31	3.72	288.58

2.6.2 Sensor Accuracy

Along with a tolerance analysis for the battery life, it is important to analyze the sensors for their accuracy. Because these sensors are not specifically tailored to sunlight, they have a larger range of intensity than we need for our device. The UV-A sensor has an output range of zero to five volts corresponding to UV-A light intensity from zero to 2.5 mW/cm^2. Similarly, the UV-B sensor has an output range of zero to five volts corresponding to UV-B light intensity from zero to five mW/cm^2. UV light coming from the sun is on the order of $\mu W/cm^2$. Typically, UV-A intensity maxes around 6 $\mu W/cm^2$ and UV-B intensity maxes around 17 $\mu W/cm^2$ [20]. This means that the unamplified voltage response from these sensors is under one volt. Our microcontroller has a 10 bit ADC, corresponding to 1024 discrete levels. With a supply voltage of 3.3 volts, the voltage increments we can measure is given by:

$$VoltageIncrement = \frac{3.3V}{1024} = 3.2mV \tag{4}$$

Referencing the graph provided in the UV-B datasheet, the difference between two UV indices corresponds to 8 mV. To ensure we can easily differentiate between UV indices, we amplify the voltage from the sensors using op-amps, making the maximum voltage from the sensors (80 mV, corresponding to UV Index of 10) equal to the maximum supply voltage (3.3 V). Setting 80 mV equal to 3.3 V, we find that our op-amps should have a gain of 41.25 using equation 5.

$$Gain = \frac{V_{\text{out}}}{V_{\text{in}}} \tag{5}$$

We have implemented a op-amp in a non-inverting op-amp configuration, as shown in Figure 9. This will have a gain of:

$$Gain = 1 + \frac{R_f}{R_2} \tag{6}$$

To reach our targeted gain, we choose two resistors with commercially available resistances. Let R_f be 4.12 kΩ and R_2 be 100 Ω. This provides us with an overall gain of 42.2.

Our chosen resistors, from Table 3.1, have a tolerance level of ±0.1%. This means that the 100 Ω resistor has a variance of 0.1 Ω. The 4.12 kΩ resistor has a variance of 0.00412 kΩ. The most extreme case of this would be to have the 100 Ω resistor read as 100.1 Ω and the 4.12 kΩ resistor read as 4.11588 kΩ. This gives us a final gain of 42.1177, still above our desired gain of 41.25 with a relative error of 2.10%. In the opposite direction, the 100 Ω resistor would read as 99.9 Ω and the 4.12 kΩ resistor read as 4.12412 kΩ. This gives us a final gain of 42.28, with a relative error of 2.50%.

Figure 9 and Figure 10 show the simulated circuit and input and output voltages for our op-amp. V_{in} is the output from the UV sensors, sweeping from 0 mV to 80 mV, corresponding to the possible outputs for UV indices from the UV-B sensor's datasheet [6]. The output is 0 V to 3.3 V, as we expect.

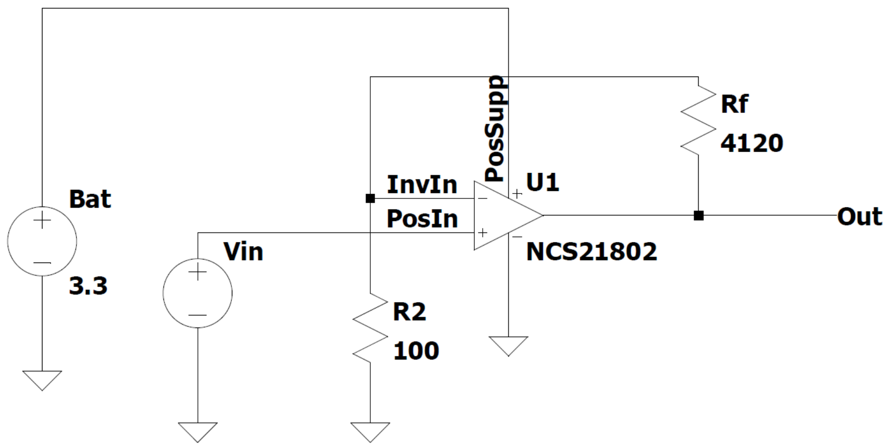

Figure 9: Simulated Op-amp Circuit for UV Sensors

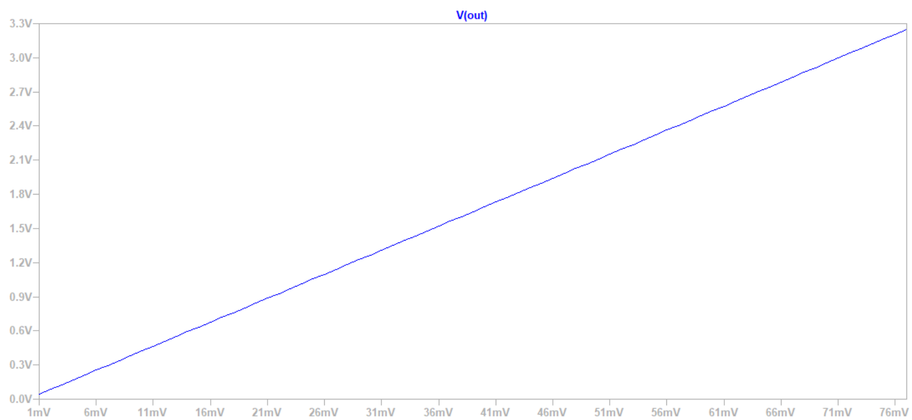

Figure 10: Simulated Op-amp Input and Output for UV Sensors

3 Cost and Schedule

3.1 Cost Analysis

Table 15: Cost Table

Component	Manufacturer	Part Number	Quantity	Price
Battery	Tiny Circuits	ASR00007	1	$5.95
Battery Charging IC	Torex Semiconductor Ltd	XC6802A42XMR-G	1	$1.74
Battery PCB Connector	JST Sales America Inc	BM02B-SRSS-TBT(LF)(SN)	1	$0.64
Mini USB Connector	TE Connectivity AMP Connectors	2172034-1	1	$1.12
Voltage Regulator	Texas Instruments	LP3988IMFX-3.3/NOPB	1	$0.87
UV-A Sensor	Genicom Co Ltd	GUVA-T21GH	1	$18.86
UV-B Sensor	Genicom Co Ltd	GUVB-T21GH	1	$19.94
Microcontroller	Microchip Technology	ATMega4808	1	$1.85
Buttons	Microchip Technology	2-1825027-0	2	$0.25
Vibration Motor	Vybronics Inc	VZ6SC0B0060081	1	$2.49
RGB Light	NTE Electronics	NTE30156	1	$0.68
Jumpers	Sullins Connector Solutions	QPC02SXGN-RC	3	$0.05
2x3 header	Sullins Connector Solutions	PRPC003DAAN-RC	1	$0.19
ISP Programming Diode	Micro Commercial	MBR0520L-TP	1	$0.52
Resistor 17.4k	Panasonic Electronic Components	ERA-6AEB1742V	1	$0.36
Resistor 100k	YAGEO	AC0805FR-7W100KL	1	$0.08
Resistor 1k	Stackpole Electronics Inc	RNCP0805FTD1K00	3	$0.07
Resistor 10k	Stackpole Electronics Inc	RNCP0805FTD10K0	2	$0.07
1uF Capacitor	Samsung Electro-Mechanics	CL21B105KAFNNNG	5	$0.07
15pF Capacitor	YIC	32.768K12.5P2/DT38	2	$0.12
Charging LED	Wurth Electronik	150080VS75000	1	$0.18
Fuse	Murata Electronics	PRG21BC4R7MM1RA	1	$0.89
Amplifier	Onsemi	NCV21802DMR2G	1	$1.42
Resistor 4.12 k	Panasonic Electronic Components	ERA-6AEB4121V	2	$0.30
Resistor 100	Vishay Dale	TNPW0805100RBEEN	2	$0.80
MOSFET	Rohm Semiconductor	RK7002BMHZGT116	1	$0.22
			Total Cost:	$61.81

The average hourly salary of ECE graduate is $34.14 [21].

We estimate that each person on the team will work for 15 hours per week for 10 weeks. Therefore,

34.14 $/hour * 2.5 * 150 hours = $12,802.50 per person

$12,802.50 x 3 = $38,407.50 = Total Labor Cost

The shop services is rated at $36.65/hr plus materials [22].

Our project is expected to require five hours of labor from the machine shop.

36.65 $/hour * 5 hours = $183.25 = Machine Shop Cost

Total Project Cost = Total Labor Cost + Machine Shop Cost + Parts Cost = **$38,666.84**

3.2 Project Schedule and Task Allocation

Table 16: Schedule

Week	Team Deliverables	Gavin	Jimmy	Liz
2/21	Design Document	Design Doc Finish PCB Layout	Design Doc PCB Battery, Connectors	Design Doc Sensor Equation Setup
2/28	Design Review PCB Board Review	Unit Test Microcontroller, Motor, LED, Buttons Finalize PCB Design	Unit Test Power Subsystem	Unit Test Sensors Create UV Testing Circuits
3/7	PCB Order 1 Teamwork Evaluation	Complete Teamwork Evaluation Edit PCB Design Start Microcontroller Code	Teamwork Evaluation Edit PCB Design Start Microcontroller Code Fix Power Subsystem (If needed)	Complete Teamwork Evaluation Edit PCB Design Start Microcontroller Code
3/14	**BREAK**			
3/21	PCB Order 2 Assemble Full Design	Assemble PCB PCB Redesign	Assemble PCB Test revised Power Subsystem	Assemble PCB Debug Sensor Issues
3/28	Individual Progress Reports Reassemble Design (if needed)	Complete Progress Reports Assemble PCB (if needed)	Complete Progress Reports Assemble PCB (if needed)	Complete Progress Reports Verification Testing on Sensors
4/4	PCB Order 3 (If needed) Debug and Software Refinements	Debug Full System Software Refinements	Debug Full System Software Refinements Test Battery Life Claims	Debug Full System
4/11	Mental Health Check	Software Refinements Demo Preparation	Demo Preparation	Testing Sensor Accuracy Demo Preparation
4/18	Mock Demos Real Life Testing	Final Testing of Full Design	Final Testing of Full Design	Final Testing of Full Design Real Life Testing
4/25	Demos	Work on Final Presentation	Work on Final Presentation	Work on Final Presentation
5/2	Final Paper Presentations	Work on Final Paper	Work on Final Paper	Work on Final Paper

4 Ethics and Safety

There are several ethical and safety issues associated with our project. Accordingly, we focus on the health and safety of the user and ensure this is held in the highest regard throughout our project, as stated in the 7.8 IEEE Code of Ethics, Section I.1 [23].

We must ensure that the batteries used in our device are handled with care. This includes preventing over and under charging and safe usage to prevent leaking or exploding batteries.

The battery comes with a protection circuit that prevents overcharging and over-discharging. However, those are not the only dangers. The battery must be handled with care when not in use and therefore is carried in a hard box with bubble-wrap to avoid any puncture or hard hits. Additionally, to prevent any accidental short-circuits, there is a fuse before any electrical connections that disables the battery before the current reaches the battery's maximum current rating.

- Transporting of the battery must be done in three layers
  - Inner layer is a sealed plastic bag
  - Middle layer is bubble wrap
  - Outer layer is a nonconducting hard shelled casing
- Before and after use, the battery voltage must be measured
  - The battery voltage must be within 3.0 V and 4.2 V
- Before and after use, the battery exterior must be inspected for any damage
- Charging of the battery must be done with a commercial charger or charging IC that performs the entire charging algorithm
  - Charging current must be no greater than 100 mA
  - Charging voltage must be no greater than 4.3 V
  - Charging must be done in a sealed plastic bag
  - The battery voltage must be no greater than 4.3 V after charging is completed
- Storage of the battery while not in use must follow these requirements
  - Humidity must not exceed 60%
  - Temperature must be between -20°C and 45°C
- In case of an incident with a battery, contact TA, Casey Smith, and possibly 911
  - TA: zhicong2@illinois.edu
  - Casey Smith: (217)-300-3722; cjsmith0@illinois.edu
- In case of a battery fire, extinguish and contact both above
- In case of a swelling battery disconnect, place in a battery bag, place bag as far from flammable material as possible, and contact both above
- In case of a battery leak, evacuate and contact both above

As the device is related to human medical safety through skin protection, we must ensure that the device is presented simply as a prototype and as an extra layer of monitoring for UV exposure. It does not replace other skin protective measures, such as sunscreen or getting into shade. Within the scope of the project, the device is not rated for medical use.

Because we are measuring and testing using UV light, there are safety issues associated with UV light. UV light is known to cause skin damage, such as sunburn, skin cancer, and premature skin aging. In addition, UV light can damage the eye. It can lead to photokeratitis, corneal injuries, and cataracts of the lens [24]. We must ensure these risks are known and presented while testing and using the device.

There are three types of UV light: UV-A (320 nm - 400 nm), UV-B (280nm - 320 nm), and UV-C (100 nm - 280 nm). The most dangerous of these wavelength is between 240 nm and 320 nm, which falls into both UV-B and UV-C light. UV-C light is blocked by Earth's atmosphere and is not being tested in our device, so it is not of concern. UV-B light falls into the most dangerous spectrum, so we must be the most careful when testing using UV-B light. Although UV-A light is not the most dangerous, it can still be harmful. As a result, the maximum recommended energy a human should be exposed to can be characterized by the threshold limit value (TLV). For UV-B light, the TLV is 10 mJ/cm^2. For UV-A light, the TLV is 1 mJ/cm^2 [25]. To ensure that we do not exposure ourselves to these levels, we must shield the lights used during testing by using opaque materials, such as cardboard or wood, in order to minimize direct exposure.

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