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 1 in 5 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 tell 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 will alert the user to take preventative measures against skin damage, such as applying sunscreen or seeking shade. With our device, a user 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

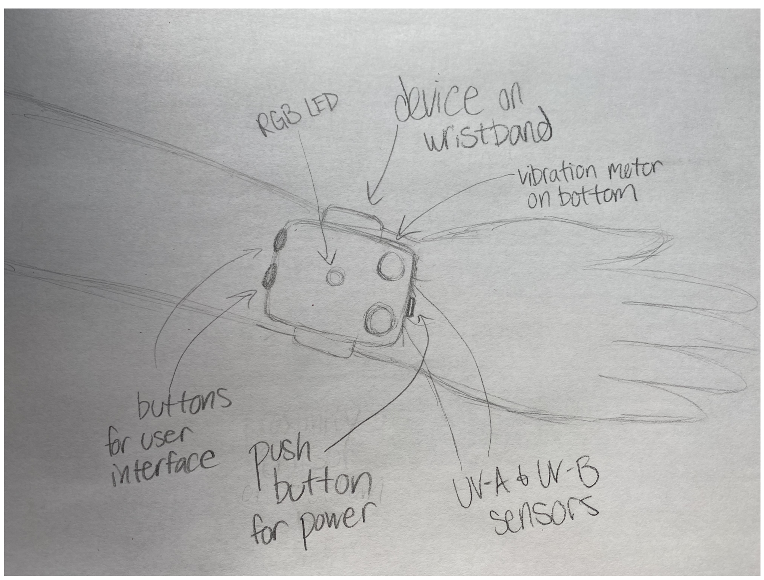

Figure 1: Drawing of Ideal Design

1.4 High-level requirements list

Battery Life

Our goal is to have a battery life of at least 16 hours. This will allow the user to use the device during daylight hours, and the user can recharge the device at night when they would not need to monitor UV exposure.

UV Exposure Time and Intensity Accuracy

We want to ensure that our device can accurately measure the UV intensity and exposure time of the device wearer. These are important to ensure the device is properly alerting the user of the real danger from their exposure. To ensure accuracy, we will verify our device readings with the National Weather Service UV Index ratings at the area of testing. In addition, we will test our device using photodiodes with set intensities.

Input and Output To and From User

For maximum efficiency, our device will give and receive feedback from the user. To warn the user of harmful UV exposure, we will use a vibration motor as an alert system for when to apply sunscreen or find shade. When the user has applied sunscreen, the user can press the respective button, which will reset the exposure timer, since applying sun protection will decrease the relative danger of UV exposure. In addition, we want the user to be able to check the current UV exposure. By short pressing the respective button, an RGB LED will illuminate indicating the current UV Index. Finally, skin type can affect the amount of exposure before skin damage. Therefore, by long pressing the respective button, the user can set their skin type and the device will incorporate that into its exposure time.

2 Design

2.1 Block Diagram

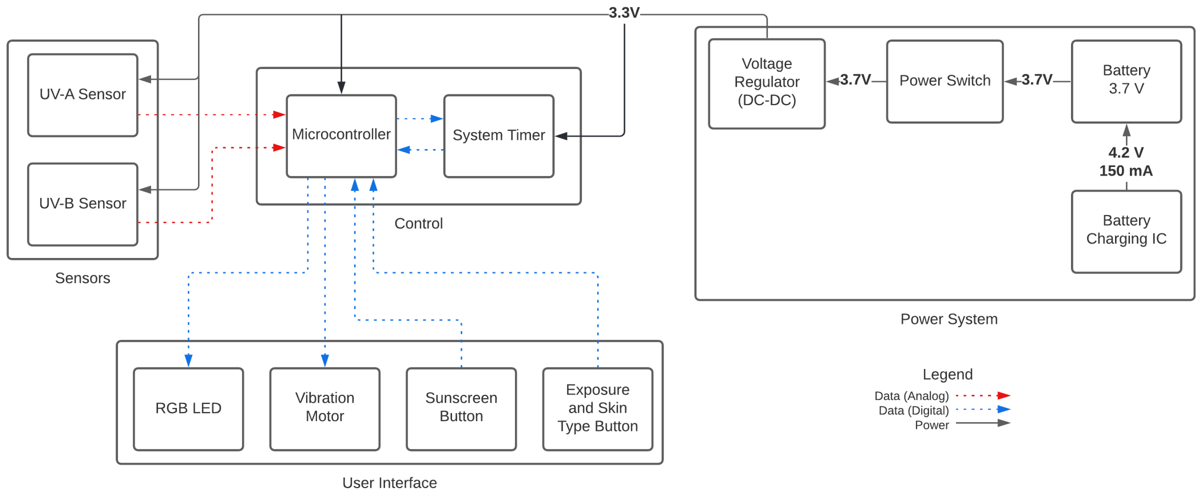

Figure 2: Block Diagram

2.2 Subsystem Overview

2.2.1 Sensors

UV Sensors

The UV Sensors used in our device will consist of one UV-A sensor and one UV-B sensor, which have peak intensities within the distinct ranges of the 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 interact with the Control Subsystem and the Power Subsystem.

Requirement 1: The UV-A sensor will output an analog voltage corresponding to the intensity of light within the wavelength range of 320nm to 370 nm.

Requirement 2: The UV-B sensor will output an analog voltage corresponding to the intensity of light below a wavelength of 320 nm.

2.2.2 Control

Microcontroller

The microcontroller for our device will be the ATtiny441. The ATtiny441 was chosen because of its I/O, part availability, and low power consumption. This microcontroller contains 12 I/O pins used to interface with our other subsystems as described in the block diagram. In addition, this microcontroller has ADC capability, which will be used to measure the analog voltage output from the UV sensors. The ATtiny441 is also designed for low power consumption in both its active and sleep modes. As a whole, this 8-bit microcontroller will allow for timing storage to track how long the user has been exposed to UV light and provide feedback to the user.

The microcontroller will interface with the Sensor Subsystem through analog I/O pins. The microcontroller will also interface with the User Interface Subsystem through digital I/O pins. Finally, the microcontroller will interface with the Power Subsystem through 3.3V.

Requirement 1: The microcontroller must have at least 2 ADC's with a resolution of 0.01 mV or better.

Requirement 2: The microcontroller must input at least 3 digital signals.

Requirement 3: The microcontroller must output at least 5 digital signals.

Requirement 4: The microcontroller must have a power-saving mode to limit current consumption to at most 5mA.

Requirement 5: The microcontroller must be able to wake from a power-saving mode within one second of an external interrupt signal.

System Timer

The System Timer will be a TPL5010. The System Timer allows the device to enter a low power mode, and after a set period of time, the System Timer will send an interrupt to the microcontroller to wake the microcontroller from this low power sleep state. By using this, we will be able to reduce power usage in between UV measurements and extend battery life. The System Timer will interface with the microcontroller and the Voltage Regulator.

Requirement 1: The System Timer must send an interrupt signal to the microcontroller every minute as a rising edge, i.e., low signal (ground) to high signal (V_{cc}).

2.2.3 Power

Battery

The battery used for this device will be an RJD3048. The Lithium-Ion battery has a nominal output voltage of 3.7V[1] and an output current of 150mA for a total maximum output power of 555mW. The total capacity of the battery is 300mAh or alternatively 1.11Wh. The discharge cut-off voltage is at 3.0V which will be discussed in the Voltage Regulator section.

[1] The maximum output voltage is 4.2V.

Requirement 1: Last at least 16 hours with a load at 3.7V and an average current of 8mA.[2]

Voltage Regulator

Our device will have a linear voltage regulator, an LP3988IMFX-3.3/NOPB. It is rated for a maximum input voltage of 6V, a fixed output of 3.3V, a dropout voltage of 150mV,[3] and a maximum output current of 150mA. The fixed output voltage will keep all sensors and electronics at a steady V_{cc}. The regulator will stop operating at a battery voltage of 3.42mV but the benefits of a clean output power and smaller circuit footprint[4] make the linear regulator the optimal choice.

Requirement 1: Supply a DC 3.3V (±500mV) output with any voltage input range between 4.2V to 3.42V.

Battery Charging PMIC

The battery charging will be handled by an XC6801A42XPR-G. With a maximum input voltage of 30V and input current of 1.5A, this device can be charged with many generic chargers for electronic devices. The charger used for the device will be a USB wall charger with an output of 5V and 1A DC. The charger will be connected to the device using a UJ31-CH-G1-SMT-TR connector.[5]

Requirement 1: The device should be able to accept 5V at 1A and supply the battery 150mA at 4.2V.
Requirement 2: The device should be able to stop charging when the battery reaches 300mAh of capacity without the user unplugging the charging cable.

2.2.4 User Interface

Vibration Motor

The vibration motor will alert the user when they have been exposed to UV light for an extended period of time. Similar to vibration motors in smartphones or smartwatches, the vibration motor will be the VZ6SC0B0060081. This will interface with the Control Subsystem through a digital signal.

Requirement 1: When UV intensity reaches the threshold for safety, the vibration motor will run for 0.5 seconds.

Requirement 2: The vibration motor will run each time a new threshold is met.

RGB LED

The RGB LED will be the NTE30156. The RGB LED will allow the user to see the current UV intensity as detected by the device. The colors shown will indicate current UV intensity, 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 [4]. The RGB LED will interface with the Control Subsystem through 3 digital pins (one for each red, green, and blue).

[2] Based on expected current draw at 5V in Table 1
[3] With an output current of 150mA.
[4] Compared to a switching regulator
[5] This is a USB-C connector, USB 3.2 Gen 2

Requirement 1: The LED will reflect the current UV Index within one second of the exposure button being pressed.

Requirement 2: The light will remain on for at least 5 seconds.

Sunscreen Button

The button will be the 2-1825027-0. The button will be mounted on the side of the device, allowing the user to input into the device that they have put on sunscreen and resetting the device exposure timer. The button will interface with the Control Subsystem through a digital signal.

Requirement 1: Pressing the button must reset the exposure time to zero within one second.

Exposure and Skin Type Button

The button will be the 2-1825027-0. The button will be mounted on the side of the device. The button usage will be two-fold. If the button is pressed for a short duration, the user will query the device for the current UV Index (see the RGB LED section for usage). For a long duration press, the device will wait for further presses from the user corresponding to their skin type. For example, if they are skin type I, they will press the button once. If they are skin type II, they will press the button twice, and so on.

The button will interface with the Control Subsystem through a digital signal.

Requirement 1: Pressing the button for less than 3 seconds (short press) must display the current UV Index on the RGB LED within 1 second of the button being processed as a short press.

Requirement 2: Pressing the button for more than 3 seconds (long press) must cause the device to enter Skin Type Mode[6] *within 1 second of the button being processed as a long press.*

Power Switch

The power switch will be the M2012TXW41-DA. The rocker will be mounted on the side of the device, allowing the user to easily turn the device on and off. This ensures that the device is not measuring UV exposure when the user is not using the device. This will increase power efficiency. The switch will interface with the Power Subsystem.

Requirement 1: Toggling the switch must turn the device on (or off) within one second.

[6] Skin Type Mode will allow the user to set their skin type.

2.3 Tolerance Analysis

As a wearable device, the main constraint will be battery life. We can mathematically analyze the expected minimum and maximum battery life. The device will have two states: Active and Low Power. During the Low Power state, all unnecessary functions of the microcontroller will be turned off. Specifically, the only components that will be active are the microcontroller (in an idle state with only the timer running), the System Timer (to wake up the microcontroller), and the sensors. During the Active state, the microcontroller will function 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 5V or 3.3V (since most of our components have the capability of doing either). This analysis of battery life can be found in Table 1 and Table 2, running all components[7] at 5V and at 3.3V, respectively. To calculate battery life, we implement Equation (1), where H is the total battery life in hours, I_{total} is the total current draw from our device's components in mA, and C is the battery capacity in mWh.

$$H = \frac{I_{total} * V_{cc}}{C} \tag{1}$$

Then, we factor in the efficiency of our linear regulator, which can be found by using Equation (2) [5].

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

Taking $V_{out} = 3.3V$ and $V_{in} = 3.7V$, [8] we find that the efficiency of our linear regulator is 89.2%. By using Equation 3, we can find the power drawn from the battery, which is listed in Table 1 and Table 2.

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

Notably, running the entire system at $V_{cc} = 3.3V$ gives us a significant boost in battery life (around 353 hours versus 99 hours), considering the device will spend most of its time in the Low Power Mode. Even not running Active (MCU + Sensors) mode, there is still a significant increase in battery life (83 hours versus 25 hours). Finally, the time the device will spend in the "Active (Everything On)" mode will be very little, as the LED and Motor will be on for less than 5 seconds for each notification. Overall, we expect to see a long battery life for our device.

[7] The System Timer is not included in this calculation, as it draws a max of 50 nA and is considered negligible.

[8] We assume that the battery runs at its nominal voltage of 3.7V. However, the battery voltage will vary depending on its discharge capacity from 3.0V to 4.2V [6]. However, because the battery spends most of its discharge cycle near or around 3.7V, we assume this voltage in our efficiency calculation.

Table 1: Total Battery Life Analysis, $V_{cc} = 5V$, $C = 1110mWh$

	Current Draw (mA)								
Mode	MCU	UVA	UVB	LED	Motor	Total Current (mA)	Total Power (mW)	Total Power at Battery (mW)	Total Runtime (Hours)
Active (Everything On)	7.8	0.05	0.05	20	70	97.9	489.5	548.83	2.02
Active (MCU + Sensors)	7.8	0.05	0.05	0	0	7.90	39.5	44.29	25.06
Low Power Mode	1.9	0.05	0.05	0	0	2.00	10.00	11.21	99.00

Analysis of Battery Life at 5V using current draw of the Microcontroller running at 16MHz in its Active and Idle power states[7], UV-A Sensor[8], UV-B Sensor[9], RGB LED[10], and Vibration Motor[11]

Table 2: Total Battery Life Analysis, $V_{cc} = 3.3V$, $C = 1110mWh$

	Current Draw (mA)								
Mode	MCU	UVA	UVB	LED	Motor	Total Current (mA)	Total Power (mW)	Total Power at Battery (mW)	Total Runtime (Hours)
Active (Everything On)	3.5	0.05	0.05	20	70	93.6	308.88	346.32	3.21
Active (MCU + Sensors)	3.5	0.05	0.05	0	0	3.6	11.88	13.32	83.33
Low Power Mode	0.75	0.05	0.05	0	0	0.85	2.80	3.15	352.94

Analysis of Battery Life at 3.3V using current draw of the Microcontroller running at 12MHz in its Active and Idle power states[7], UV-A Sensor[8], UV-B Sensor[9], RGB LED[10], and Vibration Motor[11]

3 Ethics and Safety

There are several ethical and safety issues associated with our project. Accordingly, we will 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[12].

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.

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 will not be rated for medical use.

Because we are measuring and testing using UV light, there are safety issues associated with UV light and skin. UV light is known to cause skin damage, such as sunburn in the short term and skin cancer and skin aging in the long term. In addition, UV light can damage the eye. It can lead to photokeratitis, corneal injuries, and cataracts of the lens [13]. We must ensure these risks are known and presented while testing and using the device.

UV light with wavelengths in the range of 240-320 nm is the most dangerous. UV-B light falls from 280 nm to 320 nm, so we will be the most careful when testing using UV-B light (since we will not be testing for UV-C light as it is blocked by the atmosphere). In this range, the threshold limit value (TLV) is less than 10 millijoules per square centimeter. UV-A light is less dangerous due to the longer wavelength (falling in the range of 320 nm to 400 nm). The TLV for UV-A is 1.0 joules per square centimeter. We will use these limits to ensure we are safely using the UV light for testing [14].

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