Blue Light-Tracking Glasses

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ECE 445 Spring 2020 Project Proposal
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1. Introduction

1.1 Objective

Since its inception, artificial light has changed the world dramatically: it has allowed humans to function in environments without sunlight, providing us with the opportunity to function effectively during the night or in enclosed spaces, and in modern times it has given us the ability to view and communicate complex visual information, making concepts such as television and computer displays possible. However, the development of modern artificial lighting has far outpaced the evolution of human beings' mechanisms for sleep regulation. In the last three decades, research on the impact of light pollution has demonstrated that exposure to shorter wavelengths of visible light can disrupt the human circadian rhythm[1] through suppression of melatonin[2] secretion [1]. Specifically, two pioneering studies by Brainard et al. [2] and Thapan et al. [3] on the action spectrum of melatonin suppression showed that maximum melatonin suppression from artificial light occurs at wavelengths of 446-477 nm; in other words, exposure to blue light alters hormone secretion, which can interfere with our sleep cycle. This interference is particularly significant when blue light exposure occurs in the evening: as little as 2 hours of night-time blue light exposure is enough to suppress melatonin [1]. Long-term night-time blue light exposure that leads to disruptions in our circadian rhythm is associated with higher incidences of cancer, diabetes, mental health disorders, age-related macular degeneration, and obesity [1], [4]. Therefore, night-time blue light exposure is a public health issue that has implications not only for workplace standards, but also for our daily lives.

In order to address this issue, we propose to develop a device known as Blue Light-Tracking Glasses, which would allow members of the public to monitor the extent of night-time[3] blue light exposure in their daily lives without the need for expensive and clunky instrumentation, and in a way that most closely accounts for the actual light that is reaching their eyes. The device would therefore be used in the evening to measure a user-set time limit of blue light exposure (2 hours or less given the above information) and would alert the user when this time has been reached. A photo-sensing circuit located

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[1] A term collectively referring to the endogenous processes regulating our internal physiological state that cycle within a 24-hour time period.

[2] A hormone that positively regulates sleep in the body.

[3] Here we define night-time as any time after sunset and before sunrise, which is relevant because there is no sunlight in this period of time, and it is sunlight that regulates biological sleep. Previously cited studies may have different definitions.

near the lateral rim of the glasses will specifically detect blue light incident on the sensor. When the device is turned on, the user will simply set an alarm to indicate when a certain exposure time has been exceeded, at which point an LED indicator will turn on. These glasses will be light enough to wear comfortably, and will be electrically insulated to protect the user.

1.2 Background

Blue light (380-500 nm[4]) exposure can cause oxidative damage in the cornea, degeneration of the retina, and alteration of the circadian rhythm [5], [6], [7]. However, although blue light alters circadian rhythm, it is not always detrimental; in fact, blue light is beneficial in regulating the circadian rhythm when exposure occurs in the daytime [8]. Only evening blue light exposure has negative effects on sleep regulation due to its suppression of melatonin secretion and the associated induction of cortisol secretion, which effectively keeps the body physiologically "awake," thereby affecting sleep quality and potentially causing daytime fatigue [5], [7]. Thus, in addition to concerns about short wavelength light causing direct damage to parts of the eye, public health concerns are also warranted for the use of blue-light emitting devices at night.

In an article addressing the pros and cons of blue light exposure, an optometrist on the website "All About Vision" explains that while sunlight is the major source of blue light in our lives, LED lights, fluorescent bulbs, and electronic displays containing LED lights also emit blue light, and the length of time and proximity at which we are exposed to these sources of light can potentially be harmful [7]. Generally, the medical consensus is that people should avoid or limit exposure to blue light in the few hours before going to sleep [9]. Besides limiting exposure, other available solutions to this problem are blue light-filtering glasses and electronic display color-shifts. Blue light-filtering glasses are glasses that have lenses that specifically block out high-energy visible light using reflective coatings: example products include Quay Australia's "BLUE LIGHT Computer Glasses" [10] and Blokz™ Blue Light Lenses [11]. A color-shift in an electronic display refers to the ability to reduce the amount of blue light emitted from the display by changing its emission spectrum. Common examples include "Night Light" on Windows 10 and "Night Shift" on MacOS operated computers [12].

The Mayo Clinic Health System as well as Harvard Health both list blue light-filtering glasses as a way to help prevent digital eye strain and reduce night-time blue light exposure (in order to improve sleep quality) [9], [13]. However, these glasses show no significant clinical efficacy against digital eye strain [14]. Consequently, the American Academy of Ophthalmology states that they "do not recommend any special eyewear for computer use," a subtle but firm rebuke [15]. Regarding the improvement of sleep quality, participants in multiple clinical trials who wore blue light-filtering glasses reported no significant changes in subjective sleep quality, though no objective measurements of melatonin levels were taken [16], [17]. In contrast, a separate study reported that users wearing blue light-filtering glasses experienced increased melatonin secretion and improved subjective sleep quality [18]—which is the expected result given the relationship between blue light and melatonin secretion. As for the

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[4] High-energy visible light wavelength range. Commonly referred to as 'blue light'. Blue-violet extends from 380-450 nm, while true blue light ranges from 450-485 nm [6], [7].

color-shift on computers, the Night Shift on an iPhone 7 could already reduce activation of melanopsin[5] by 67% [19]. Free software called "f.lux" that automatically shifts your computer display to warm colors at night, has been shown to significantly improve subjective sleep quality in night shift workers [20]. Although there are mixed results on the effects of blue light-filtering glasses, the objective measurements of circadian rhythm (i.e. melatonin levels) indicate that blue light-filtering glasses and color-shifts in electronic displays are both able to reduce the alteration in sleep regulation from blue light at night.

Considering the extent of research completed and the efficacy of available products, the solutions to the problem of blue light exposure at night—including completely avoiding blue light exposure, wearing blue light-filtering glasses, or using a color-shift on electronic displays—seem to be well developed and readily accessible to the public. However, we believe that the one flaw among the provided solutions is that besides not being able to work at all for the case of complete avoidance of blue light exposure, the latter two solutions (filtering glasses and color-shift) do not allow us to work on color-sensitive work at night because they filter out some of the visual information coming from the environment. Perhaps someone needs to accurately distinguish between certain colors in a graphic design; to control an airplane while seated in the cockpit; or to monitor process feedback on electronic displays in a factory.

Not every type of blue light source can be filtered at the display level, and some applications cannot tolerate removal of blue light from the spectrum. Indeed, some people certainly would not enjoy their movie as much if they had to shift the colors to favor one side of the spectrum. Thus, a niche product audience can be found among people who are conscientious about their health and long-term sleep quality but who do not want to filter out light from their environments. This warrants a device like our Blue Light-Tracking Glasses, which are able to detect blue light in the environment and assist users in setting exposure time limits, but which do not filter the light out. The closest existing product to our device is a patented smart wristwatch that can detect blue light and alert a user via textual notification [21]; still, our Blue Light-Tracking Glasses device is more applicable and more elegant in that it most accurately resembles measurement of light that actually hits your eyes (as opposed to light which hits your wrist) and that it simply turns on an LED to alert the user that the blue light exposure time limit has been reached (rather than textual notification).

1.3 High-Level Requirements

- Sensor module is able to detect blue light (380-500 nm) of intensity equal to or higher than a specific intensity threshold.
- Power module should be able to provide enough power to the device for 6 hours of constant device usage.
- User should be notified when blue light exposure time has exceeded the user-set time threshold while the device is in use.

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[5] Photodetector molecule involved in blue light-induced suppression of melatonin secretion.

2. Design

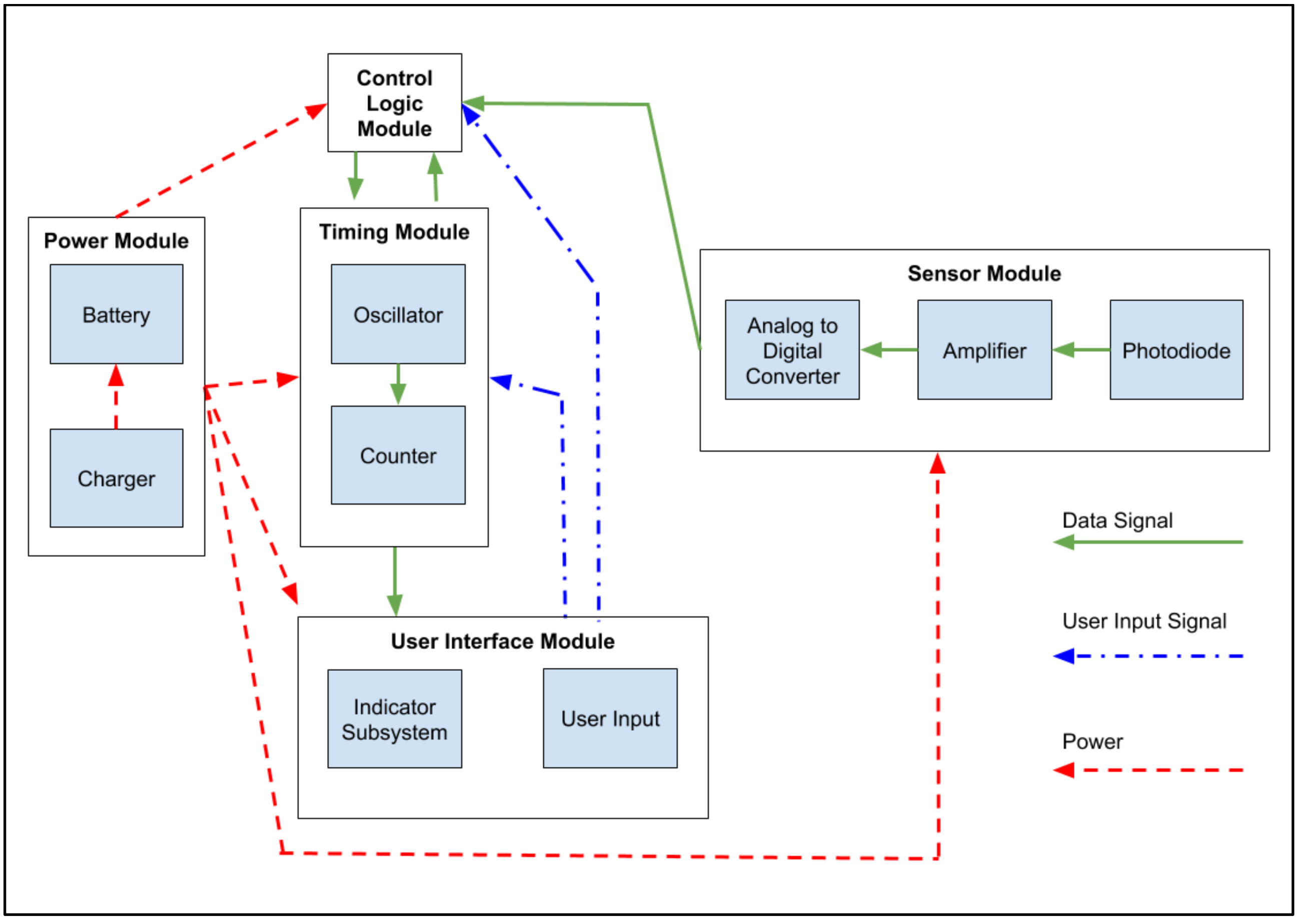

Figure 1. Block Diagram of Blue Light Tracking Glasses

2.1 Sensor Module

2.1.1 Photodiode

The photodiode is used to detect blue-light (380-500 nm). Dichroic filters are placed near the photodiode to selectively pass the appropriate wavelengths. This circuit will be calibrated to best respond to a range of around 0.6 meters from a EWS monitor at full brightness.

> *Requirement 1: Photodiode detects light within the blue-light spectrum (380-500 nm).*
> *Requirement 2: Responsivity of at least 0.2 A/W within this spectrum.*
> *Requirement 3: Outputs 0-2.4 μA depending on the blue light power incident on the device.*

2.1.2 Amplifier

The amplification circuit uses a transimpedance amplifier to convert the photodiode current to a usable voltage range for the analog to digital converter.

Requirement 1: Amplifier can convert photodiode current to 0-5V signal.
Requirement 2: The minimum intensity threshold for a logical 1 signal (meaning blue light is detected) corresponds to the voltage output from incident blue light with intensity 150 $\mu W/cm^2$*.*

2.1.3 Analog to Digital Converter

The analog to digital converter converts the amplifier voltage to a digital 1 or 0 depending on if the intensity threshold is surpassed.

Requirement: Outputs digital 1 when amplifier voltage has a magnitude over the threshold voltage.

2.2 Timing Module

2.2.1 Counter

The counter IC takes the output from the control logic and counts up when it receives an input of 1. If a time threshold is set, the timer will continue to count up normally but will output a signal when the exposure time has passed to the indicator subsystem.

Requirement 1: Counter should be able to reset asynchronously.
Requirement 2: 24-32 bit counter.

2.2.2 Oscillator

The oscillator provides a clock to the counter. Its frequency will be controlled by the user input subsystem in order to achieve different time ranges.

Requirement 1: Operates on a supply voltage between 3-5V.
Requirement 2: Oscillator can be enabled and disabled.
Requirement 3: Oscillator oscillates between 10-100kHz.
Requirement 4: Must be able to measure user-inputted exposure time threshold within a 15 minute accuracy.

2.3 Power Module

2.3.1 Charger

The charger safely charges the lithium-ion batteries to the appropriate voltage level.

Requirement: Charges the battery to full charge within 2 hours.

2.3.2 Battery

The battery pack contains the batteries and the circuit that converts the battery power for internal use. It delivers power to the timing module, sensor module, state machine, indicator subsystem, and other system components as needed.

Requirement 1: Provides 4-6 V.
Requirement 2: Maximum current output 50 mA.
Requirement 3: Enough charge to provide 25 mA continuous current for at least 6 hours.

2.4 User Interface Module

2.4.1 Indicator Subsystem

This subsystem consists of one indicator LED. If the time threshold is passed, the LED will turn on. The LED will only turn off if the reset button is pressed or the power is shut off.

Requirement 1: Red LED.
Requirement 2: Less than 30mA current draw.

2.4.2 User Input

This interface consists of a knob, an on/off switch, and a reset button at the side of the glasses. The knob will control a variable capacitor in order to change the frequency of the oscillator.

Requirement: Exposure time threshold should be adjustable within 15 minute intervals (e.g. the user can set the time threshold to 15, 30, 45, 60 minutes, etc.).

2.5 Control Logic Module

This module will reset the counter and turn off the LED when the reset button is pressed. It will also use the digital signal from the sensor module to determine when the counter is enabled. If the counter reaches the final count state it will pause the counter and turn on the LED.

Requirement: Must be able to take reset signal and data signals (from user interface, timing, and sensor modules) and adjust corresponding system components (enabling the timing module and LED indicators).

2.6 Risk Analysis

The sensor module poses the greatest risk to the successful completion of this project. The whole functionality of the device relies on the ability of the photodiode to detect blue light which corresponds to a wavelength between 400nm and 495nm. Photodiodes with a high and narrow responsivity in this range would consume a significant portion of our budget [22] and don't actually provide a much higher responsivity at blue light wavelengths when compared to a broadband photodiode [23]. Because of this it may be necessary to filter the light before entering the photodiode. In order to generate enough current for the detection circuit a photodiode with an adequate responsivity around blue light must be chosen and further light filtering will most likely be necessary.

The photodiode also needs to be properly biased in order to get an accurate light measurement. The two ways of biasing a photodiode are photoconductive and photovoltaic mode [24]. In photoconductive mode the diode is reversed biased which increases the responsivity and means that the measured current is proportional to the light incident on the detector. In photovoltaic mode there is no bias across the photodiode and a voltage will begin to build up across the load. For our application we would like to maximize the responsivity of the photodiode so running it in photoconductive mode would be desirable, however, it may be difficult to achieve and adequate reverse bias on battery power alone. If we instead run it in photovoltaic mode the output voltage will most likely require amplification before the signal can be further processed.

3. Ethics and Safety

There are three major concerns that will need to be handled carefully during the development of the device. The first concern is regarding charging lithium-ion batteries. Our device is powered using lithium-ion batteries which will be charged. When charging lithium-ion batteries there is a chance for chemical reactions to occur due to physical damage or electrical damage, which could be introduced due to overcharging [25]. The consequences of such a reaction occurring can range from smoke to large explosions. It is necessary according to IEEE code of ethics, #1: “to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment” [26]. In order to uphold this practice it is necessary to make certain that the process of charging and discharging the batteries is safe for the regular consumer. To ensure this we will make certain that the batteries involved will never be overcharged (above 4.2 V) or over-discharged (below 3V) by using an off the shelf battery charger in addition to testing using an oscilloscope to measure output voltage prior to connecting to the device.

The second concern is regarding water damage. As this device can be used in place of a pair of regular glasses, there is a possibility the device may be submerged the user washes the glasses. As such there is a chance that the user could be shocked. It is necessary according to the IEEE code of ethics, #9: “to avoid injuring others, their property, reputation, or employment by false or malicious action” [26]. Hence it is necessary that the device is safe to use even in the presence of water and will not harm someone. To do this, all electrical components will be secured using a case with a thickness sufficient to keep water out.

The third concern is regarding the dangers of electromagnetic radiation. The type of electromagnetic radiation that is of greatest concern with regards to our project is radio frequency. Electronic devices such as radios, Wi-Fi and Bluetooth devices, and radars can produce radio frequency. Radio frequency can cause damage to the human body if absorbed in large amounts [27]. According to the FCC's policy on radio frequency safety, "the NCRP's recommended Maximum Permissible Exposure limits for field strength and power density for the transmitters operating at frequencies of 300 kHz to 100 GHz" [28]. Our project is unlikely to operate at such frequencies so the danger of electromagnetic radiation will be limited.

In the case that any additional concerns that we are unable to handle appear during the development process in order to adhere to IEEE code of ethics #6: "to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations", we will discuss how to overcome the challenges concerned or seek someone with greater knowledge with regards to the challenge [26]. We will disclose any additional safety concerns as they appear.

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