LED Lighting for Photography

ECE 445 Design Review
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Contents

1. Introduction

1.1 Objective

The industry of photography has an immense market and provides information about products that cannot be communicated through text. The advertising and marketing industry alone provide over 500 billion USD[1], and photography plays a great role in the effectiveness of advertisements. In the case that these photographers purchase subpar equipment, improper lighting can create a dull and listless photo, losing the appeal that a vivid image can have.

Our project is to create an affordable lighting fixture that can offer tunable lighting effects such as smooth lighting gradients, adjustable color temperature, and mobility to create dynamic lighting for stunning photographs. By designing a programmable 2D LED array, we can enable photographers to “paint with light” by utilizing the effects provided from our design.

1.2 Background

Current lighting used in photography can cost thousands of dollars, and does not easily provide the dynamic lighting needed for certain effects used in photography. This lack of mobility of the current lighting limits the abilities of the photographer, and therefore the quality of the image. Without desired effects, photos of ordinary objects stay ordinary, but with control over certain features of the lighting, these photos can become extraordinary.

We propose that a single light source can be used in place of many, high cost, immobile lights. This light fixture can be swept past an object to offer a scanning effect and produce an image with dynamic lighting; giving photographers a whole new dimension to their photography. By incorporating tunable brightness, light gradient, and color temperature, our project will allow for more versatility than many professional lights can.

1.3 High-Level Requirements

- Our design requires a cordless power source capable of at least 55Wh capacity
- The LEDs must have a maximum brightness of at least 1000 Lumens to provide sufficient lighting for photography
- The LEDs must span a color temperature range between 3200K-5600K at a resolution of 50K

2 Design

2.1 Block Diagram of Entire System

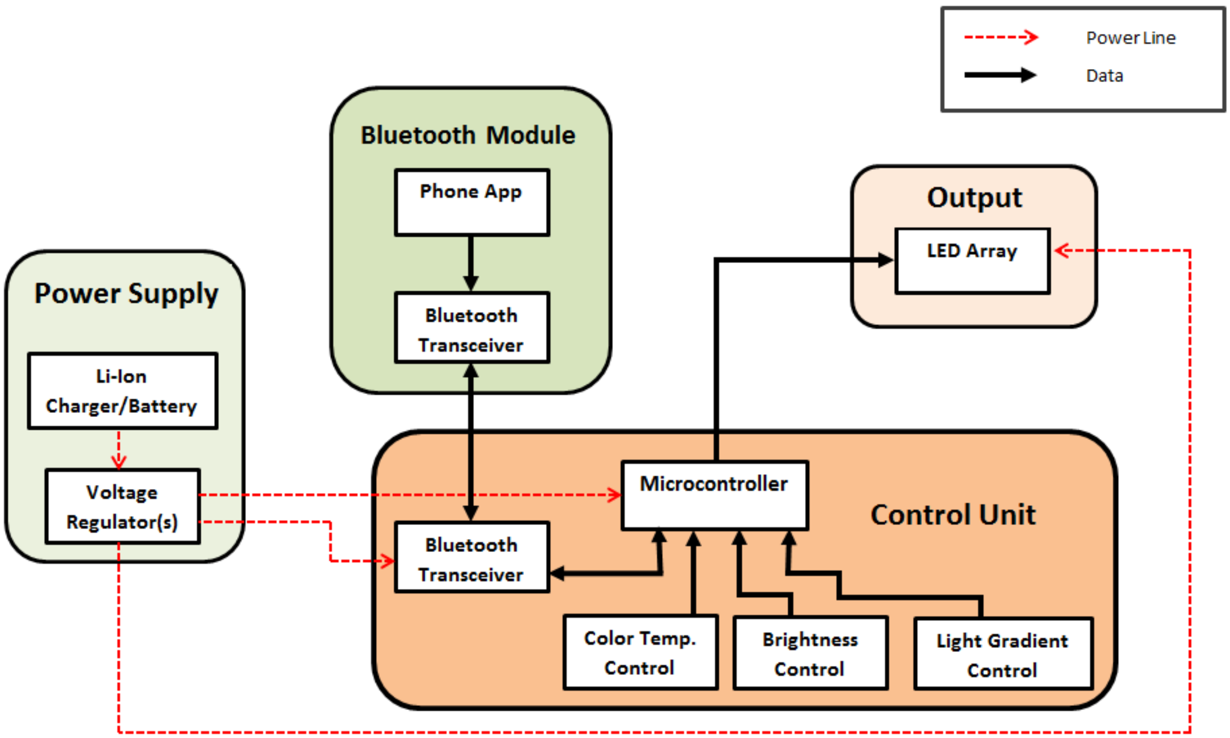

Figure 1: Block Diagram of Entire System

2.2 Physical Design

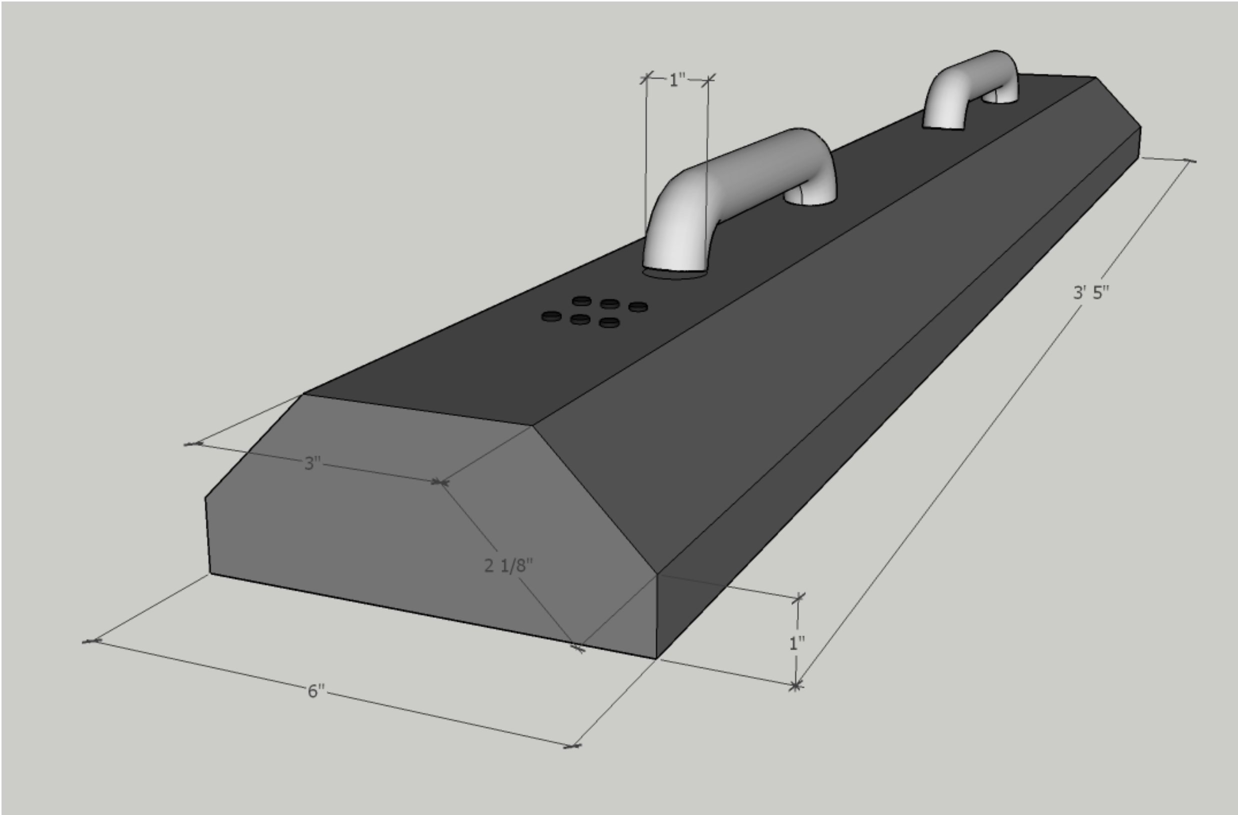

Figure 2: Physical Design of Array

2.3 Block Design

2.3.1 Rechargeable Li-Ion Battery

Input: Power from Li-Ion charging circuit up to 4.2V
Output: Powers voltage regulator, sending power to Bluetooth module, microcontroller, and LED array

This is the core power of the entire system. The 3.7V nominal output of the battery connects to the voltage regulator since the devices that need power require a 5V supply. The rechargeable battery will provide the user with repeatable use of the LED array without the cost of replacing batteries.

Requirements and Verifications for Li-Ion Battery

Table 1: Requirements and Verification of Li-Ion Battery

Requirement	Verification
Must consistently provide safe power as defined in the Safe Practice for Lead Acid and Lithium Batteries [10] Points: 5	a. Discharge battery to below 4.0V b. Begin charging battery and verify charging stops at 4.2V or less with multimeter c. Begin discharging battery and verify power from battery is cut off at 3.0V or above with multimeter
Must provide at least 55W of power Points: 3	a. Calculate maximum current draw from the devices connected to the voltage regulator b. Verify current draw ratings of battery c. Attach an equivalent load at the output of the voltage regulator and turn on the supply from battery d. Confirm battery operates under above conditions and does not overheat
Must be replaceable if lifetime of battery significantly diminishes over repeated use Points: 2	a. Open battery compartment and remove and reattach battery
Must be at least 55Wh capacity to provide power for at least 1 hour Points: 5	a. Power on light b. Set light to full brightness c. Wait 1 hour to verify light is still operating at end of hour

Points: 15/50

Calculations

Maximum current draw (in amps):

$$\frac{32.88 + 0.04 + 0.05}{80\%} = 10.9125\,Amps \quad (1)$$

Minimum power rating (in watts):

$$510.9125 = 54.5625\,Watts \quad (2)$$

Schematic

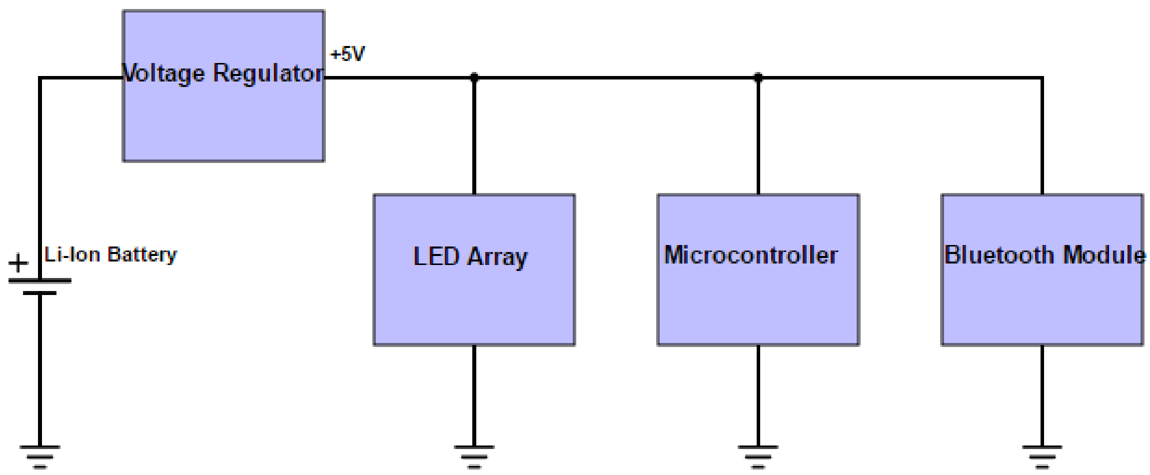

Figure 2: Schematic of output from Li-Ion Battery

2.3.2 Voltage Regulator

Input: Li-Ion Battery
Output: Supplies 5V to Bluetooth module, Microcontroller, and LED Array

The output voltage coming from the Li-Ion battery (3.7V) is not at an appropriate level for each module that the battery is powering. Our design will use a switch mode regulator which will also boost the 3.7V input to a steady 5V. This interface protects each of the modules from the low voltage coming from the battery, and maintains a steady output voltage no matter the current draw (up to 10A). This device takes its input from the Li-Ion battery and outputs a constant voltage to the Bluetooth module, microcontroller, and the LED array.

Requirements and Verifications for Voltage Regulator

Table 2: Requirements and Verification of Voltage Regulator

Requirement	Verification
Must provide constant voltage between 4.5V-5.5V at the output for Bluetooth, LEDs, and microcontroller to function properly Points: 4	a. Attach variable resistor to output of the regulator and vary the resistance from an (effective) open circuit to a resistance corresponding to the max current of the devices the regulator powers (8.6902A). b. Measure the output voltage with a voltmeter to ensure output stays between 4.5-5.5V

Points: 4/50

2.3.3 Microcontroller

The microcontroller for this project is the ATmega 328P-PU. It is the interface between the control buttons, Bluetooth module, and LED strips.

Input: Data from brightness, gradient, and color temperature buttons, data from bluetooth module, and power at 4.5V-5.5V from voltage regulator.
Output: Data to Bluetooth module and data to LED array

The microcontroller stores the current state of the gradient position, color temperature, and brightness. It uses these to calculate the data for each of the 60 LED's along the strip. It also stores the table with color temperature information to translate a color temperature to an RGB value. In order to have the change in output appear smooth as a button is held, the microcontroller will have to update the array at a rate of 60 Hz minimum. The communication with the Bluetooth module is handled by the serial I/O pins on the microcontroller.

Requirements and Verifications for Microcontroller

Table 3: Requirements and Verification of Microcontroller

Requirement	Verification
Must be able to change logic pins at a rate of at least 24 kHz according to equation (4) Points: 3	a. Connect oscilloscope to logic pin on microcontroller serving as LED clock and to ground b. Manipulate LED control signals c. Check frequency of clock signal to LED's to verify a frequency of at least 24 kHz
Must contain 1152 bytes of storage for color temperature information in addition to rest of program according to equation (7) Points: 3	a. Check datasheet for microcontroller to verify storage space is large enough for program plus 1152 bytes

Points: 6/50

Calculations

Minimum required frequency of digital output pins controlling LED strips:

$$bits\ per\ update = 32\ bit\ start\ frame + 32\ bit\ LED\ frame * 60\ LED's + 32\ bit\ end\ frame = 1984\ bits \quad (3)$$

$$Minimum\ Pin\ Speed = \frac{60\ Hz * bits\ per\ update}{50\%\ cpu\ cycle\ use} = \frac{60\ Hz * 1984}{0.5} = 23808\ Hz \approx 24\ kHz \quad (4)$$

Required storage space for color temperature data calculation with control granularity of 50K:

$$Temperature\ Range = 5600K - 3200K = 2400K \quad (5)$$

$$Number\ of\ Table\ Entries = \frac{2400}{50} = 48\ Entries \quad (6)$$

$$Table\ Size = 48\ Entries * 3\ Channels * 8\ bits\ per\ channel = 1152\ bytes \quad (7)$$

Schematic

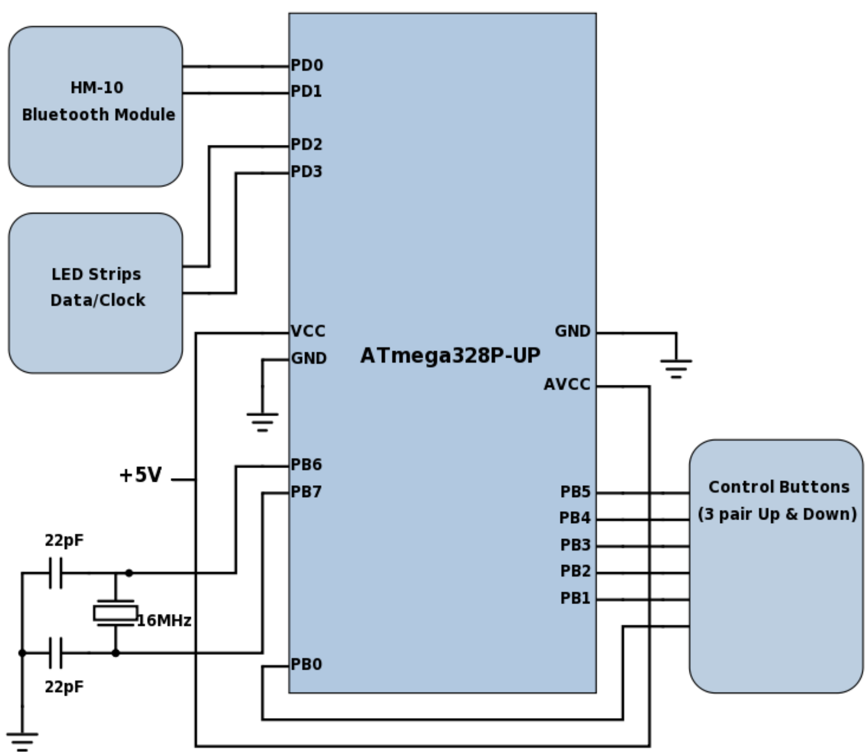

Figure 3: Microcontroller Pin Connection Schematic

2.3.4 Bluetooth Transceiver Module

Input: Smartphone Application, Microcontroller Data Output
Output: Data sent to Smartphone, Control Signal Sent to Microcontroller

To communicate between the smartphone application and the microcontroller wirelessly, our design will utilize Bluetooth communication. This module receives the desired input from the phone app and relays relevant values back to the phone from the microcontroller. The module sends and receives data serially, and will need to store the data in shift registers within the microcontroller. Because the transceiver is bidirectional, it inputs and outputs are both the smartphone application and the microcontroller, each sending and receiving information or control signals.

Requirements and Verification of Bluetooth Module

Table 4: Requirements and Verification of Bluetooth Module

Requirement	Verification
Transceiver must communicate with smartphone app over a distance of at least 10m to provide wireless control of the light with a latency of less than 1/60th of a second at a rate of at least 0.036kbps Points: 4	a. Pair module with smartphone and transmit data b. Continuously send data from at least 10m away c. Confirm data reception by displaying receiver output on oscilloscope d. Confirm response latency with cell phone application
Must receive data about current state from smartphone app to provide accurate information to the app Points: 2	a. Connect module to smartphone and transmit state b. Check phone app to verify that states are being relayed back from microcontroller

Points: 6/20

Calculations

The Bluetooth transceiver must be able to transmit all relevant data to the microcontroller within one frame of the LED array. The transceiver sends(receives) a signal declaring that there is incoming data, and then the relevant information is sent(received). The signal that our phone app will send is 6 bits, an up and down signal for each level of control. Ignoring the incoming data signal, our transceiver needs to be able to process 6 bits of data in under 0.0167 seconds. The transmission rate of the module used in our design is 6 kbps. Below is the calculation showing our device has a high enough transmission rate for our design.

$$\frac{6\ bits}{0.0167\ seconds} = 359.3\ bps = 0.036\ kbps < 6\ kbps \tag{8}$$

Schematic

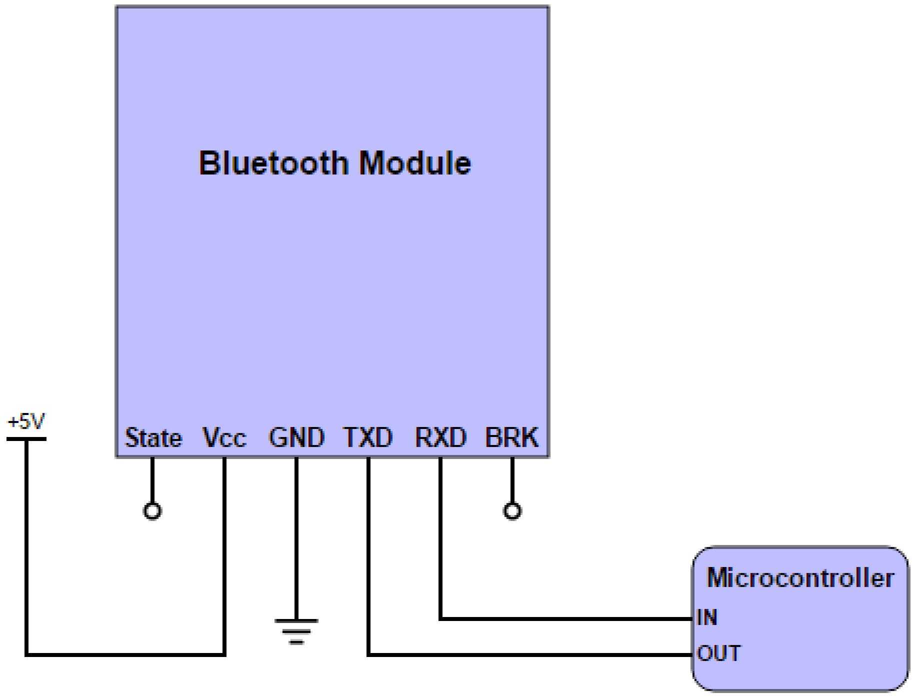

Figure 4: Schematic of Bluetooth Module Connections

2.3.5 Color Temperature, Brightness, Gradient Buttons

Input: User Control:
Output: Up/Down signals sent to the microcontroller

This is one of the levels of control to the system by the user. There will be two buttons per control input, one up and one down. The buttons will be connected to a debouncing circuit to protect the system from receiving undesired input from the switches. The up/down signal is sent to the microcontroller to be affected in the LED array.

The physical interface on the external housing is the simplified version of the digital interface provided by the phone app (details explained in 2.3.8). The interface will have six buttons in a two down-three across grid, providing an up or down option to the Color Temperature, Brightness, and Gradient Positioning.

Requirements and Verifications

Table 5: Requirements and Verification of Control Buttons

Requirement	Verification
The buttons paired with the debouncing circuit should not have any bounces within 5ms Points: 2	a. Probe the circuit and use the oscilloscope display to show a 5ms period after the button is pressed to verify no bounces

Points: 2/50

Calculations

The calculations used to design the debouncing circuit below were made using a debounce calculator online [2]. We used a bounce time of 5ms, high level logic value of 2.7V, final voltage of 5V, and resistor value of 1000 Ohms. This produced a capacitor voltage of 6.44 µF.

Schematic

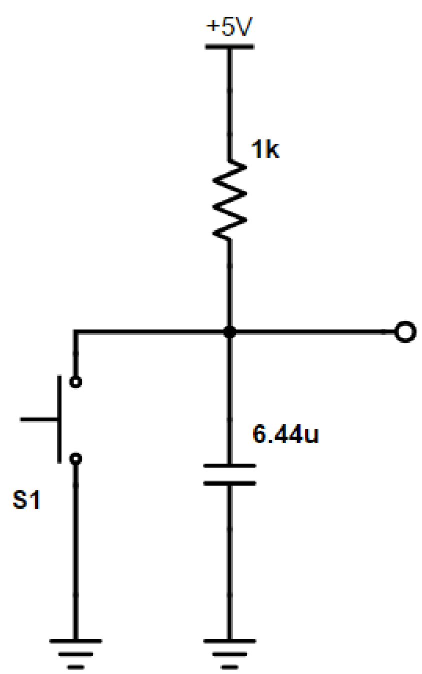

Figure 5: Schematic of the debounce circuit to be used with our switches

2.3.6 Phone App

Although there is a physical interface on the housing unit, this is a second interface between the user and the LED array. It allows for the same control as the physical buttons, but is sent wirelessly via Bluetooth. The app communicates with the smart phone, sending relevant data such as up/down signals to be sent by the Bluetooth transceiver.

The flowchart for the phone app's output signal control code is shown in figure 6 below. The phone app takes in the values for the current color temperature, brightness, and light gradient of the LED array via the Bluetooth transceiver. The output signals that are transmitted to the microcontroller are determined by buttons which will be designed into the phone app that increment or decrement the values of the three array parameters to within a certain minimum or maximum value for each. The flowchart shows the process of running through each signal and checking to see if it should send an increment or decrement command for each parameter and all the signals will be sent as 1 -bit binary.

Input Values:

ct_in : Color Temperature Input
bright_in : Brightness Input
lg_in : Light Gradient Input

App Buttons:

ct_up : Increment Color Temp.
ct_down : Decrement Color Temp.
bright_up : Increment Brightness
bright_down : Decrement Brightness
lg_up : Increment Light Gradient
lg_down : Decrement Light Gradient

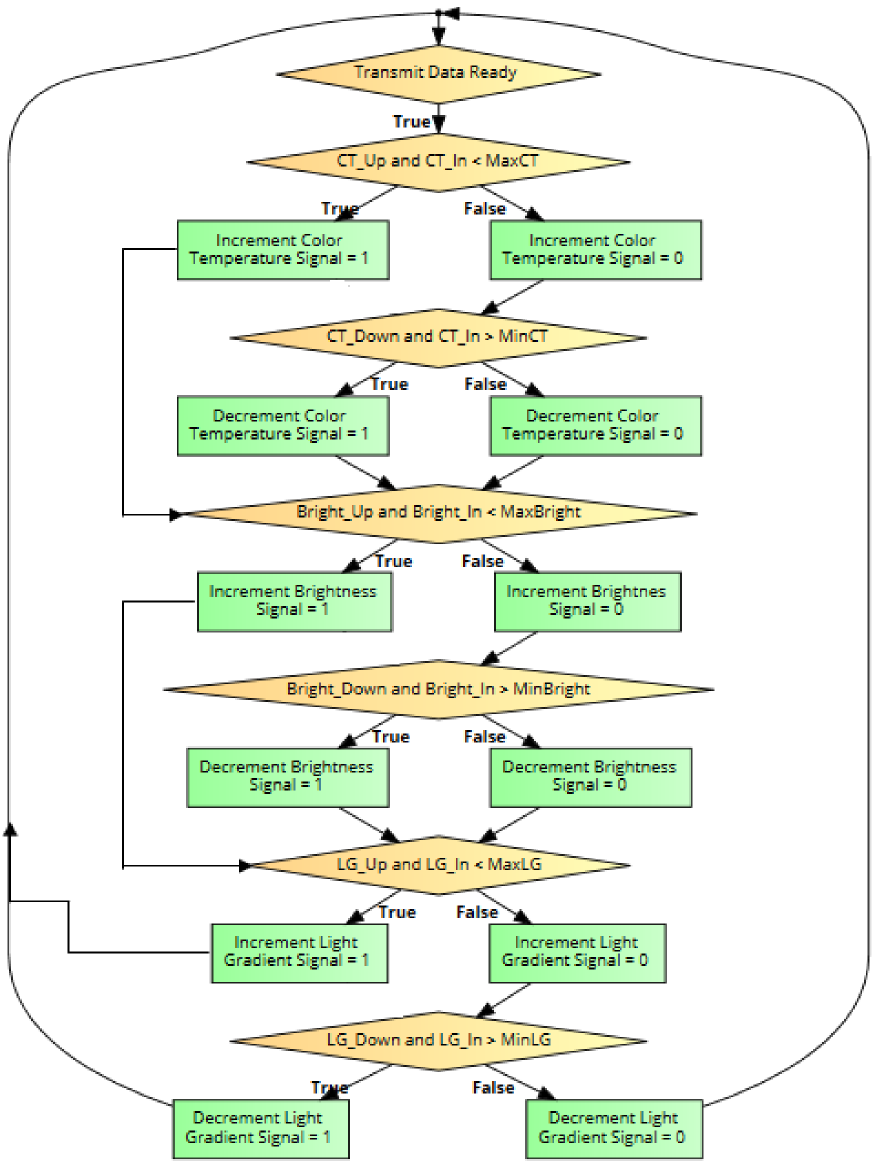

Figure 6: Flow Chart for Phone App Output signal Control Code

Requirements and verifications for the Phone App

Table 6: Requirements and Verification of Phone App

Requirement	Verification
Must be able to receive and display latency of the bluetooth module and color temperature, brightness, and light gradient of the LED array via Bluetooth Points: 5	a. Open app on Android device b. Send signals and check LED array for changes c. Check display to make sure array parameter information is being received and displayed on app

Points: 5/50

2.3.7 Output - LED Array

Input: Each strip receives string of 1984 bits from microcontroller which controls each individual LED in the strip.

Output: N/A, this is the final output of the entire system

The LED array consists of strips of individually addressable RGB LEDs with 8 bits of control for each color. The control input to these strips is provided by the microcontroller, and the power is provided by the power supply module. Each strip in the array is 1m long and contains 60 LEDs.

Requirements and verifications for LED Array

Table 7: Requirements and Verification of LED Array

Requirement	Verification
Color temperature range should be between 3200K-5600K Points: 4	a. Connect an RGB color sensor (Adafruit TCS3472) to an arduino b. Aim color sensor towards LED array and verify color temperature[4]
Maximum brightness of at least 1000 lumens to provide enough lighting for photography Points: 4	a. Use an optical power meter to confirm brightness level
Power consumption of LED array of less than 42W[5] to allow maximum runtime Points: 4	a. Power single LED strip using controlled power source and measure consumption over time b. Multiply power consumption of one strip by number of total strips in array (3)

Points: 12/50

Calculations

To calculate the number of LEDs that our design will require, we first decided upon an optical power that our device should output. We chose approximately 1000 lumens somewhat arbitrarily since typical LED bulbs output about this much light. The LED strip used in our design outputs 14 watts, which is roughly 800 lumens. Since our initial choice of 1000 lumens was somewhat arbitrary, we decided that it was beneficial to overshoot the number of LEDs used in case we undershot the brightness needed for photography. The following calculations calculate the number of LEDs used in our design, and the duty cycle at which they will be run to provide an output of approximately 1000 lumens.

$$\frac{18\text{ watts}}{1000\text{ lumens}} * \frac{\text{LED strip}}{14\text{ watts}} \approx 2 \text{ LED strips (rounded up to 3 to allow for overshoot)} \tag{9}$$

$$\frac{60\ LEDs}{LED\ Strip} * 3\ LED\ Strips = 180\ LEDs \tag{10}$$

$$3\ LED\ Strips * \frac{14\ watts}{LED\ Strip} * \frac{1000\ lumens}{18\ watts} = 2{,}333\ lumens \tag{11}$$

$$\frac{1000\ lumens}{2333\ lumens} = .428 = 43\%\ duty\ cycle \tag{12}$$

Plots

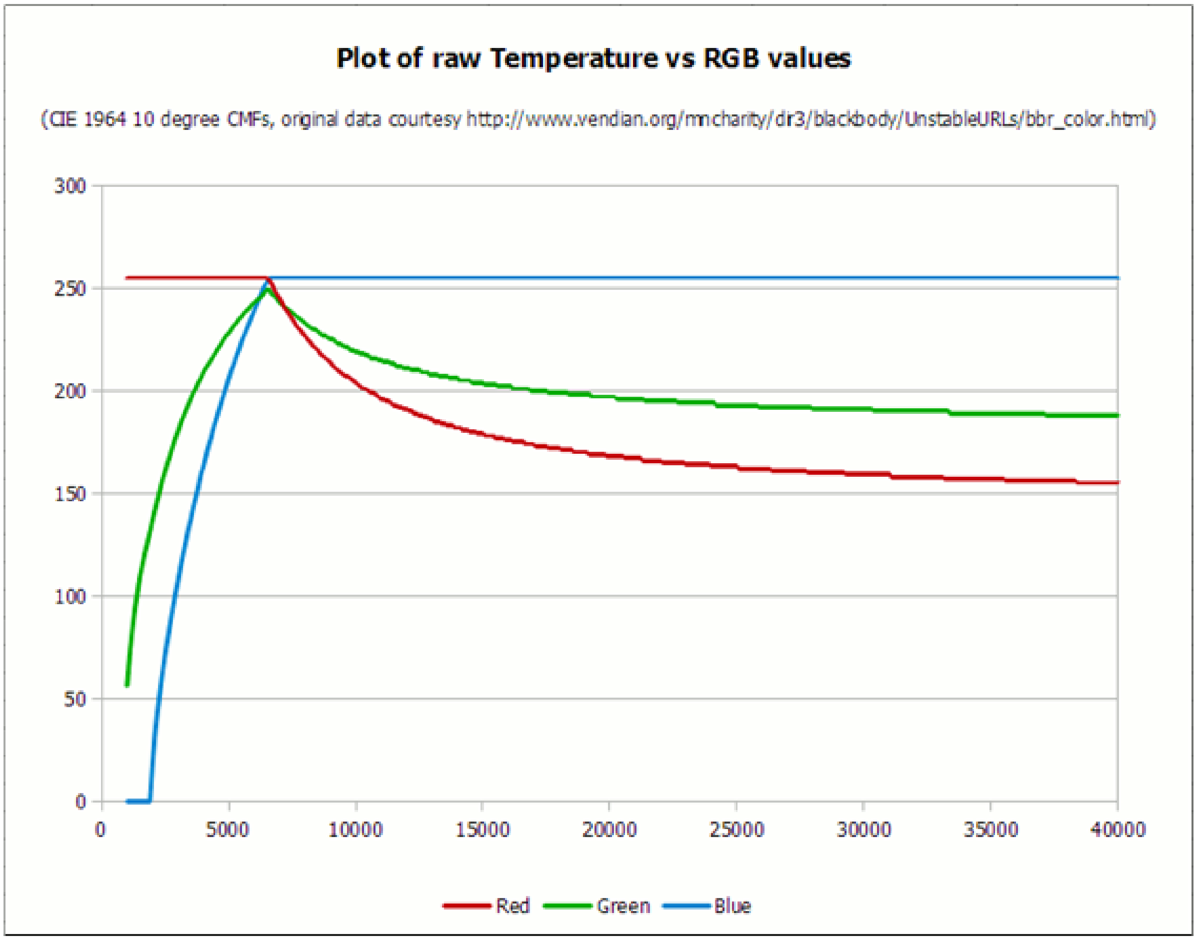

Figure 7: Simulation of RGB values for desired color temperature

Using the pseudocode provided by Tanner Helland [6], we can directly apply his algorithm to generate color temperature from RGB values since his simulation uses RGB values from 0-255, and our design has 8-bit control for RGB channels (8 bits provides 2^8 = 256 values).

2.4 Tolerance Analysis

The riskiest part in our entire design is the Li-Ion batteries, however, each cell contains a built in PCB protection circuit. It is critical that these specific batteries be used if they are to be changed in the future. Since the batteries are protected, the next most critical component in our design is the voltage regulator. Not only does it ensure that the Li-Ion battery does not discharge too much current and begin thermal runaway, but it also ensures that Bluetooth, microcontroller, and LED array all operate within their recommended voltage ranges. The voltage regulator used in our design is the LTC3785 which will provide a voltage boost from our 3.7V Li-Ion battery to the desired 5V output for all other devices. The device itself contains a current limit, short circuit protection, and overvoltage protection, all which ensure the safety of the devices connected to it.

Because the operating voltage ranges for each component are different, we decided to limit the range of the voltage regulator to ±10%. This window stays between the 2.3-7.0V range of the Bluetooth module, the 1.8-5.5V range of the microcontroller, and the 4.5-5.5V range of the LED strip.

Our choice of voltage regulator was determined mostly by the current drawn by the LED array. Since each strip pulls 2.88A, we needed to find a suitable regulator that was capable of outputting at least 8.64A at the desired voltage of 5V. Our regulator is capable of a wide range of input and output voltages (2.7-10.0V), and has a maximum output current of 10A, making it an ideal candidate for our design. The chip simply requires certain exterior circuitry to tune the output voltage to a desired level.

To achieve an output voltage of 5V, the feedback pin on the device must have a resistor network connected to it following equation 13:

$$Vout = 1.225V \frac{R1 + R2}{R2} \tag{13}$$

To make the calculations simple, let us set R2 to be 10kΩ. For an output voltage of 5V, R1 would have to be 30.8kΩ. If we allow for a 5% tolerance on the resistor values, using 30kΩ and 10kΩ, the following table shows that even if both resistors are off by 5% either way, the output voltage remains within 4.5V-5.5V.

Table 8: Output voltage with R1 and R2 off by ±5%

R1	R2	Vout
30kΩ	10kΩ	4.9V
28.5kΩ	9.5kΩ	4.9V
31.5kΩ	9.5kΩ	5.29V
31.5kΩ	10.5kΩ	4.9V
28.5kΩ	10.5kΩ	4.55V

3. Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

Table 9: Labor Cost Analysis

Name	Hourly Rate	Hours Worked	Total	Total x 2.5
Abizer Daud	$30	240	$7,200	$18,000
Michael Miwa	$30	240	$7,200	$18,000
Thomas Winter	$30	240	$7,200	$18,000

Total Cost for labor: $54,000

3.1.2 Parts

Table 10: Parts Cost Analysis

Part	Description	Manufacturer	Part Number	Quantity	Cost/unit
Bluetooth Module	Interface between phone application and microcontroller.	JNHuaMao Technology Company	HM-10	1	$10.90
Microcontroller	Central Processor controlling LED array output	Atmel	ATmega 328P-PU	1	$2.08
LED strip	Addressable LED strip of 60 LEDs	iPixel LED Light Co., Ltd	APA102C	3	$15.95
Li-Ion Battery	18650 Rechargeable Li-Ion Cell	Samsung	FB-18650P-2600	6	$8.23
Control Buttons	Buttons that control Color Temperature, Brightness, and Gradient Positioning	Lamb Industries	TL3300CF160Q	6	$0.50
Voltage Regulator	Boosts and regulates voltage output to other components	Linear Technology	LTC3785	1	$4.24
Battery Charger	Recharges Li-Ion Batteries	Battery Space	CH-L3718	1	$16.95

Total Cost for parts: $126.17

3.1.3 Total Cost

Table 11: Total Cost

Section	Cost
Parts	$134.43
Labor	$54,000
Total	$54,134.43

3.2 Schedule

Table 12: Schedule

Week	Abizer Daud	Michael Miwa	Thomas Winter	All
2/27	Research writing phone apps	Purchase Bluetooth module	Purchase Microcontroller (MC)	Design Review (Tue)
3/6	Begin writing phone app	Test Bluetooth module	Research and begin programming MC	Soldering Assignment Due (Fri)
3/13	Work on PCB design for debouncing circuits	Work on PCB design for Voltage Regulator (VR)	Work on PCB design for MC	Order LED strips and remaining components
3/20	Spring Break	Spring Break	Spring Break	Last Day for First Revision of PCB (Wed)
3/27	Test Phone app connection with Bluetooth module	Work on connecting Bluetooth and phone	Begin connecting Control Buttons and MC	Individual Progress Reports (Mon) Last Day for Revisions to the Machine Shop (Tue)
4/3	Begin testing R&Vs	Begin testing LED array	Begin Testing battery functionality	Last Day for Revised PCB (Mon)
4/10	Begin connecting VR to necessary devices	Connect LED array to MC	Test Functionality of MC with other components	N/A
4/17	Debug	Prepare presentation	Prepare for Demo	Mock Demo
4/24	Begin Final Report (Phone app, Debouncing)	Begin Final Report (Bluetooth, LED strips)	Begin Final Report (MC, Battery)	Demo and Presesentation
5/1	Finish Final Report (Phone app, Debouncing)	Finish Final Report (Bluetooth, LED strips)	FinishFinal Report (MC, Battery)	Final Papers Due Lab Notebook Due

4. Ethics and Safety statement

The biggest safety concerns for our project lie with including a lithium-ion battery. Due to the high energy density of lithium-ion cells, a failure can be very energetic. The battery must be protected from short circuiting, overheating, overcharging, and physical damage. [7] This will require temperature detection, charging/power circuitry that prevents the voltage and current from exceeding safe levels, and careful design of the housing for the battery cells. The safe practice for lithium batteries can be found at the following link. [8] https://courses.engr.illinois.edu/ece445/documents/GeneralBatterySafety.pdf

We also need to take into consideration the effect that flashing lights can have on people such as those prone to seizures. Frequencies between 5-30 Hz are the most dangerous. [9] Any PWM control or large color changes must stay outside of this range.

One ethical issue that we might run into is unintentionally copying the design of an existing product. There are many designs already for battery powered LED lights. We must do research as we go to prevent our final design suffering from intellectual property issues as per part 9 of the IEEE code of ethics which says “to avoid injuring others, their property, reputation, or employment by false or malicious action.” [10]

We must also be responsible in developing the mobile device software. Accessing only what is necessary on a device is important to the security of the user. Part 1 of the IEEE code of ethics instructs “to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment.” [10] We will develop software such that we don’t provide a way for somebody with malicious intent to access sensitive information.

5. Citations

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