LED Lighting for Photography

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Abstract

The purpose of this project is to create a lightweight, cordless, and programmable 2-D LED array, which will allow the user to control the array's brightness, color temperature, and light gradient. The device is operated by using either the physical push buttons located on the back of the housing or by using a smartphone app that controls the three array parameters using slide bars. The current values of the three parameters are sent back to the phone app and displayed on the screen to show the user the current state of the array. Our finished product is a fully functional LED array and smartphone app that provide simple control and accurate information to the user.

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1. Introduction

The industry of photography has an immense market and provides information about products that cannot always 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.

In the following chapters, we will present the overall system design, break down the design into its individual modules, explain each module's purpose and design, and summarize the cost of parts and labor for designing and building our device. We will show that our design meets all requirements that were set out at the beginning of the design process and explain the procedures for verifying each of those requirements.

1.1 Objectives

- Our design requires a cordless power source capable of lasting up to 1 hr
- The LEDs must be bright enough (at least 1000 lumens) to provide sufficient lighting for photography
- The LEDs must span a color temperature range between 1500 K-7850 K
- The LEDs must have a controllable gradient position (or no gradient at all)

2. Design

The overall design of our device is shown in Figure 1, breaking down our design into four main modules: Power Supply, Bluetooth, Control Unit, and Output. Each module has its own set of requirements and verifications which are all listed in Appendix A, but a brief description for each module and submodule is provided in this chapter, along with any design details.



2.1 Power Supply

The power supply module is broken down into two sub-modules, the lithium ion batteries/charger and the voltage regulator.

2.1.1 Li-Ion Batteries/Charger

We chose the Tenergy 18650 lithium ion batteries due to their rechargeability, high capacity, and high discharge current. Each cell (eight in total were used) has a capacity of 2600 mAh and has a standard discharge rate of 0.5 C up to a maximum of 1.5 C. This translates to a standard current rating of 1.3 A and maximum of 3.9A as shown in equations 1 and 2. Another reason for selecting these specific batteries was each cell is individually protected from overcharge and overdischarge by a protection circuit board (PCB) on the ends of the battery. The protection circuit allows each cell to charge up to 4.35 V and discharge to 2.5 V. Once either of these values is reached, the circuit cuts off the power to the cell until the voltage has settled to 4.2 V or risen to 3.0 V.

$2600 \text{mAh} \times 0.5\text{C} = 1.3 \text{ Amps}$	(1)
$2600 \text{mAh} \times 1.5\text{C} = 3.9 \text{ Amps}$	(2)

By combining eight of these cells in parallel, we were able to adequately power the entire system at max current draw of each device. Equation 3 shows the minimum power rating of the battery, assuming an 80% efficient voltage regulator. Equation 4 shows the maximum current drawn from the battery assuming the power rating of Equation 1 and the voltage of the batteries at their minimum 3.0 V. Equation 5 calculates the number of cells needed assuming the cells discharge 1.0 C which is above their average discharge rate, yet still safely within their rated maximum discharge rate. The 7 cells calculated in this equation was rounded up to 8 to lower the discharge current needed from each cell and to ease the packaging of the batteries.

Minimum power rating (in watts):

 $\frac{5 \text{ V}(32.88 \text{ A} + 0.04 \text{ A} + 0.05 \text{ A})}{80\% \text{ efficiency}} = 54.5625 \text{ Watts} \quad (3)$ $\frac{54.5625 \text{ W}}{3.0 \text{ W}} = 18.1875 \text{ Amps} \quad (4)$ $\frac{54.5625 \text{ W}}{3.0 \text{ V}} = 18.1875 \text{ Amps} \quad (4)$ $\frac{18.1875 \text{ Amps}}{2600 \text{ mAh} \times 1.0 \text{ C}} \cong 7 \text{ cells} \quad (5)$

The charger used in our design is a 3A Li-ion charger that cuts off the charging current when the cells reach 4.2 V. This part was not explicitly designed by our group, but chosen because it met safety requirements and had the highest charging current for a reasonable price.

2.1.2 Voltage Regulator

The voltage regulator was designed with two parameters in mind, boosting the 3.7 V of the lithium ion batteries to 5 V, and providing the output with a voltage between 4.5 V and 5.5 V regardless of the current draw from the devices that it powers. The IC (LTC1871) that runs the whole circuit of the voltage regulator is a switching regulator, which was chosen because its higher efficiency was desirable for our high current draw from the LEDs.

The skeleton of the circuit used in our voltage regulator was found in the datasheet of the LTC1871, however, a few changes were needed for the regulator to support our required current draw. As seen in Figure 2, there are two MOSFET transistors in parallel rather than the one in the original circuit. During our testing of the regulator, it was seen that a single transistor could not carry the total current drawn from the circuit. Therefore, a second MOSFET transistor was added in parallel and heat sinks were attached to both transistors to help lighten the load on each device. In addition to the extra transistor, extra energy storing elements were added to the design so that the regulator could sustain the output voltage requirements even with higher current draw. Three inductors totalling 5.5 μ H were used in series, replacing the single 1 μ H inductor from the original design, as well as two additional capacitors totalling 550 μ F were added in parallel to the output. Lastly, the frequency pin resistor was changed from 80.6 k Ω to a 10 k Ω resistor in series with a 100 k Ω potentiometer so that the frequency of the LTC1871 could be fine tuned to an ideal value.



Figure 2: Voltage Regulator Schematic

2.2 Bluetooth Module

The Bluetooth module consists of the mobile phone application designed in Android Studio and the HM-10 Bluetooth low energy module.

2.2.1 Mobile Phone App

The smartphone app runs on Android devices and was created using Android Studio. The app controls the brightness, color temperature, and light gradient of the LED array using slide bars on the user interface as shown in the design views of the app in Figure 3. The progress of the slide bars is used to format the output string which is sent to the Bluetooth module and then to the microcontroller to change the specified parameter of the LED array. Every time an array parameter is changed a 32-bit message is sent by the phone app to the Bluetooth module. The message is broken up into 4 bytes where the first byte signals the microcontroller that a new message has come in. The second byte contains the light gradient information and uses all 8 bits in the byte to represent the 242 different gradient values in the output string. The third byte contains the brightness information and uses the least significant 5 bits in the byte to represent the 32 brightness levels. The three most significant bits in the third byte are hard coded to 111. The fourth byte contains the color temperature information and uses all 8 bits to represent the 255 different values of color temperature that ranges from 1500K-7850K.

The phone app is also capable of receiving data from the microcontroller through the Bluetooth transceiver, and this data is in the same 32 bit format as the output string. The one difference in this string is that the sixth least significant bit in the byte that has the brightness information is actually used to indicate whether the battery level is low by reading as a 0 for low or a 1 for normal. The received data is used to relay the current state of the array from the microcontroller and change the slide bars positions and display values so that the user can see the real-time values of the brightness, color temperature, and light gradient of the LED array. In addition, the latency, which is the time it takes for data to be sent to the microcontroller and the updated data to be sent back to the phone app, is calculated using the latency button and displayed on the user interface.

	7:00		Saving screenshot	
LED Control			CELE LED Light	DISCONNECT
Output String:	DipitSt		Output String: 0x000	7EA3B
Bluetooth: Disconnected	Bitetoota:		Bluetooth: Connected	l
Input Data: No data	hpit Data		Input Data: 0x003BEA	07
Brightness:		Brigitaess	 Brightness:	10/31
Color Temperature:		Color Temperature 1	Color Temperature:	2950K / 7850K
Light Gradient:		Lig it Gradie it	Light Gradient:	7 / 242
Latency		LATENCY	Latency 6.3	47631 ms
V Item 1 Sub Item 1			Unknown serv	vice -8000-00805f9b34fb
Litem 2 Sub Item 2			A HM-10 Service	2 3000-00805f9b34fb
			LED Light 0000ffe1-0000-1000-8	8000-00805f9b34fb

Figure 3: The display view, schematic view, and real-time view of the app (from left to right respectively)

2.2.2 Bluetooth Transceiver

The HM-10 Bluetooth transceiver was chosen for the ability to both receive and send data while consuming low power. The radio is designed to spend nearly all of the time in power-down mode drawing a negligible current and even in active transmit mode it draws a low peak current of 50mA. [2]



Figure 4: Schematic of Bluetooth connections

2.3 Control Unit

The control unit consists of the Atmega 328P microcontroller and the physical control buttons on the housing along with their debounce circuits.

2.3.1 Microcontroller

We chose the Atmega 328P microcontroller due to its availability in a DIP form factor, low power consumption, and the large amount of information regarding its use since it is the microcontroller used in the Arduino. The microcontroller coordinates input from the buttons and information flow between itself and the Bluetooth module. It then uses that input to determine what data should be sent to the LEDs.



Figure 5: Schematic of connections to microcontroller

2.3.2 Control Buttons

Our design includes 3 pairs of buttons on the light to adjust color temperature, gradient position, and brightness up or down. The buttons are connected to an RC debouncing circuit to prevent any bounces from affecting a smooth transition within 5ms of initial contact.



Figure 6: Schematic of debounce circuit

2.4 Output LEDs

We chose the APA102 LED Strip for our design because it is an individually addressable chain of RGB LEDs with control of the brightness and the red, green, and blue channels of each LED. We were able to achieve the required 1,000 lumens by connecting three of these strips in parallel, and by manipulating the color channels we were able to adjust color temperature of the LEDs by following the conversion shown in Figure 7. The input of each LED strip is a power line from the voltage regulator, a clock signal from

the microcontroller, a data signal from the microcontroller, and ground. The data signal from the microcontroller is a string of 1984 bits, with the data for brightness, red, green, and blue channels for each LED with four bytes of leading zeros and four bytes of trailing ones.



Figure 7: Graph [3] showing conversion of 8 bit RGB values to color temperature

3. Verification

This chapter will describe the process of verifying all the requirements that we placed on each module or submodule. Appendix A contains the original R&V table with all changes made since the design review.

3.1 Power Supply

3.1.1 Li-Ion Battery

To verify the battery, we first charged it until the protection circuits cut off current from the power supply. The now fully charged battery was put under load and the current and voltage were measured in 3 minute intervals. When the battery was fully discharged, the protection circuits were verified to again cut off current through the cells. The data while discharging was then used to calculate and verify that the battery has sufficient capacity as shown in Figures 8 and 9.

The last step we did to verify the battery satisfies our requirements is connect it to a load and increase the current draw through the load until it consumed at least 55 W of power.





Figure 9: Voltage, current, and accumulated energy measurements under load 2

3.1.2 Voltage Regulator

The requirement that we placed on the voltage regulator was that the output voltage stay between 4.5 V and 5.5 V up to the max current draw of the device. Shown in Figure 10 is a plot of the output voltage with respect to the brightness setting (brightness ranged from 0 to 31, with 31 being 100% brightness). The process for collecting this data was to power on the light, connect to the smartphone app, connect a



voltmeter to the output of the voltage regulator, and then set the brightness to each level and record the data.

Figure 10: Graph showing that the output of the voltage regulator stays within the required 4.5-5.5V range up to max brightness of the light

Brightness

20

25

30

35

15

3.2 Bluetooth Module

4.5

4.4

0

3.2.1 Mobile Phone App

5

10

We verified that the phone app satisfied the requirement of being able to display the changing state of the light by connecting the app and changing the LEDs with the physical buttons on the housing for each parameter. The sliders on the phone app changed position to correctly match the state displayed on the light. Then to verify latency, the phone app has a function that measures the round-trip time from when it sends a state update to the light until the app receives the updated state echoed back.

3.2.2 Bluetooth Transceiver

The four requirements that we placed on the Bluetooth module were 1.) ability to connect to the smartphone app from a distance of at least ten meters away, 2.) send and receive signals from the app with a latency of under 1/60th of a second, 3.) send data to the microcontroller at a speed of at least 0.036kbps, and 4.) return data from the microcontroller to the app about current state of the light.

Verifying all four of these requirements is possible in one test. The setup for this test is to connect an oscilloscope to the receiver pin of the Bluetooth module to display the data speed to the microcontroller. The rest of the requirements can be verified by connecting the app, walking ten meters away, and sending data from the app. The latency of the Bluetooth transceiver is calculated within the code of the app, and the fourth requirement is verified by pressing the buttons on the light and confirming that the sliders are updated on the app. Our tests showed that the Bluetooth module was able to send 32 bits within 367.9µs, and Equation 6 shows that this speed is clearly greater than necessary for our requirement.

$$\frac{32 \text{ bits}}{367.9 \text{us}} = 86.98 \text{kbps} >> 0.036 \text{kbps} \quad (6)$$

3.3 Control Unit

3.3.1 Microcontroller

To verify that the microcontroller meets the requirements we first checked the datasheet of the 328P to show that it had enough storage for the color temperature data as well as the program. The 32 kB of flash on the 328P is well over the required 1020 bytes. Then we measured the maximum oscillation speed of its logic pins by connecting the oscilloscope to the toggling pin and measuring the frequency. The 5 MHz we measured is shown in Figure 11.

MSO-X 6004A, MY54390377: Tue Apr 18 09:25:53 2017



Figure 11: Oscilloscope measurement of maximum pin toggle speed

3.3.2 Control Buttons

The control buttons had a single requirement, which was that there be no bounces in the signal within five seconds of the original contact. To verify this, we connected the output of the buttons to an oscilloscope and showed that to get to a logic "1" value, which is a voltage of 2.7 V, it takes at least 9ms. Figure 12 shows the oscilloscope reading showing this verification.



Figure 12: Oscilloscope reading of the debounced buttons

3.4 Output LED Array

The LED array has three requirements: 1500K-7850K color temperature range, 1,000 lumens max brightness, and a maximum of 42W power consumption. To verify the color temperature range, we performed a visual comparison of the light at its minimum and maximum color temperature settings to Figure 13.



Figure 13: Color temperature scale against which we compared our light

Verification of the brightness of the light required a lux meter; we used the Adafruit RGB Color sensor 1334. By connecting this device to an Arduino Uno, we were able to see a live feed of the lux. To convert lux to lumens, we multiplied by the apparent size of the light which we calculated to be 5 cm by 1 m. This required the light to produce 20,000 lumens, and at max brightness it was able to output over 21,000 lux.

Lastly, to verify the power consumption of the light, we simply connected a current probe to the power input, connected a voltmeter across the power input, and turned the light to max brightness. Equation 7 shows the max power consumption of the LEDs to be lower than the requirement.

6.43 A * 4.5 V = 28.9 Watts < 42 Watts (7)

4. Costs 4.1 Parts

Part	Manufacturer	Part Number	Cost/Item (\$)	Quantity	Actual Cost (\$)
3A Li-ion Charger	AA Portable Power Corp.	CH-L373	24.95	1	24.95
LED RGB Strip	iPixel LED Light Co.	COM-14015	15.95	3	47.85
Atmega328P Microcontroller	Atmel	328P-PU	2.14	2	4.28
18650 Li-ion cell 4- pack	Tenergy	39170	33.99	2	67.98
18650 Heat Shrink	uxcell	a15012900ux0399	6.86	1	6.86
18650 Solder Tabs	Geilienergy	STL50N	7.99	1	7.99
20 MHz Crystal 8- Pack	uxcell	a14030700ux0673	2.63	1	2.63
150uF Ceramic Capacitor	Taiyo Yuden	JMK325ABJ157MM -T	1.17	4	4.68
Shottky Diode	ON Semiconductor	MBRB2515LT4G	2.2	1	2.20
22kΩ SMD Resistor	Panasonic	ERJ-12ZYJ223U	0.27	1	0.27
12.1kΩ SMD Resistor	Panasonic	ERJ-12SF1212U	0.39	1	0.39
6.8nF SMD Capacitor	TDK Corporation	C1608C0G1E682J08 0AA	0.27	1	0.27
Voltage Regulator	Linear Technology	LTC1871	6.19	1	6.19
Voltage Regulator Breakout Board	Chip Quik Inc.	IPC0077	5.79	1	5.79
RGB Color Sensor	Adafruit Industries	1334	7.95	1	7.95
N-Channel MOSFET	Fairchild/ON Semiconductor	FDP6030BL	1.29	2	2.58
1.5uH Inductor	Sumida America Components	CEP125NP-1R5MC- D	2.66	1	2.66
2uH Inductor	Eaton	HCV1206-2R0-R	3.53	1	3.53
3uH Inductor	EPCOS/TDK	B82559A302A13	3.57	1	3.57
37.4 k Ω Resistor	Yageo	MFR-25FBF52-37K4	0.1	1	0.10
Push Buttons	E-Switch	PS1040ABLK	1.7	6	10.20
Power Switch	Judco Manufacturing INC	40-4520-00	1.3	1	1.30
Total					213.95

Table 1: List of parts, their manufacturer, cost, and quantity purchased

4.2 Labor

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

 Table 2: Labor Cost Analysis

Total cost for labor: \$54,000

5. Conclusion

5.1 Accomplishments

Our finished LED array was able to reach all of the initial goals we set out with. The user can easily control the brightness, color temperature, and light gradient of the array using either the push buttons located on the back of the housing or by using the slide bars located in the user interface of smart phone app that controls the array over Bluetooth. The array is very lightweight and very portable using the handles making it ideal for photographers who want to use it in the painting-with-light method. Also, the rechargeable lithium-ion batteries make the array cordless and have a very long usage time of over an hour when the batteries are fully charged. The phone app is also able to accurately receive and display the values of the current state of the three lighting parameters from the microcontroller so the user can adjust or verify as needed.

5.2 Uncertainties

The biggest uncertainty in the project is a bug in the smartphone app that seemingly occurred randomly when changing the three controllable light parameters. Sometimes when changing the brightness, color temperature, or light gradient on the app using the slide bars, the other two parameters that were not being changed would jump to different values. Although it happened very sparingly, it could still disrupt a photographer's shot and be an annoyance.

5.3 Future work

In the future, we would like to add an RGB control feature on the phone app to add more functionality to the array by allowing the light to change to any color in the visible spectrum outside the color temperature range that we specified. This would allow the user to make custom colors which can be used for applications other than photography. We could also add optional full spectrum LEDs for general lighting purposes. Another improvement we would like to make is to the voltage regulator so it can handle higher current draw which will allow for an increased maximum brightness. Currently, the voltage regulator does not allow close to the rated current it should be able to, but it is still serviceable at the brightness levels our design uses. Also, a stable reference voltage for the low battery indicator would be ideal, and we could also add additional references so that we can display different battery percentages to the user.

Appendix A: Requirements and Verifications Strikethroughs and words in red signify changes to the original requirement and verification table from the design review.

Requirement	Verification
Must consistently provide safe power as defined in the Safe Practice for Lead Acid and Lithium Batteries [4]	 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	 a. Calculate maximum current draw from the devices connected to the voltage regulator a. Calculate maximum current used by 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 c. Attach an equivalent load at the output of the battery 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	 a. Open battery compartment and remove and reattach battery a. Open housing and remove old battery and reattach battery
Must be at least 55Wh capacity to provide power for at least 1 hour	 a. Power on light b. Set light to full brightness c. Wait 1 hour to verify light is still operating at end of hour a. Connect fully charged (4.2V) battery to load drawing no more than 10.4A b. After 1 minute of discharging, record current draw and voltage at battery terminals every 3 minutes c. Stop recording when battery reaches 3V or when 55Wh of energy has been used

Table 3: Requirements and Verification of Li-Ion Battery

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

Table 4: Requirements and Verification of Voltage Regulator

Requirement	Verification
Must be able to change logic pins at a rate of at least 24 kHz	 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 a. Program logic pin to oscillate at max frequency b. Connect oscilloscope to logic pin on microcontroller c. Check frequency of signal to verify a frequency of at least 24 kHz
Must contain 1152 1020 bytes of storage for color temperature information in addition to rest of program	a. Check datasheet for microcontroller to verify storage space is large enough for program plus 1152 1020 bytes

Table 5: Requirements and Verification of Microcontroller

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	 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 microcontroller to provide accurate information to the app	a. Connect module to smartphone and transmit stateb. Check phone app to verify that states are being relayed back from microcontroller

Table 6: Requirements and Verification of Bluetooth Module

Table 7: Requirements and	Verification of Control Buttons
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Requirement	Verification
The buttons paired with the debouncing circuit should not have any bounces within 5ms	a. Probe the circuit and use the oscilloscope display to show a 5ms period after the button is pressed to verify no bounces

Table 8: 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	 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

Requirement	Verification
Temperature of LED strips must stay between -40° and 40°C to ensure proper functionality	a. Use a temperature sensor to measure temperature of the devices
Color temperature range should be between 3200K-5600K with a resolution of 50K Color temperature range should be between 1500K-7850K with a resolution of 25K	 a. Connect an RGB color sensor (Adafruit TCS3472) to an arduino b. Aim color sensor towards LED array and verify color temperature a. Change color temperature using the phone app and check display for current temperature b. Visually compare to a color temperature reference
Maximum brightness of at least 1000 lumens to provide enough lighting for photography	 a. Use an optical power meter to confirm brightness level a. Use a lux meter to confirm brightness level b. Confirm that light achieves at least 20,000 lux at surface of diffuser (20,000 lux * .05m * 1m = 1,000 lumens)
Power consumption of LED array of less than 42W[5] to allow maximum runtime	 a. Power single LED strip using controlled power source and measure consumption over time by measuring output current and voltage b. Multiply power consumption of one strip by number of total strips in array (3) a. Power all three LED strips using power supply and use multimeters to obtain the current draw and voltage to calculate power

Table 9: Requirements and Verification of LED Array

References

[1] "Industry statistics, advertising, Branding & marketing business statistics analysis - Plunkett research, Ltd," in Plunkett Research, Ltd., Plunkett Research, 2015. [Online]. Available: http://www.plunkettresearch.com/statistics/advertising-branding-industry-market-research/. Accessed: Feb. 9, 2017.

[2] "The pros and cons of Bluetooth Low Energy" Electronics Weekly, 2014. [Online]. Available: https://www.electronicsweekly.com/news/design/communications/pros-cons-bluetooth-low-energy-2014-10/. Accessed: Mar. 2, 2017.

[3] T. Helland, "How to convert temperature (K) to RGB: Algorithm and sample code," in tannerhelland.com, 2012. [Online]. Available: http://www.tannerhelland.com/4435/convert-temperature-rgb-algorithm-code/. Accessed: Feb. 18, 2017.

[4] "Safe Practices for Lead Acid and Lithium Batteries", ECE 445 Spring 2016 Course Staff, 2016. [Online]. Available: https://courses.engr.illinois.edu/ece445/documents/GeneralBatterySafety.pdf. Accessed: Feb. 24, 2017.

[5] "SK9822/APA102--Addressable LED Strip 1 Meter with 60pcs LEDs," in iPixel LED Light Co., Ltd. [Online]. Available: http://cdn.sparkfun.com/datasheets/Components/LED/S60102.pdf. Accessed: Feb. 18, 2017.