LED PAINTING DEVICE

By

Pablo Stantolaya

Yangyang Wang

Yangkanghong Qu

Final Report for ECE 445, Senior Design, Spring 2017

TA: Daniel Gardner

03 May 2017

Project number:36

Abstract

The problem is that currently there is no effective way for a photographer to perform LED painting art. The only option out there are large, expensive, not customizable, and not portable light boxes. The size of the equipment could become a problem for when the surrounding environment has limited space like a garage. Also since light diffuses having a large light box in bringing in unnecessary noise light which defeats initial intention of the photo [2]. In addition, not being able to customize the lighting luminosity and area is a hindrance to the amount of detail that 20

photographers and work on, and creates noise lighting. Moreover, they are expensive and hard to move around so this could prove to be a problem for many indie or less renowned photographers. Our new design changes all of this. It is small, portable, customizable, inexpensive, and most important of all doesn't create any noise lighting. Our light will be small enough to be carried around by hand, cheap to make and purchase, highly customizable to control how much of the light is on or off. It will even can create a light gradient which can also be controlled to how fast the fade would be, if it is fading from top to bottom, bottom to top, from the middle outwards, or from the sides to the middle. The fading is important because the photographer needs to be able to control the light intensity to bring out curtain aspects of the picture. For example, in picture one there are many curves and edges in the car so to create a smooth looking picture the photographer will need a fading effect on the light to create the effect. Our light will also be able to store and return to the previous exact setting so that incase that the power supply fails in the middle of a shot the photographer can return to the exact same lighting settings.

Contents

1.Introduction

Light painting isn't a new idea that people just came up with, it dates to 1889 when Etienne-Jules Marey and Georges Demeny traced human movement with this technique. However ever since this concept has only been previously used to create the effects of writing out letters with pixie sticks (a type of firework), stretching our street lights, much like what Marey and Demeny did back in 1889. This concept of light painting was always used in the mentality of capturing radiating light, but never was it used to project directed light off an object to create a photo that is much more vibrant and crisp than traditional methods due to the cancelation of noise lighting. The old way of light painting is to project light into the camera to create and effect, but this new method is to reflect the light off an object to a certain degree it is a completely new technique for the photography industry. Now there are many photographers experimenting with this idea to create visually stunning works of art like the figure show below. Due to the limited time since this technique has been used and accepted, there are no products like ours available making it more necessary for us to create this design. The photo was created using a regular long ceiling light and the luminosity of the light was controlled by the photographer coloring a translucent film in black to block the light. So, we do not have any competitors, if any it would be the homemade ceiling light create by a photographer named Rick Kessinger.

Figure 1: The picture from Kessinger gallery

2 Design

The LED light that we built will required of three part to successfully work: a power supply, a control unit and the actual LEDs. The power supply ensures that the light can be powered continuously throughout a normal photo shoot at 13.8V. The control unit contains a microcontroller to manipulate the LEDs in the different modes as well as the positioning of the reference for the dimming of the lights, having all this control by 3 different potentiometers.

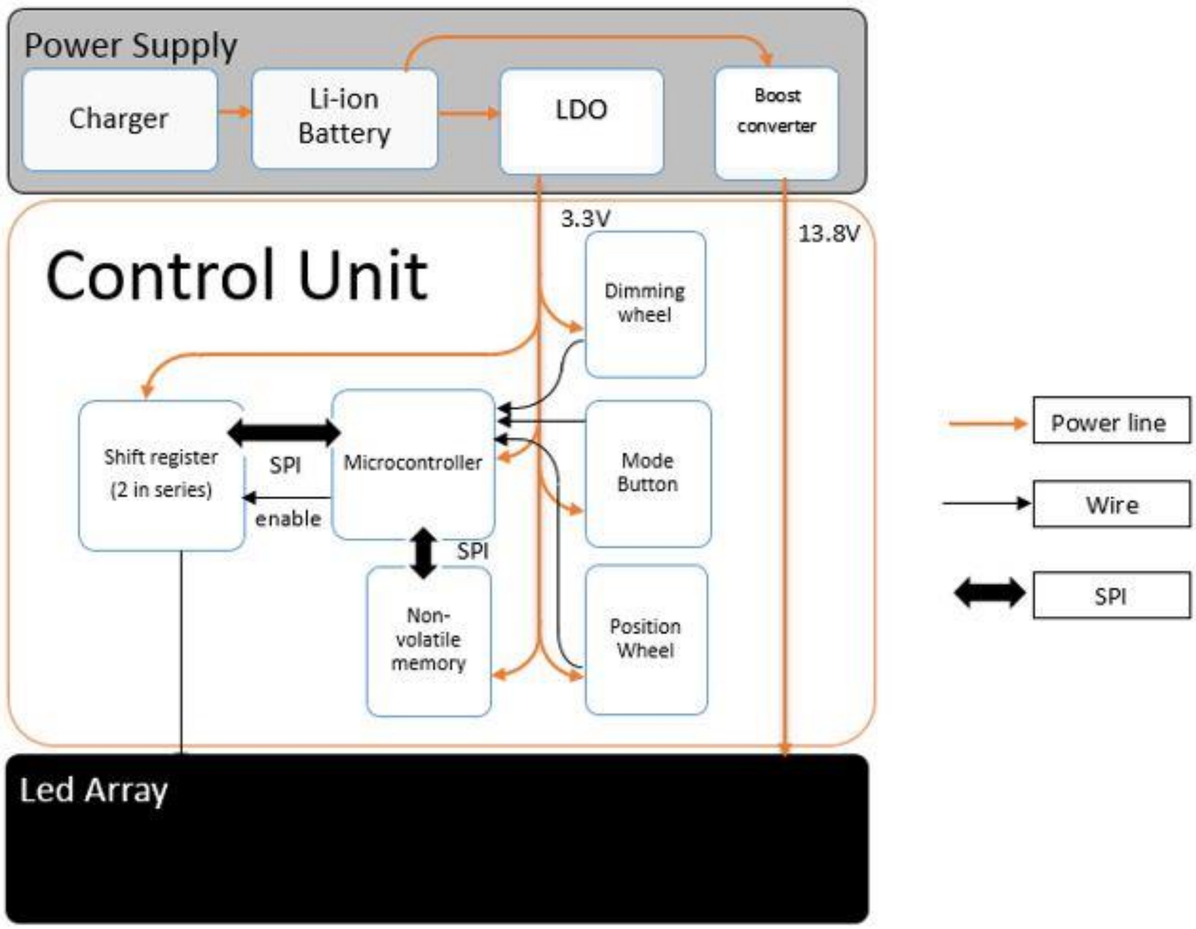

Figure 2: the overall block diagram of the design

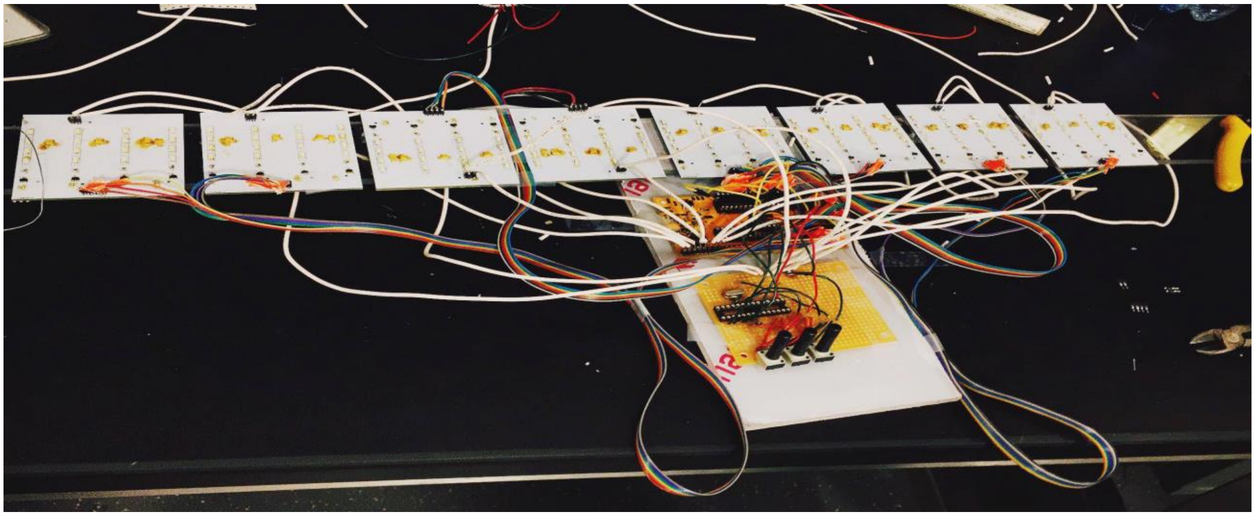

Figure 3: Implementation

In this picture, we can see our entire system implemented. Our LEDs PCB consist of 4 of them connected in series with a transistor and a resistor to control the current going through the LEDs. Eight of them are then put together to form the LED array. The control unit board is on the side of the device together with the power unit in in the same PCB board. We had to add a proof board to the design to build in the user interface and the microcontroller due to bad connection made during our design.

2.1 Power Supply Unit

The power supply provides stable power for the LED-lighting device. The charger supplies the Li-ion battery with stable DC power. In turn the later powers both to the control board and to the LED arrays. Having 32 rows of 4 LEDs in series each (20mA per row) we have a power consumption of around 640mA. As for the control board, our power budget will be of around 200mA at 3.3V.

Other alternatives were considered. Our previous design consisted of 14.8 Li-ion batteries that supplied the control unit at 3.3V through a buck converter and a LDO to provide power to the LEDs at 13.8V. This approach was then dropped due to efficiency issues since the LDO, a linear regulator has low efficiencies compared to a switching power converter and it was not idea to use it were our main part of the power was being consumed, per our estimations it would have dissipated by itself 2.7W. Hence we change our design to the current power supply system.

LDO: P_{Loss} = $$(V_{\mathrm{IN}} - V_O)I_0 + V_{IN}I_q \quad (1)$$

Boost converter: $$V_{IN}I_{IN} - V_OI_O \quad (2)$$

	P loss (W)	P tot (W)	Efficiency (%)
LDO control	0.652	1.147	43.15
Boost LED	2.186	18.6	88.2
Total	2.695	19.747	0.8635

Figure 4: Efficiency of power supply unit

2.1.1 Li-Ion Battery & Charger

The battery used is the Tenergy Li-Ion 7.4V 2200mAh Stick Rechargeable battery w/PCB Protection. The battery itself can provide stable power up to 1.5 hours per our calculations. The demand capacity will be of up to 1.3Ah. Each row of LEDs consumes 20mA, so a total of 0.64Ah with the 32 rows in mind. Converting that power to the input side of the boost converter we get around 1.35Ah considering the efficiency of the converter. The power consumed by the control unit is divided in 3 parts: microcontroller with a 10mA current consumption, user input with 15mA and the shift registers with a total of 160mA in normal operating conditions. This results in a total current draw of 1.76mAh.

At first we considered using another charging IC but due to the reduced number of packages available and the difficulty soldering them we decided to change it to the actual one which also provides all the necessary protection features for the charging process for the Li-ion batteries like programmable input current limit and bad battery detection.

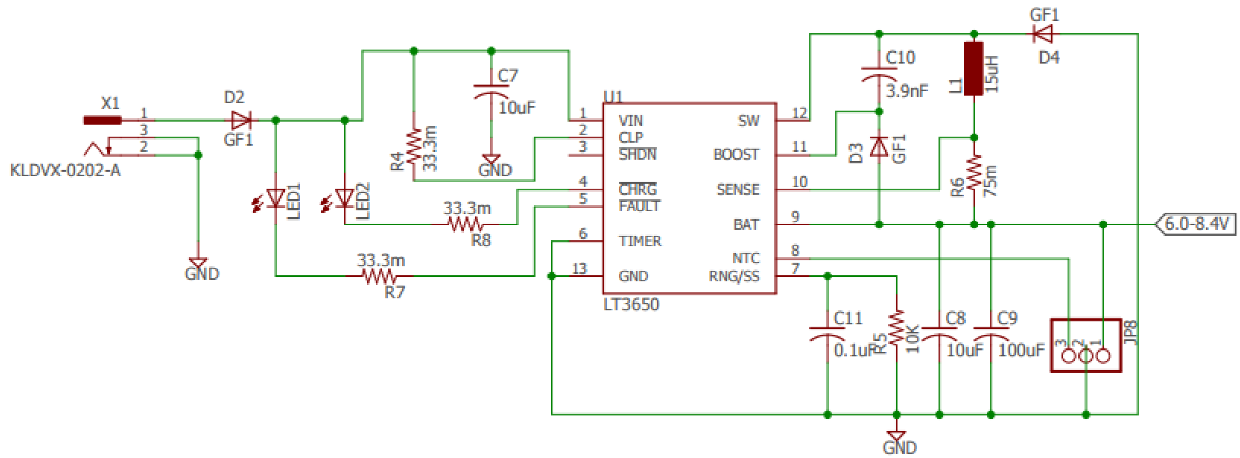

Figure 5: Charging chip schematic

2.1.2 Boost Converter

The boost converter supplies the required 13.8V to the LED array from the 7.4V batteries. The IC used is the LM2700 which can handle up to 2.5A more than enough for our project as explained above. This chip can handle an input range of 2.2 to 12V and the output does not depend on the input voltage value providing us with a steady voltage to power the LEDs through the entire discharging process of the battery.

$$R_1 = R_2 \frac{V_{out} - 1.26}{1.26} \tag{3}$$

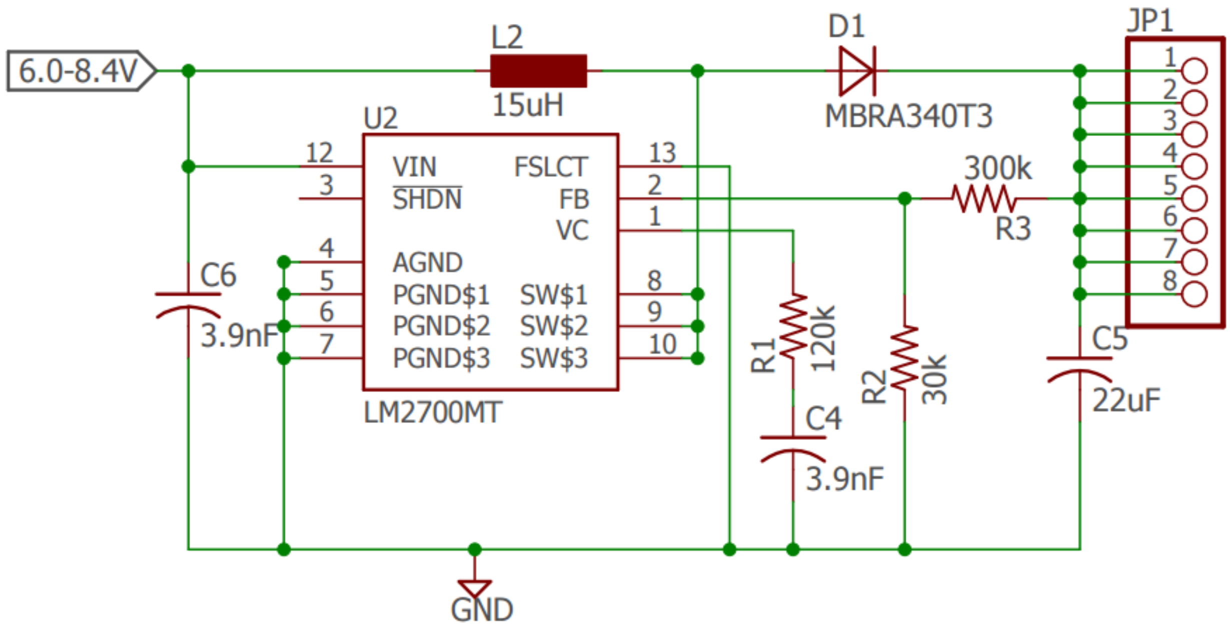

Figure 6: Boost converter schematic

2.1.3 Low Dropout Voltage Regulator

To provide power to the control unit, we use a LM2937 Low drop out Voltage Regulator which introduces a linear drop in the voltage, leaving us with a steady 3.3V. To protect the microcontroller this chip also provides overcurrent protection, thermal shutdown, overvoltage protection and short circuit protection.

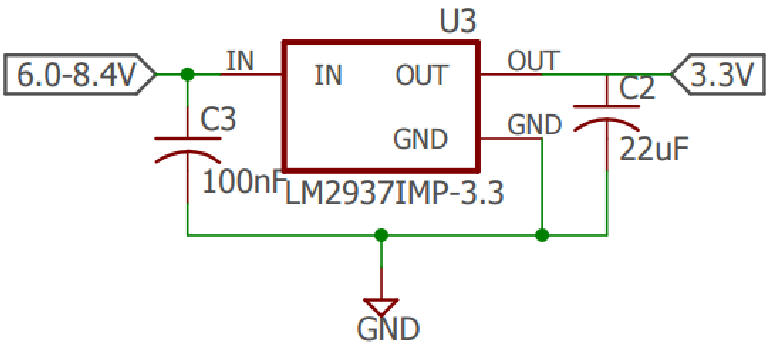

Figure 7: LDO schematic

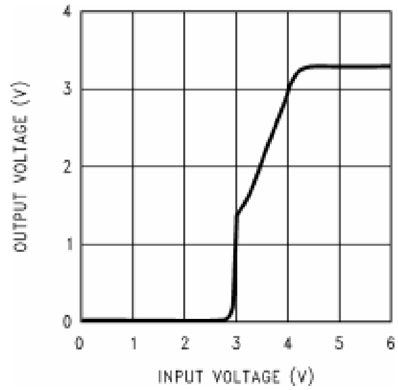

Figure 8: LDO Output vs input voltage

2.2 Control Unit

The control unit manages multiple shift registers to manipulate 32 rows of 4 LEDs from a limited number of pins and chose which ones are on and how much brightness should they give out. This is controlled by the user by means of multiple potentiometers. This part of the circuitry consumes approximately 200mA @ 1MHz with a 3.3 V from the LDO. The microcontroller will communicate with the shift registers through an SPI connection being the atmega328p the master and the shift register the slave of the connection. The MC reads the values of the different potentiometers and changes the LEDs that are on and their respective dimming as well as the mode that they are operating on by means of analog reads of the input voltage through 3 ports in comparison with the analog voltage reference set to 3.3V

2.2.1 Microcontroller

The microcontroller chosen is an ATmega328 which controls the shift register to manipulate the LEDs accordingly through an SPI bus. This microcontroller was also chosen due to its compatibility with SPI as well as the multiple PWM pins available and the easiness of programming it as it is Arduino software ready. It communicates between the 4 IC without the need of extra wiring. Allowing us to make the circuit board smaller.

After implementing the design and testing it we were not able to get up to the required speed we calculated for the SPI connection. The best solution for future work would be to choose a microcontroller with DMA capabilities to use a DMA+SPI connection. This could improve our speed up to 10 times and would solve our issues with the communication between the microcontroller and shift registers.

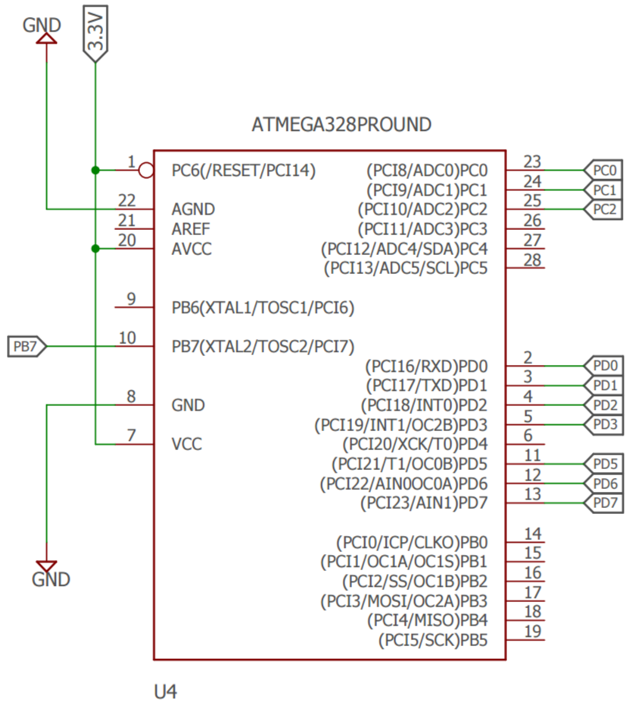

Figure 9: Microcontroller schematic

2.2.2 Shift register

There are 4 8-bit shift registers connected in series which will allow to control which LED rows are on using fewer pins, as well as manipulating the duty cycle to control the dimming by means of pulse width modulation using the clock as reference. The shift register chosen is the 74hc595 which is a Data/Delay type flip flop. This kind of shift register receives all the data through a serial connection and when the latch pin is enabled it starts loading all the information into the different outputs with each rising edge of the clock. When all bits are loaded the latch pin is deactivated and the information is then sent to the LEDs.

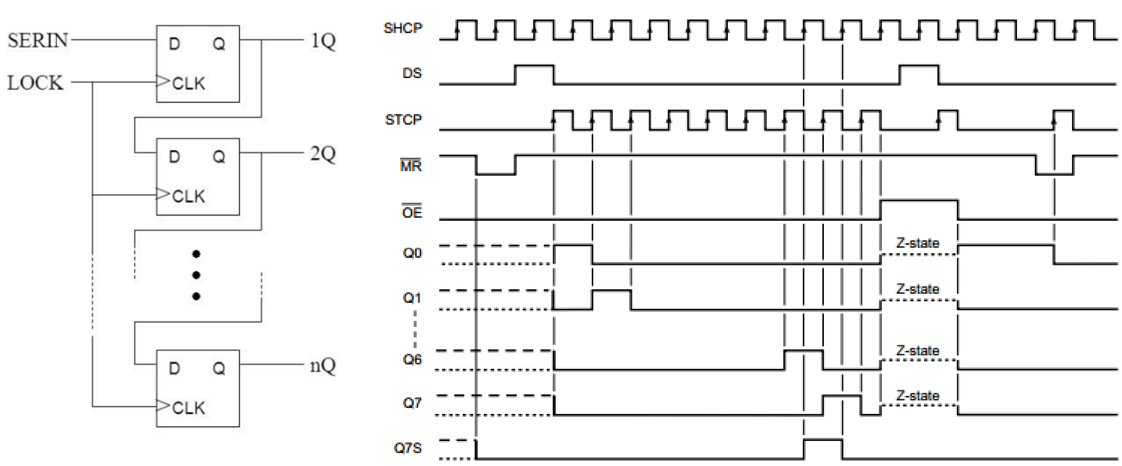

Figure 10: Shift register functional diagram

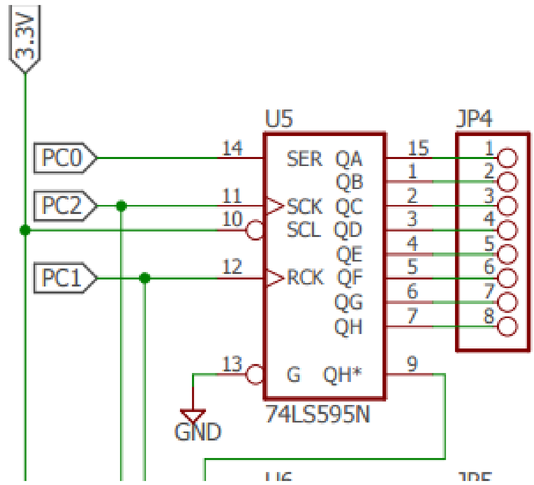

Figure 11: Shift register schematic

2.2.3 Potentiometers

For the potentiometers in charge of changing the position, dimming and mode of the LED array we are using 200kohms potentiometers that send a value to the analog pins of the microcontroller which is then compared to the analog reference for the voltage set to 3.3V and transformed into a value from 0 to 1023 being 0 equal to 0V and 1023 to 3.3V input.

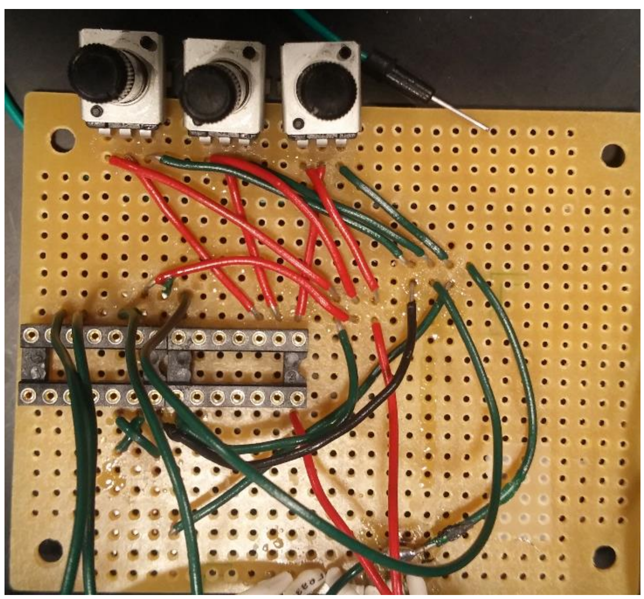

Figure 12: Potentiometers proof board

2.3 LEDs

The LEDs used are the DURIS E3 LCW JNSH.PC from Osram. Each individual LED consumes 20mA at 3.05V. The LEDs will be connected in an array consisting of blocks of 4 simultaneously controlled LEDs and 32 of these blocks connected to different transistors to regulate them at different rates of PWM. This transistors, which act as switches are connected to the shift registers and are turned on and off according to the information sent by the microcontroller according to the values registered on the potentiometers. Per our calculation the entire array will consume around 18.6W.

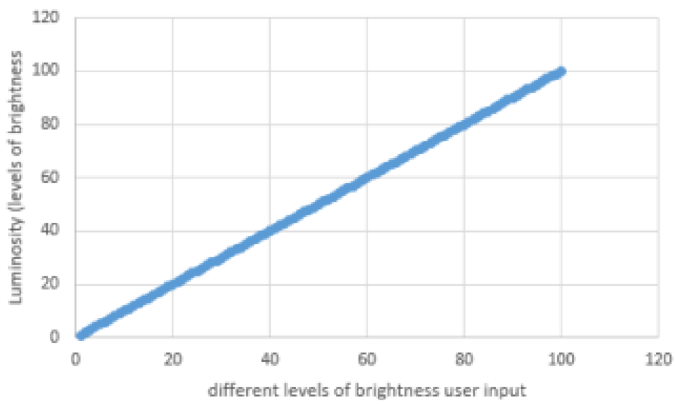

Figure 13: Diagram of different levels of light vs luminosity

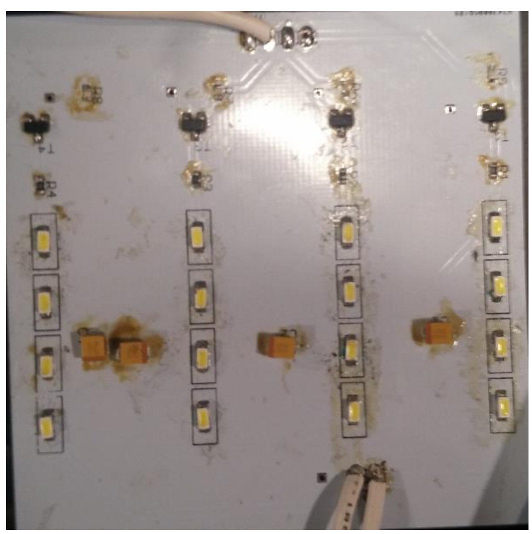

Figure 14: LED row

2.4 Software

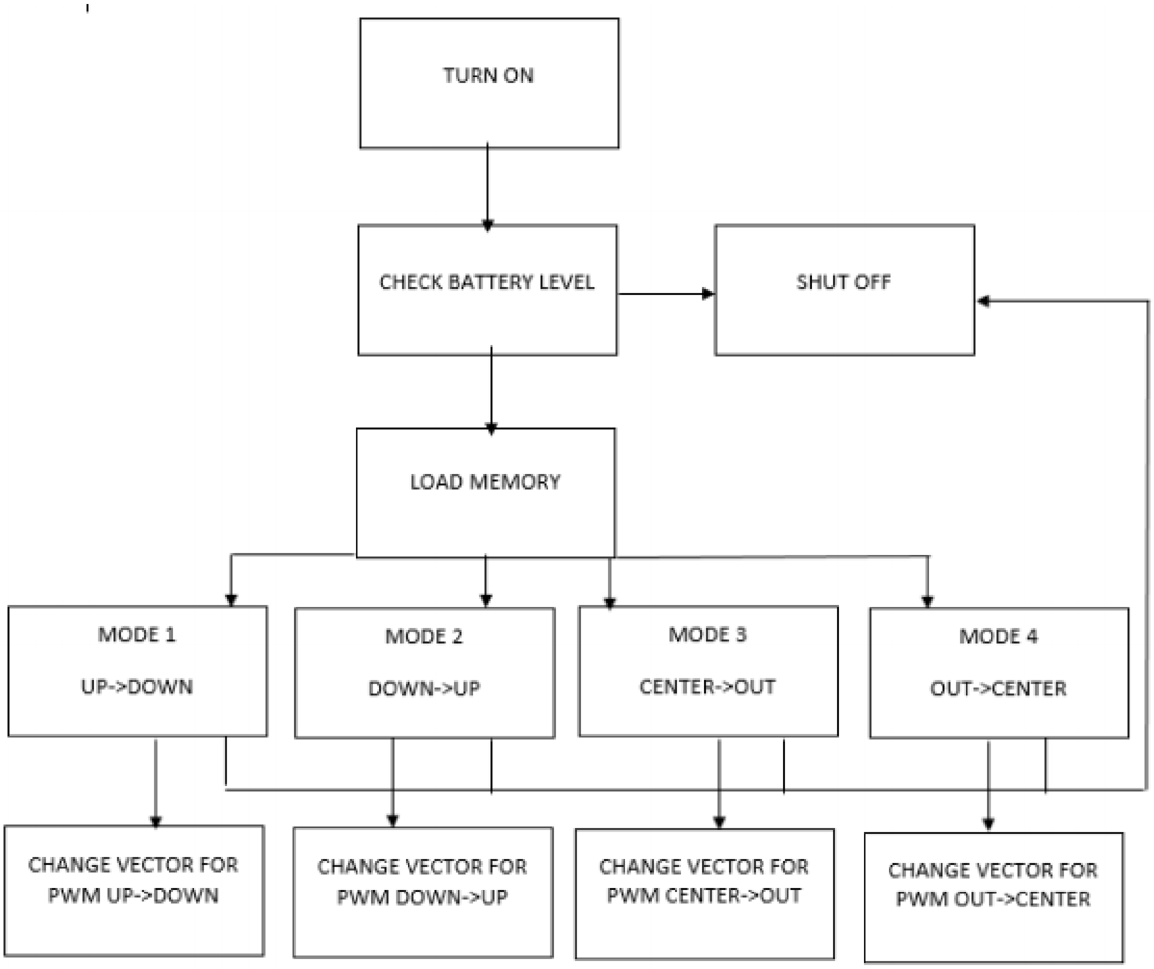

Figure 15: Flow chart

3. Design Verification

Our R&V requirements can be found in Appendix A. We are able to satisfy most parts of these requirements and demonstrated a partially functional product at the time of our demo. To test the discharging time for our battery, we connect a new pack of Li-ion battery with the positive terminal at VDD and the negative at ground. Then we discharge battery 1.5A for about 1 hours. Then we take video to prove that during the discharging time (1 hour), the battery voltage can remain above 6.6V. The result proves that the battery can provide stable power for approximately 1 hour.

3.1 [Power part]

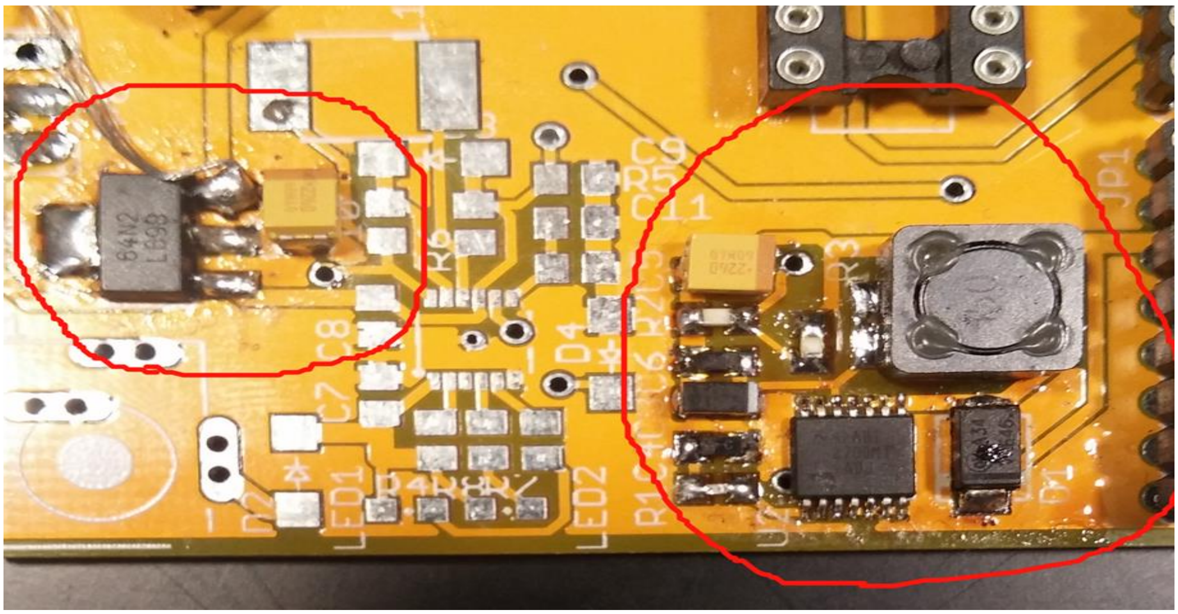

Figure 16: One snapshot of our control & power PCB

The power part verification is easy to do. First we use the DC power source to provide 7.4 V power to the PCB board, this stimulates the battery Voltage of 7.4V. The part in the left region is our Low drop voltage regulator part, and the part in the right region is our booster converter. After we connect the DC power source, we use other two wires which connect to the multimeter to test the output of the low drop voltage regulator. The top pin of the low drop voltage regulator is the output pin. The results are match our expectation. We use the same method to test the output from the booster converter, and the results are also match our expectations.

3.2 [Control part]

As for the control part, the major problem we have meet is the SPI speed. The required speed for our SPI interface 800Kbits. The speed we get by using oscilloscope is around 147kbits. The gap between the idea speed and the goal speed is not small. The way we can use to debugging this problem is to use the busy loop. The following graph is an example of busy loop.

```
int i = 0;

while (1)
{
    i++;
}
```

Figure 17:example of the busy loop

As we can see, busy loop is an active polling where the application is waiting on some event to occur and continuously checks for it. By continuing sending the same signal, we can use oscilloscope to check the SPI frequency speed. If the speed matches our goal, the problem is relying on the software part. We did make some changes on software part, we use bitwise diving to replace the original dividing method. By doing that, we can save some time because bitwise diving is much faster than the normal dividing method. Also, the further step we can do is to check the SPI settings.

4. Costs

4.1 Parts

Table X Parts Costs

Part	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
BCX70JCT-ND (12)	Digikey	0.186	0.186	2.23
478-9836-1-ND (35)	Digikey	0.491	0.491	17.19
478-8656-1-ND (9)	Digikey	0.74	0.74	6.66
478-8654-1-ND (10)	Digikey	0.771	0.771	7.71
311-10KJRCT-ND (10)	Digikey	0.011	0.011	0.11
RMCF0603FT200RCT-ND (10)	Digikey	0.019	0.019	0.19
541-300KGCT-ND (10)	Digikey	0.023	0.023	0.23
LM2937IMP-3.3/NOPBCT-ND (7)	Digikey	1.77	1.77	12.39
CMSH3-40MA TR13CT-ND (5)	Digikey	0.69	0.69	3.45
296-35267-1-ND (6)	Digikey	3.81	3.81	22.86
MBRA340T3GOSCT-ND (4)	Digikey	0.48	0.48	1.92
ATMEGA328P-PU-ND (2)	Digikey	2.14	2.14	4.28
LT3650IMSE-8.4#PBF-ND (2)	Digikey	6.88	6.88	13.76
475-1301-1-ND (9)	Digikey	0.61	0.61	5.49
541-2716-1-ND (10)	Digikey	0.539	0.539	5.39
541-2718-1-ND (4)	Digikey	0.65	0.65	2.6
718-1718-1-ND (4)	Digikey	1.96	1.96	7.84
BCX70JCT-ND (30)	Digikey	0.186	0.186	5.58
SRR0745A-150MCT-ND (4)	Digikey	0.75	0.75	3
541-78.7HCT-ND (50)	Digikey	0.0176	0.0176	0.88
541-200GCT-ND (50)	Digikey	0.013	0.013	0.65
541-10.0KHCT-ND (50)	Digikey	0.0176	0.0176	0.88
478-1683-1-ND (40)	Digikey	0.45	0.45	18
478-5701-1-ND (2)	Digikey	1.01	1.01	2.02
PTV09A-4030U-B204-ND (4)	Digikey	0.83	0.83	3.32
Total				**148.63**

4.2 Labor

Our fixed development costs for labor is $40/hour and there are three of us working on average 8 hours a week on this project. We are planning to complete the end resulting project within this 16 week semester without accounting for the cost of production the development cost will be.

$$3 * \frac{\$40}{hour} * \frac{8hours}{week} * 16weeks * 2.5 = \$38400$$

5. Conclusion

5.1 Accomplishments

Our accomplishments throughout this project was that we learnt a lot about the process of designing and building a device. Even though we did not get our project to be working completely we have gained a lot of insight on how to design and build projects more effectively through our mistakes. For example, we have learnt that often there will be PCB errors so it is best to avoid them in the beginning, and to order our PCBs early so if there is an error we can send in a second patch of orders. Secondly, we should order more parts and chips since there could often be an accident where we would burn one of the chips or parts, and not having extras to replace it proved to be detrimental to our time schedule. Moreover, we learnt that we should always plan to leave enough time for ordering extra parts since sometimes the resistor or capacitor values would not match the values needed.

Since we designed and built our project in a modular fashion even though we did get the project to work we got most of the individual modules to work on their own, which enhanced our understanding of the technical aspects that we were dealing with. We successfully completed all our requirements and verifications except for the SPI frequency needed. By trying to optimize the SPI frequency we learnt a lot about how SPI works and what it does. By designing and building the other modules like the boost converter, low drop voltage regulator, and LED circuits we have enhanced our understanding of how each of these very common electrical components work and how to apply them to the real world.

5.2 Uncertainties

Our project was mostly controlled, however there were some uncertainties that we needed to be careful of. For example, since we did not pin point the exact solution the how to raise the SPI frequency to meet our requirements. Also, there could be a chance that the battery can't power the entire system since we did not complete the entire project we could not test the actual battery life, instead we simulated an equivalent load based on our calculations to test the battery life. Moreover, when we did not consider the chance that the capacitors might hold charge therefore powering the system even we the power is turned off. This happened when we were debugging the control portion of our system by connecting a 3.3V power supply across the VCC pin of the ATMEGA chip and ground, there would be a reverse current created through the low drop voltage regulator supply about a 10V voltage to the power portion from the control portion. This issue caused the capacitors to hold charge and power the LED portion of our device even when the power turned off.

5.3 Difficulties and Solutions

`During the implementation of the project we ran into a lot of problems that we had to find engineering solutions to. Some of them we were able to solve while others we did not. However, through this process we have learnt a lot about how to solve problems and debug our circuit so the overall outcome was beneficial.

Our IC charging chip, SPI frequency, PCB board, and boost converter all had malfunctions that we had to solve some of them were small fixes while others proved to be very difficult. Our IC charging chip did not function or charge the battery properly, after some debugging and tinkering we speculated that there was a problem with the PCB board design. The shutdown pin which enables and terminates the chip was floating. This point proves the importance of triple checking PCB designs and saving enough time for a second order. We tried to connect the pin to Vin directly however that did not solve the problem, we speculated there was another problem or there was a bad connection. When we probed the voltage and current across certain sensing resistors of the IC charging chip circuit we found that they were not giving the desired readings. This was very puzzling as we calculated their values with the equations given on the data sheet of chip. We then proceeded to switch out the resistors for different values to find the optimal value, however we ended up burning the chip and the boost converter which was situated next to it, probably due to short circuiting or too large of a current. In the end, we did not have any more extra parts and trying again would risk our whole project malfunctioning so we opted to find another solution. We bought a rechargeable li-ion battery pack that has the same model battery that we do. Then we took apart the device and isolated the protection circuit, which separated from the rest of the product. With this protection circuit, we were able to charge our batteries safely and perform most the function for our project.

Our SPI frequency also did not meet the requirements that we have set. This is most likely due to a coding issue. If we had done more research earlier, we could have opted for using UART over SPI interface. However, for future attempts we could implement a busy loop while constantly sends a high signal every cycle. This way if the output from the busy loop can meet our requirement of 800kHz we will be able to say our hardware selection and design was done correctly, and we would then only need to focus on the coding and software to optimize the SPI frequency.

Another problem that we ran into that prevented us from delivering a fully functioning device is that our PCB had a bad connection. The connection from the low drop voltage regulator to pin 10 of the last shift register (JP7) and from pin 10 to the Vcc pin of the ATMEGA chip was cutoff. We don't know if this was a manufacturing error or if it happened when we were soldering and unsoldering components of our device from the PCB. Since we had test every individual module separately there was no way of detecting this problem until the final assembly was complete. Since we ran out of parts and it was too late to order parts we could not solder another PCB to replace this one. We tried to solder wires to the pins to reestablish this connection. However, when we tested this connection by connecting a power supply of 3.3V to the Vcc of the ATEMGA chip the current reverse flowed through the low voltage regulator causing damage to our circuit. However, this revealed to us that when a reverse current is implemented across the low drop voltage regulator the capacitors will store charge and continue to power the LEDs for a short period after the power supply is taken away. This accident helped the overall design since if we were to design this device again we would likely implement a diode to stop this revers flow situation.

5.4 Ethical considerations

There are many safety hazards with our project, the most important one being those that comes with the use of Lithium-ion batteries. This is an issue since they will explode when overcharges and/or brought to extreme temperatures. Also, the battery can experience a thermal runaway which can cause battery failure and even an explosion [3]. We will bypass this with hardware to monitor the temperature of the charging node. We will design the charging circuitry to shut down when the temperature gets above 45 degrees Celsius. Also since our goal is to design a lighting instrument there could be radiated heat from the light, which can cause unstable temperatures, we will once again build in a hardware control that will shut down the entire system when the temperature rises above 45 degrees. To address the overcharging problem, we will design a voltage regulating and monitoring circuit that will ensure that the battery charge never exceeds 4V, which is the maximum voltage that battery can tolerate.

Another safety issue could be the potential of a short circuit, since the lighting device is designed to be portable and usable in outdoor environments it could get wet. We will be insulating the circuit board and all electrical components of our circuit inside of water proof material to reduce the chance of a short circuit happening.

Our project is solely for the use of photography, and light painting photography so there aren't many ethnic problems that we need to be wary about. Our project and design do have the potential to infringe IEEE code of ethics [9]. As if we do not nullify the potential safety hazards of the battery the use of our design could lead to potential injuries, so we must solve all our safety issues in order to comply with the IEEE code.

Our project is based on the IEEE code [5], as we are taking available parts and technology and applying it to something new. By doing so we are expanding and developing a new use for technology, as well as making a new breakthrough in the photography field.

5.5 Future work

In the future, we can redesign the PCB so we can avoid the short circuit problem. Since the SPI interface speed is not that high (800k bits), we can use UART to achieve that or even use FPGA device. The other thing we can try to solve the speed problem is to connect SS pin individually to each slave devices. In our design, we connect SS pin to all MISO pin on the shift register.

References

[1] Battery university, “Lithium-ion Safety Concerns” ,2016(online).

Available: http://batteryuniversity.com/learn/archive/lithium_ion_safety_concerns

[2] Rick Kessinger Studio, “Automative”, 2011(online).

Available: http://www.kessingerstudio.com/

[3] IEEE.org, “IEEE CODE OF ETHICS”, 2002(online).

Available: http://www.sfjohnson.com/acad/ethics/FourCodesOfEthics.pdf

[4] Lewis McGregor, “LED lighting guide + Aputure lightstorm Review”, Inside Tips (Aug,2015).

Available: http://www.indietips.com/led-lighting-guide-aputure-lightstorm-review/

[5] Gardner Daniel, and Suresh Jeeth “Wireless IntraNetwork”, 2016(online).

Available: https://courses.engr.illinois.edu/ece445/documents/examples/ExampleDD.pdf

[6] Texas Instruments, “TPS6306x High Input Voltage, Buck-Boost Converter with 2-A Switch Current (Rev. B)”, 2014[online].

Available: http://www.ti.com/product/TPS63060/datasheet.

[7] Texas Instruments, “Low-drop dropout voltage regulator KA278R09” 2015[online].

Available: http://www.littlediode.com/datasheets/pdf/Datasheets-KA2/KA278R09.PDF

[8] Tenergy, “AT: Tenergy Li-ion 18650 14.8V 2200mAh Stick Rechargeable Battery Pack w/PCB protection” ,2015[online].

[9] OSRAM Opto Semiconductors, “DURIS E3 Datasheet version 2,4”, 2016[online].

Available: http://www.osram-os.com/Graphics/Xpic2/00205050_0.pdf/ [10] Mann, S. (1997). Wearable computing: A first step toward personal imaging. IEEE Computer, 30(2), pp25-32.

Appendix A Requirement and Verification Table

Requirement	Verification	Verification Status(Y/N)
Li-ion battery • Stores more than 1.2 Ah of charge. • The weight must be less than 400 grams.	• Connect a new pack of Li-ion battery with the positive terminal at VDD and the negative at ground. Then we discharge battery 1.5A for about 1 hours. Use a voltmeter to ensure that the battery voltage remains above 6V. • Put the battery on the scale to weigh the weight of one pack Tenergy Li-ion battery.	Yes Yes
Booster Converter • Provides 13.8 +/- 5% from a 7.4 input Voltage. • Can operate Temperature range from 40°C to 85°C.	• Set the input voltage to the nominal requirement for your power supply. Hold one pin to the ground, and the other pin to the output side of the diode, then measure the output voltage (**V_{OUT}**) with the multimeter. The output voltage accuracy can be calculated using the following formula: $Output\ Voltage\ Accuracy(\%) = \frac{V_{out-V_{nom}}}{V_{nom}} * 100$ Then make sure the accuracy is in the +/- 5% range. To be accurate, we will measure around 5 times, then we take the average value. • During the verification, make sure the temperature is in the suggested range. We use the thermal gun to measure chip temperature.	Yes Yes

Low-drop Voltage Regulator • Provides 3.3V +/- 5% from 7.4V input Voltage. • Can work under Temperature range from -20°C to 80°C.	• Set the input voltage to the nominal requirement for your power supply. Then set the output voltage load to its maximum rated value. Measure the output voltage (**V_{OUT}**) with the calibrated voltmeter. The output voltage accuracy can be calculated using the following formula: $output\ Voltage\ accuracy(\%) = \frac{V_{out}-V_{nominal}}{V_{nominal}} * 100$ Then make sure the accuracy is in the +/- 5% range. • 2.During the verification, make sure the temperature is in the suggested range. To test it, we can put chip in the iced bag and apply above test method to make sure the chip can work around 0 degrees. To test the higher limited range, we use the heat gun to put temperature around this chip to 80°C temperature, to test the output from the Low drop voltage regulator is still functional.	Yes Yes
Microcontroller • Can transmit over SPI at speeds greater than 800Kbps. • Integrated clock can run around 50kHz. (enable)	• To make our life easier, we use the digital storage Oscilloscope to test the SPI speed. We put one pen into Atmega328 chip output pin to see the frequency. • Connect the Microcontroller chip to the Oscilloscope, run the clock and observe that the maximum steps per second is higher than 50kHz.	No Yes

Shift register • Shifting frequency should be f 800 kHz (the tolerance Analysis explains why we choose 800kHz here).	• Connect the shift register chip to the oscilloscope. We will check the sped of the shift register by put the pen into the output pin.	No
Dimming wheel • Can freely slide in both directions. • Potentiometer's resistance should increase linearly with sliding distance	• Slide both direction to make sure that this action can be done without strain. • Choose a starting point (a point between the resistor and the led) and use multimeter to measure the resistance. Sliding certain distance and use multimeter to measure the resistance. Repeat step A and step B, then draw the graph use distance as X-axis and resistance as Y-axis. Check the graph is linear or not	Yes Yes

LEDS • Must be able to be able be visible and visibly dimmed with a drive current of 16.55mA to 23.45mA • Entire led painting device has max brightness of 1000 lux +/- 10%. We have 128 LEDs, and each led has lumens around 9-11 lumens. In the data sheet, the led has 8.6 lumens @ 5000k.	• To connect the LED from the DC supply, and use the multimeter to measure the voltage drop over two sides of the LEDs. As we know the internal resistance is about 150ohm, we can use V/R to measure the drive current. • use light meter lux to measure the lumens. The light meter lux can scan the curtain area on the device and we use the equation: E(lux) = 10.79361*lumens(total)*(4πr^2)	Yes Yes