Light Painting Device

ECE445 Design Document

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Group 36

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1. Introduction

1.1 Objective

In the photography industry there is a new branch of creative work that is called light painting which allows photographers to create much more vibrant and crisp pictures, but the current lighting equipment for it expensive, not customizable, not portable, and simply not very effective [2]. To understand the problem we must first discuss a little about the concept and mechanics of taking a photo like the one in Figure 1.

Figure 1: Rick Kessinger Studio Automotive [2]

The idea behind creating a photo like this is to make the exposure time longer, and capturing the shot in a completely darkroom. Since for not only cameras, but also for the human eye to observe anything light will have to reflect off of objects the photographer directs the light to certain parts of the car so only certain parts of it will be captured at a time [2]. Much like noise canceling in electrical engineering by doing this the photographer is effectively canceling out the noise from other light sources resulting in a pristine photograph without the noise of the ambient light that is associated with the traditional methods of photography.

The problem is that currently there is no effective way for a photographer to perform this act. 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, and 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 photographers and work on, and also 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 have the ability to 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.

1.2 Background

Light painting isn't a new idea that people just came up with, it actually dates back 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 really used to project directed light off of an object in order 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 one shown in Figure 1. Due to the limited time since this technique has been used and accepted, there are no products like ours available making it all the more necessary for us to create this design. The photo in Figure 1 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.

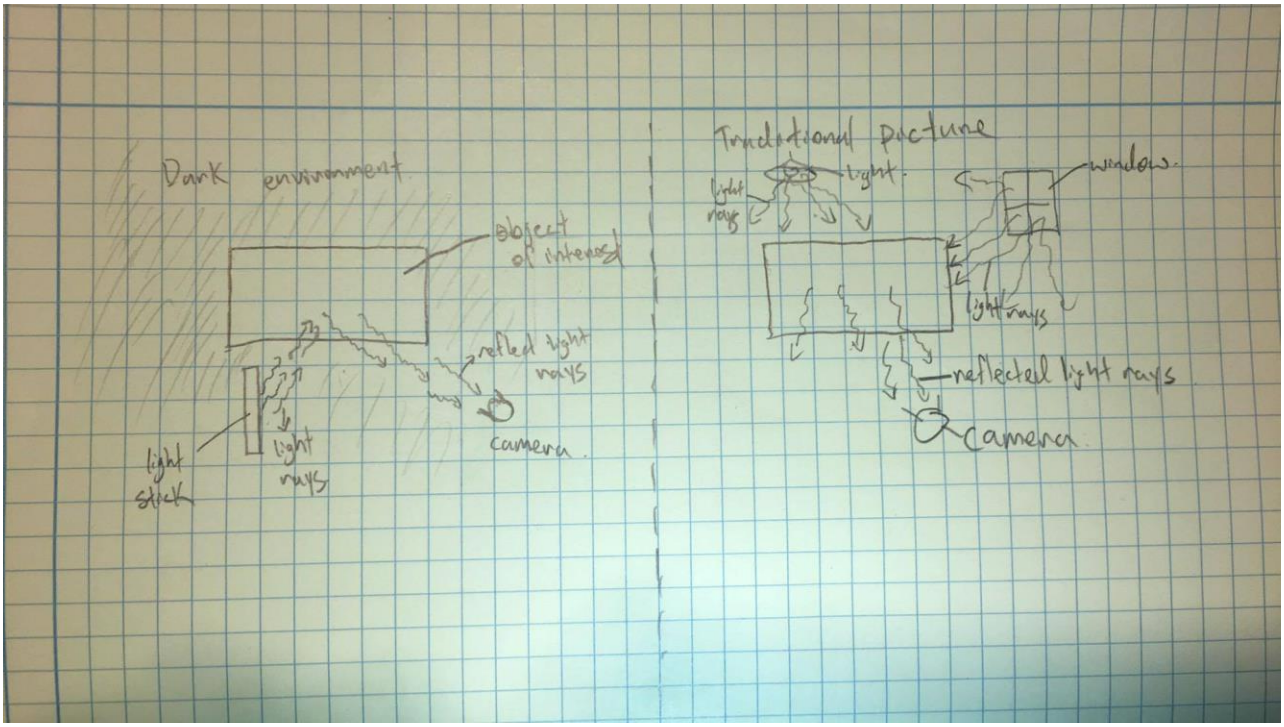
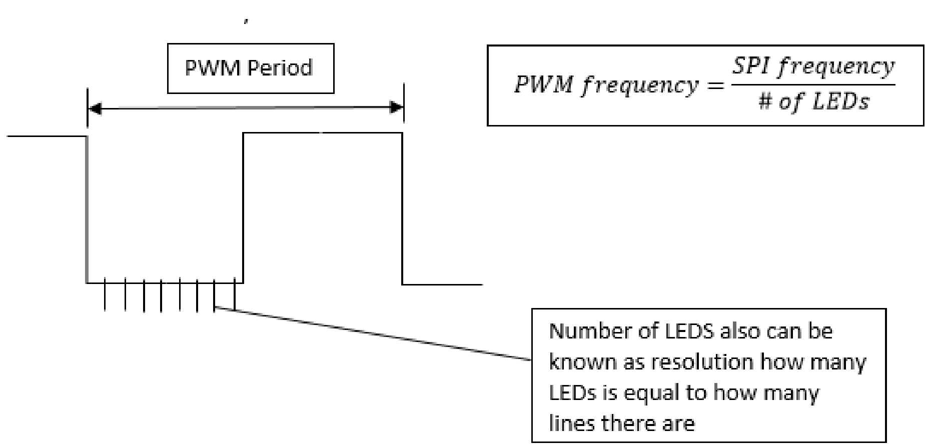


Figure 2: Diagram showing difference between traditional and light painting photography

1.3 High-Level Requirements

1. The battery life must be of at least 1 hour of continuous use.
2. The LEDs must be bright enough (approximately to 1000 lumens) to provide sufficient lighting for photographers to take shots.
3. The LEDs must span a color temperature of a range of 4500K to 5500K to make sure the quality of the photo.
4. The SPI frequency must be of at least 800kHz (for more on this refer to the diagram below and tolerance section)



2. Design

The LED light that we are going to build will require 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 of this controlled by 4 buttons and 2 wheels. There is also a non-volatile memory of small capacity (already included in the microprocessor specs), to ensure that the settings of the light are preserved even when turned off.

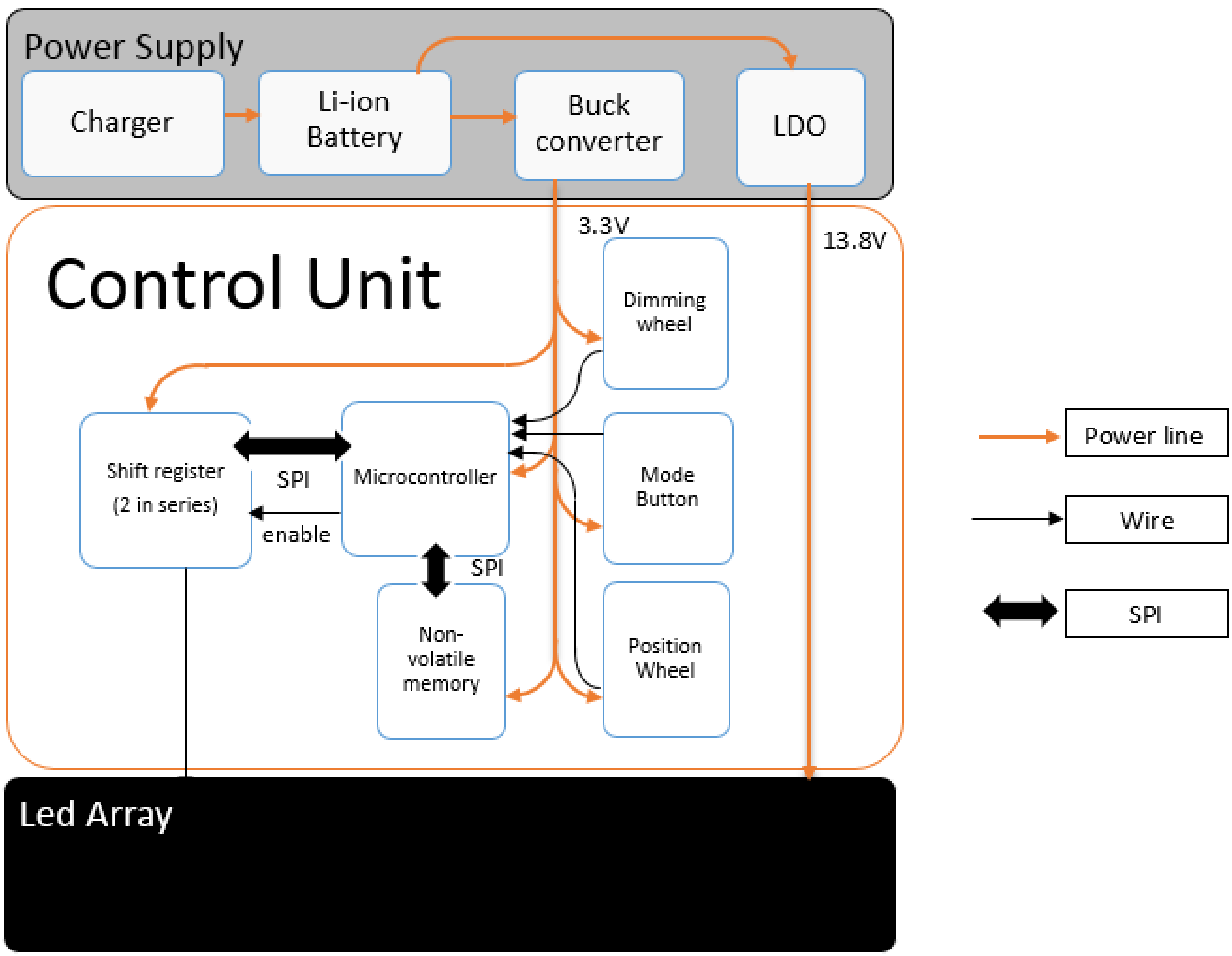


Figure 1: the overall block diagram of the design

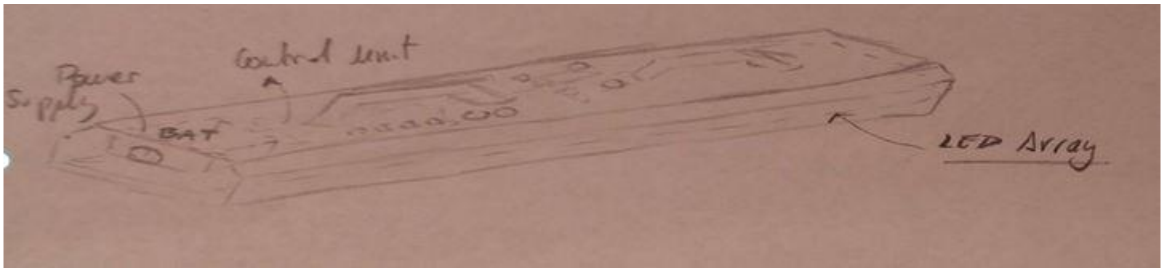


Figure 2: Mechanical design

This picture basically describes what we are going to implement in hardware. We are going to connect 4 LEDs in series then make it a LED array. Then we put serval arrays together. The control unit board is on the side of this device. The supply power will be attach to the top of that device. To balance the weight, we will put something on the bottom.

2.1 Power Supply

A power supply is required to provide stable power for the LED-lighting device. The charger will supply the Li-ion battery with stable DC power. In turn the later will power both to the control board and to the LED arrays. Having 32 rows of 4 LEDs in series each (20mA per row) we will have a power consumption of around 640mA. As for the control board, our power budget will be of around 50mA at 3.3V.

2.1.1 Li-Ion Battery & Charger

To make our life easier, we are going to order the Li-Ion battery and charger as a pack. The battery used will be the Tenergy Li-Ion 14.8V 2200mAh Stick Rechargeable battery w/PCB Protection. The battery itself can provide stable power up to 2.5 hours per our calculations. The demand capacity will be of up to 0.7Ah. Each row consumes 20mA, so 32 rows will consume 0.64Ah, and add the power that control board consumes. The total power will be around 0.7Ah.   [8]

Requirements	Verifications
1. Stores more than 0.7 Ah of charge. 2. The weight must be less than 400 grams.	1. Connect a new pack of Li-ion battery with the positive terminal at VDD and the negative at ground. Then we discharge battery 690mA for about 1 hours. Use a voltmeter to ensure that the battery voltage remains above 13.2V. 2. Put the battery on the scale to weigh the weight of one pack Tenergy Li-ion battery.

2.1.2 Buck Converter

The buck converter supplies the required 3.3V to the control board system from the output 14.8 Volts battery. We chose the TPS63060, with an adjustable output voltage that is set to 3.3V. This chip must be able to handle the constant input voltage (14.8 V) [8]. The output current will be of up to 100mA at step-down mode. The Schematic for the Buck convert is attached below:

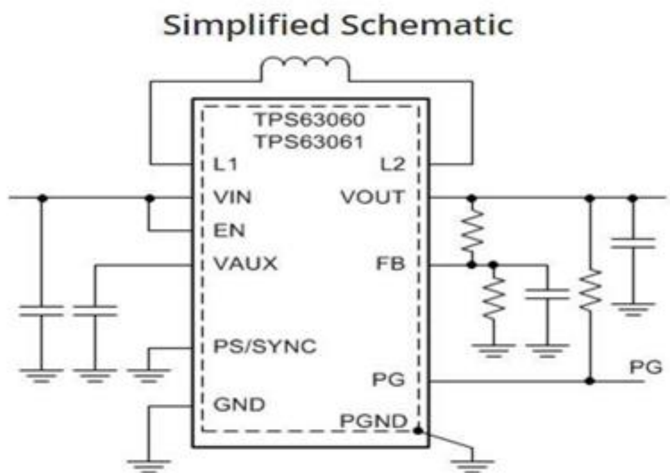


Figure 5: TPS63060(buck converter) Simplified Schematic circuit [6]

Requirements	Verifications
1. Provides 3.3V +/- 5% from a 14.8 input Voltage. 2. Can operate at currents at 50mA (which exactly we want in the control units board. 3. Can operate Temperature range from 40℃ to 85℃.	1. 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: $OutputVoltageAccuracy(\%) = \frac{V_{OUT} - V_{NOM}}{V_{NOM}} * 100$ Then make sure the accuracy is in the +/- 5% range. 2. When we connect the buck convert to the power supply which we set to be nominal voltage, then we use the current meter to measure the output current make sure it can provide enough current. 3. 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.

2.1.3 Low-drop Voltage Regulator

To provide enough voltage to the LEDs, we will use a LM2940CT Low-drop Voltage Regulator which will introduce a drop of 1V (see figure 6), leaving us with a steady 13.8V to supply the LED array. This chip has overcurrent protection, thermal shutdown, overvoltage protection and short circuit protection. See attached the Block diagram of the low-drop Voltage Regulator below.

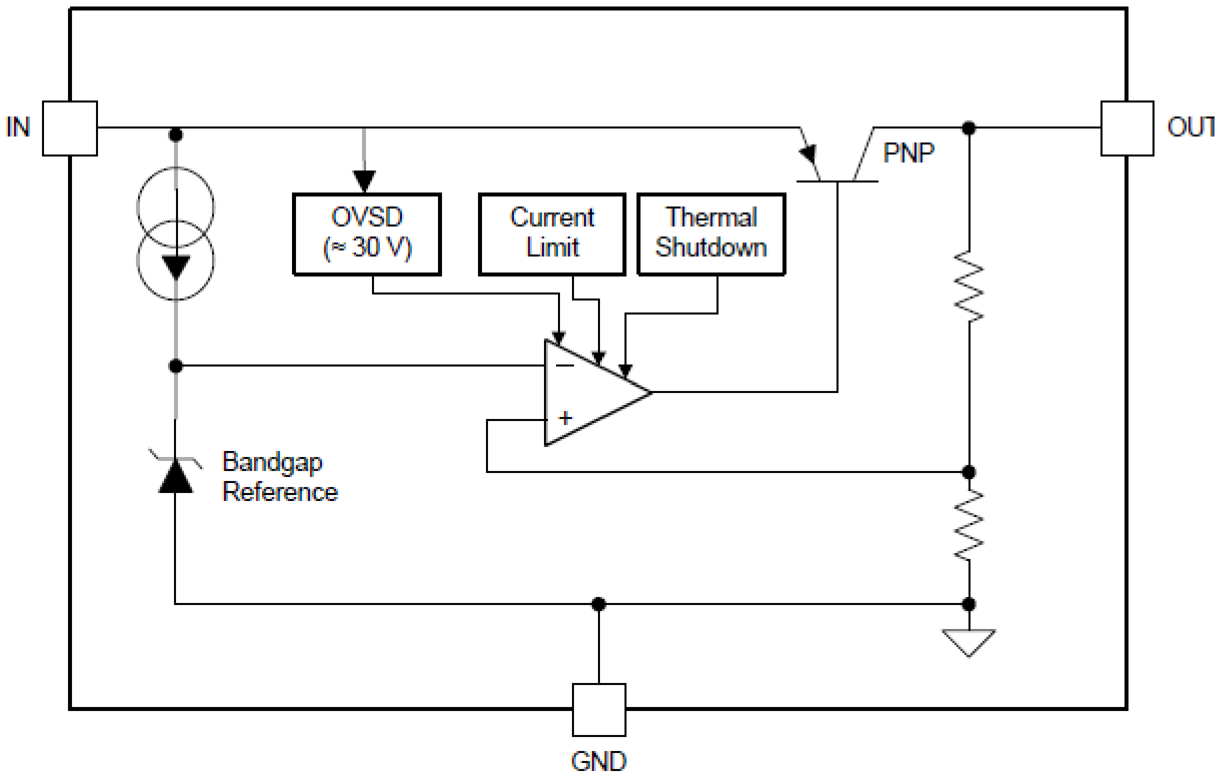


Figure 6: Low-drop Voltage regulator block diagram [7]

Also to verify the function of this low-drop voltage regulator, I attached the simulation graph of input/output Voltage.

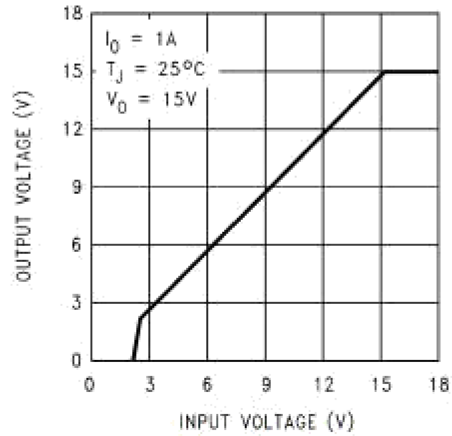


Figure 14. Low Voltage Behavior

Figure 7: Output Voltage/input voltage nominal characteristics [7]

Requirements	**Verifications**
1. Provides 13.8V +/- 5% from a 14.8V input Voltage. 2. Can operate at currents around 0.65A with a +/- 5% accuracy. 3. Can operate Temperature range from -20℃ to 80℃.	1. 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: $$OutputVoltageAccuracy(\%) = \frac{V_{OUT} - V_{NOM}}{V_{NOM}} * 100$$ Then make sure the accuracy is in the +/- 5% range. 2. When we connect the buck convert to the power supply which we set to be nominal voltage, then we use the current meter to measure the output current make sure it can provide enough current. Then we make sure the current is in the range. 3. 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.

2.2 Control Unit

A control unit manages multiple shift registers to manipulate 32 rows of 4 LEDs from a limited amount of pins and chose which ones are on and how much brightness should they give out. This would be controlled by the user by means of multiple buttons and wheels. The control unit will also be responsible for disabling the circuit should the battery voltage reach dangerous levels. The non-volatile memory will ensure that even if the power goes off the settings will be maintained. This part of the circuitry will consume approximately 50mA @ 1MHz with a 3.3 V from the voltage regulator.

2.2.1 Microcontroller

The microcontroller chosen is an ATmega328 which will read the previous setting from the memory when turned on, and will control the shift register to manipulate the LEDs accordingly through an SPI bus. This microcontroller was also chosen because it already has a flash memory implemented, making it to communicate between both IC without the need of extra wiring. Allowing us to make the circuit board smaller.

Requirements	**Verification**
1. Can transmit over SPI at speeds greater than 800Kbps. 2.Integrated clock can run around 50kHz. (enable)	1. Connect microcontroller to USB SPI bridge, such as FT4222, and to a terminal such as Putty. (Starter time) send a 10kbps block of random data from the USB kinetics. Then echo data back, this time transmitting over SPI from the Kinetis. At the same time, ensure the data received matches data sent, and the time elapsed doesn't exceed 100ms. [5] 2. Connect the Microcontroller chip to the Oscilloscope, run the clock and observe that the maximum steps per second is higher than 50kHz.

2.2.2 Non-volatile memory

This memory will keep the previous status of the device when turned off so that it can be ready to use at any time. Not much memory will be needed, so the memory already present in the microcontroller should be enough. Also we don't need to worry about losing information during a write if the system shuts down since. This is because the information that needs to be stored would be the information from the position and dimming wheel. In that case, if they are being adjusted that means the user is switching the setting so there is no need for the previous setting to be stored.

Requirements	Verification
1) Can hold all the information needed for 32 different brightness values for the LEDs and the wheel positions. (4 LEDs per value) 2) Can hold the information for at least 2 hours without being powered	**3)** To check the Non-volatile memory, we can type a small program both write and read on an Arduino board. In that case, we can check whether the memory can keep the information. 4) Repeat step 1, but wait for 2 hours before checking. In that way, we can heck the Non-volatile memory can hold the information for at least for 2 hours

2.2.3 Shift register

There will be 2 16-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.

Requirements	Verification
1) Shifting frequency should be f 800 kHz (the tolerance Analysis explains why we choose 800kHz here).	1) Connect the shift register chip to the oscilloscope. Then write a minimal program which can read and write at this specific frequency. When we connect to the oscilloscope, we will see the oscilloscope has the nice period gap. To calculate the frequency, we take 1/T.

2.2.4 Mode buttons

These buttons will set the mode in which the dimming will happen, either from top to bottom, center to outer or outer to center.

Requirement	Verification
1) Must stay pressed so that the mode will be stored analogically when the device is maintained off. 2) Small size (diameter range is 1cm-1.5cm) 3)Those buttons can be easily pressed	1) Once we turned off the device, we can check if the button bounce back or not. 2) Measure the radius, then calculate the diameter. Make sure it's in the range. 3) To test this requirement, we apply different forces to those buttons, and check how easily those buttons can be pushed.

2.2.5 Position wheel

We can use a potentiometer to decide the starting point of our device. The Potentiometer is essentially a voltage divider. By adjusting the slider, we control the resistance of the potentiometer. In that way, we can achieve the same goal.

Requirement	Verification
1) Can freely slide in both directions. 2) Potentiometer's resistance should increase linearly with sliding distance	1) Slide both direction to make sure that this action can be done without strain. 2) A. Choose a starting point (a point between the resistor and the led) and use multimeter to measure the resistance. B. Sliding certain distance and use multimeter to measure the resistance. C. Repeat step A and step B, then draw the graph use distance as X-axis and resistance as Y-axis. D. Check the graph is linear or not

2.2.6 Dimming wheel

A wheel that will control the duty cycle at which the shift register turns on and off the LEDs to control the brightness by means of PWM using the clock as reference. This is done by having the Dimming wheel act as a rotating switching giving 1 and 0 signals to the micro controller which can be visualized as a pulse train. The pulses are then counted by the micro controller to determine the dimming of the LEDs.

Requirements	Verification
1) Can freely rotate in both directions 2) Acts as a rotating switch rotating from high to low and vice versa creating a pulse train to the micro controller 3) Diameter around 3cm +/- 5%.	1) Rotate wheel to make sure that this action can be done without strain 2) A. Connect wheel mechanism to a DC voltage source B. Connect wheel mechanism to a oscilloscope at a point which between the led and resistor. C. look at the waveform generated on the oscilloscope to check if a uniform pulse train is generated. 3) Use ruler to measure the wheel

2.3 LEDs

The LEDs use will be the DURIS E3 LCW JNSH.PC from Osram. Each individual LED will consume 20 Ma 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 pins to regulate them at different rates of PWM. Per our calculation the entire array will consume around 7.8 watts. There are two requirements that LED strips need to fulfill. [9]

Requirements	Verification
1) Must be able to be able be visible and visibly dimmed with a drive current of 16.55mA to 23.45mA 2) Entire led painting device has max brightness of 1000 lumens +/- 10%. We have 128 leds, and each led has lumens around 9-11 lumens.	1) A. connect DC power source B. Connect LM2940CT voltage regulator C. Adjust nominal resistor(150Ω) to test the different currents 2) A. connect power source B. Connect voltage LM2940CT low-drop voltage regulator C. use light meter lux to measure the lumens. The light meter lux can scan the entire device and have a reading number of lumens. We want to check if it's exceed 1000 lumens.

2.4 Schematics

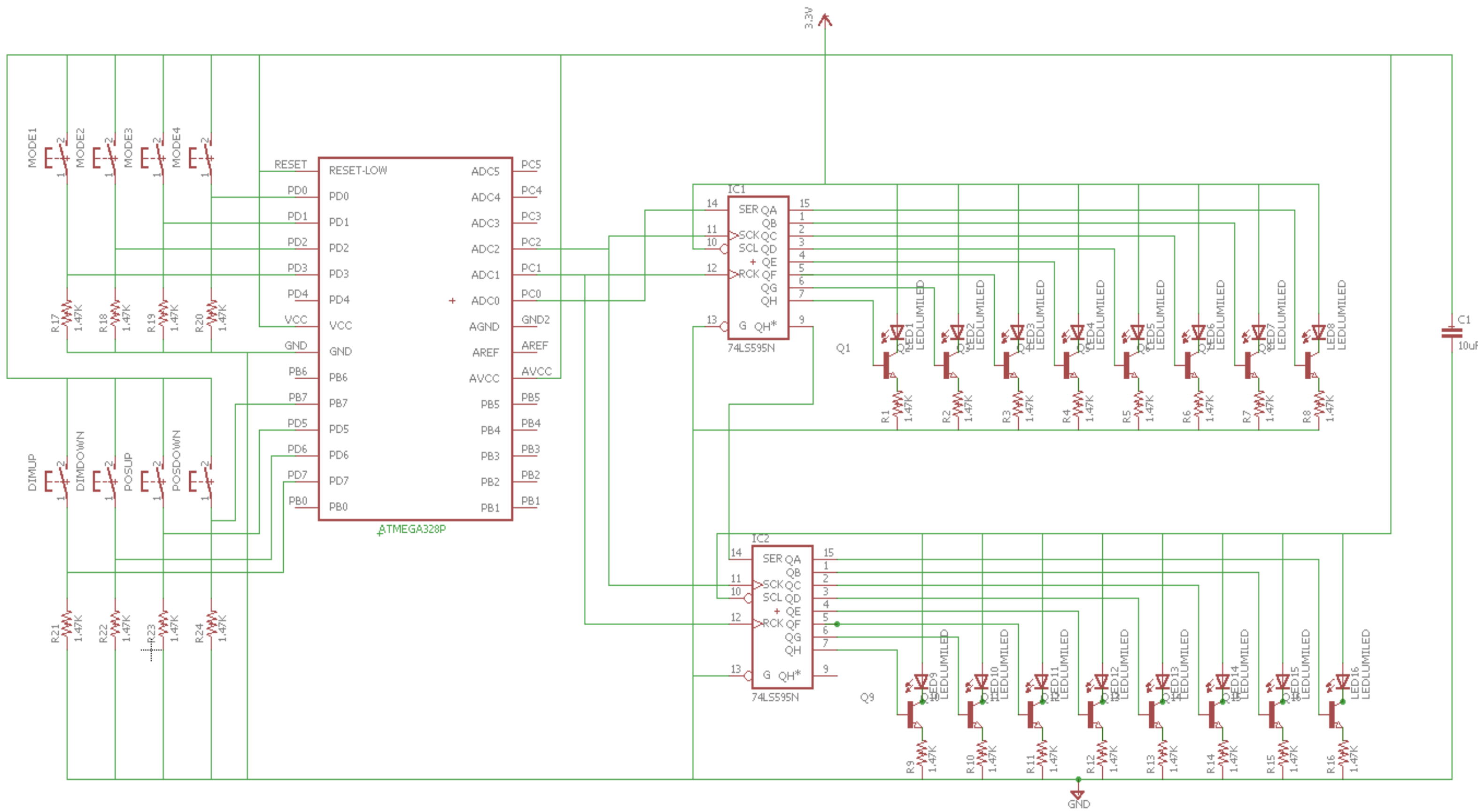


Figure 8: control unit circuit

For the control unit schematics we have calculated the necessary resistance to regulate the current through the LEDs while compromising between robustness against changes in the voltage and power dissipated by the resistance.

Having a 13.8V input and a 13.05V drop LEDs requiring 20mA:

$$\frac{13.8V - 12.2V}{20mA} = 80\Omega$$

Variations in the input voltage and the according change in the current will be discussed in the tolerance section.

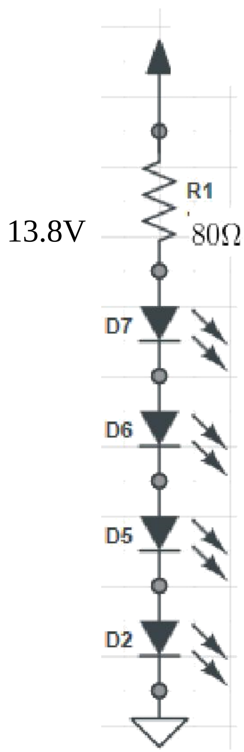


Figure 9: LED row

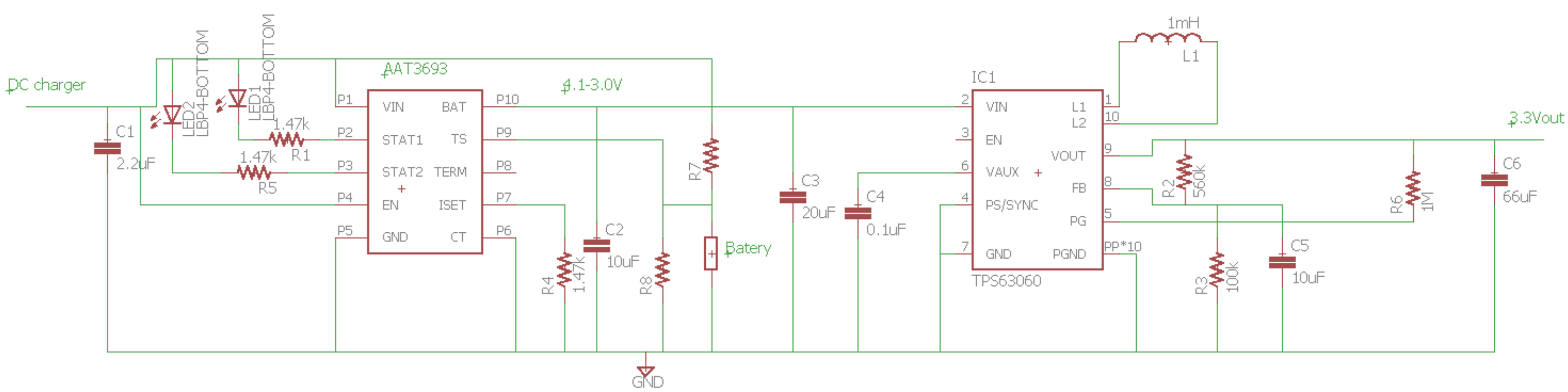


Figure 10: power circuit

For the supply unit, most of the specs for resistance capacitors and inductances where done due to the manufacturers data sheet.

For the AAT3693 a 1.47k resistor was chosen for the ISET pin in order to set the charging current to 1A.

For the TPS363060 (Buck converter) the output voltage is determined by the resistor connected to V_{out} (3.3V) and FB, following the next equation. V_{FB}=0.5V is a standard value given by the manufacturer as well as the value of all the capacitors in the buck converter diagram.

$$R_1 = R_2\left(\frac{V_o}{V_{FB}} - 1\right) \qquad R_1 = 100k\Omega \qquad R_2 = 560k\Omega$$

2.6 Tolerance Analysis

One important tolerance that we must maintain is the SPI frequency. The reason for this is because the way that we control the LEDs with pulse width modulation. By using this method the lights will be blinking on and off since every light will only get an instruction once every shift register cycle. So we must make sure that the clock speed of the control unit is fast enough so that the human eye and camera will not be effected by this LED blinking. So we must make sure that the SPI frequency is higher that of which we will calculate with the following method. First we found out that the lowest frequency for the LEDs to blink at without being detected by a human eye or camera is normally 400Hz but just to be safe we decided to choose to use 500Hz for our calculations. Also since we decided that to create a smooth gradient we would have 100 different rates of dimming for the LEDs so 1 period would be 100 bits for the resolution that we want refer to figure 10 for details. Also we have to consider the shift registers that we are using since they are 16 bits long it will take 16 clock periods for the data to get to each LED. This is because each LED will only get an instruction every shift register cycle and in this case that would be 16 clock cycles. With this information we can write the equation below.

$$Minimum\ SPI\ Frequency\ Needed = 500Hz * 100bits * 16bits = 800kHz \qquad (1)$$

So in other words we must make sure that we have a SPI frequency higher than 800 kHz.

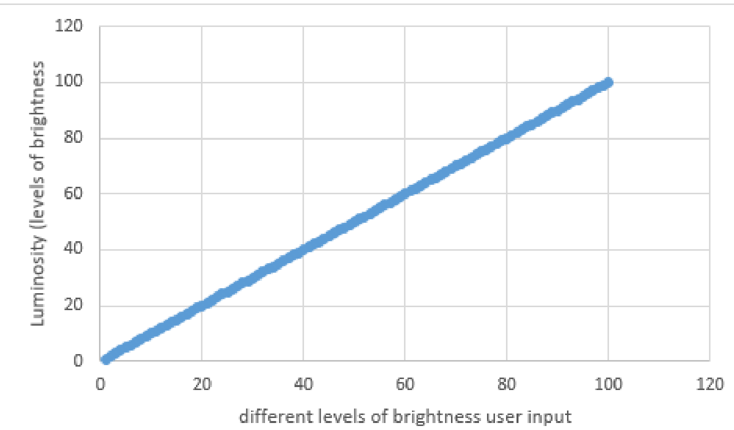


Figure 11: Diagram of different levels of light vs luminosity

Another very important tolerance that we must follow is that we must make sure that we can achieve the threshold voltage of the LEDs and current requirements without wasting power. So we must figure out a range where this is efficient. Right now we are using a 14.8V battery which goes through a voltage regulator which uses 1V, and outputs voltage between 14.07V and 13.52V. We know that we have 4 LEDs connected in series which will take 3.05V and 20mA each. So if we

$\frac{13.8V-12.2V}{20mA}$ we will get 80Ω which is the nominal resistance. With this nominal resistance we can then calculate the max and min current that we will get through this line with the following equation.

$$I = \frac{V}{R}; Imax = \frac{1.876V}{80\Omega}; Imin = \frac{1.324V}{80\Omega} \tag{2}$$

So we have a current range of 16.55mA to 23.45mA which all are above 15mA which is typically when a change in the LED light will be perceivable by the naked eye.

2.7 Software

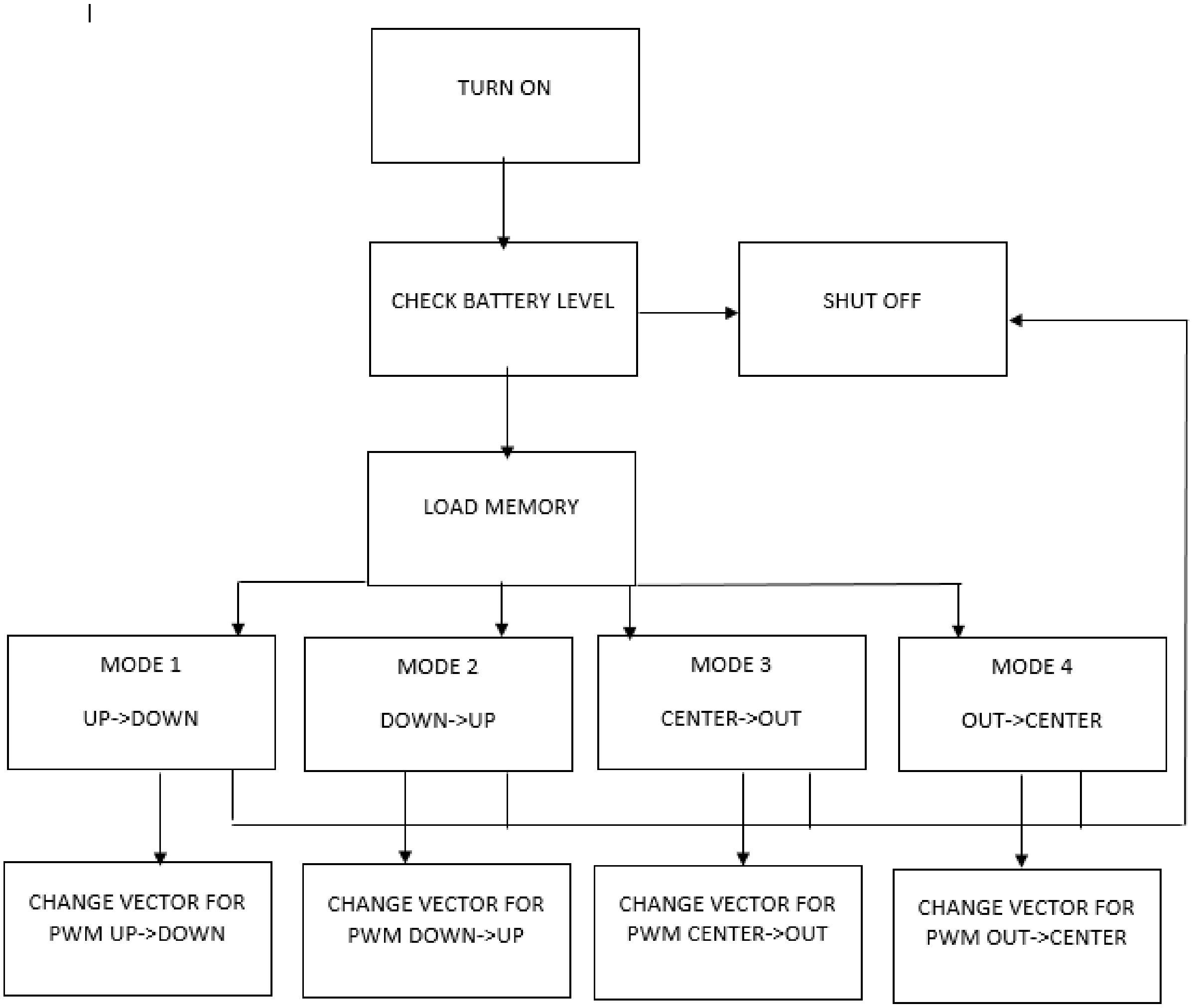


Figure 12: flow chart

3. Cost

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.

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

From the table below we can see that our total parts cost will be $56.42

Part	**Price (Prototype)**
Atmega328 x1	$13.38
Tps63060 x1	$3.07
Aat3693 x1	$0.89
LM2940CT-12	$1.14
74hc595 x2	$0.90
PCB (user input and control system)	$3.10
PCB (LED system)	$3.10
Li-ion 14.8 battery	$42.99
LEDs, resistors, capacitors and assorted circuit components	$10.00
Light Case	$15.00

Combining the two costs we arrive at our final cost of $38493.57

4. Schedule

Week	Yang	YangYang	Pablo
2/20	Look up parts work on given parts of the design documents	Work on the Design document and do research on the power supply	Work on the design document and do research on the LEDs
2/27	Purchase parts and practice soldering. Also help with schematic	Work on perfecting the power supply and battery control	Work on finishing schematic for PCB Printing
3/6	Figure out how to implement the wheel and different modes	Designing the fade control	Work on programming the Chip
3/13	Build and test LED and Shift register system	Build and test the voltage regulating system	Finish programing chip and start with pulse modulation method
3/20	Bug fix the LED and Shift register system	Bug fix the voltage regulating system	Bug fic the control chip and modulation method
3/27	Assemble LED to the whole system	Assemble power supply and control system	Assemble user input and control system
4/3	Test LED functionality and voltage control and fix bugs	Check power supply and regulating system and fic bugs	Check control system and fix bugs
4/10	Solder the project together and test/fix bugs for LED and rest of system	Solder the project together and test/fix bugs for power and regulating system	Solder the project together and test/fix bugs for control unit and user input
4/17	Test entire system and fix bugs	Test entire system and fix bugs for power system	Test entire system and fix bugs for control unit system
4/24	Write Final report, and practice presentation	Write Final report design part Power, and practice presentation	Write Final report design part control unit, and practice presentation
5/1	Finish final report intro background tolerance safety and ethnics, and presentation	Finish final report design part Power, and presentation	Finish final report design part control unit, and presentation

5. Safety and ethnics

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. That being said 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 of 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

Reference

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