Modular Light Matching Network

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Abstract

This project creates a modular light matching network which matches the brightness and color of the outside light to help reduce eye strain. People have been experiencing this issue more since the pandemic transitioned a lot of jobs to work-from-home. Using a series of sensors and an ATmega master/slave configuration, the system is able to determine when the light in a room needs an adjustment in either the color temperature or light intensity. The system can be incorporated to work for an entire house and works using a room's standard wall sockets without requiring wifi. This report provides the details of the system's design, construction, and overall costs.

Contents

1. Introduction

Employee work-from-home numbers have skyrocketed due to Covid19 in the past year. According to Global Workplace Analytics, an estimated 56% of people of current jobholders are compatible with remote work, and 25-30% plan to work from home after the pandemic is over [1]. Our customers are the individuals who have transitioned to working from home and have been experiencing eye strain and unhealthy sleep schedules due to their harsh and monotone room light. A survey done by AJMC shows that 67% of people believed their sleep schedules were healthier before Covid19 [2]. Additionally, due to this sudden increase in working from home electricity bills have risen due to the additional use of lights and simply forgetting to turn off overhead lights when leaving a room. The average electricity bill has also gone up by an average of $127 based on a PRNewswire analysis [3]. It doesn’t look like working from home will be going away any time soon, so it is time for our customers to adapt to their environment by protecting their health and staying productive.

We have constructed a light system that will emulate natural light and conserve energy during a normal work day. Through an ambient light and color feedback system, our product will determine the color and brightness of outside light and produce a matching light inside a room. Our light will evenly brighten a room with the same intensity, reducing glare on monitors and shadows cast. Additionally, the system will color correct itself until it finds the perfect match to the color temperature of outdoor lighting. Lastly, using time-of-flight sensors, the number of people entering and exiting the room will be counted to ensure that the room lights automatically shut off when no one is in the room. This will allow for optimal energy conservation and reduce electricity usage.

1.1 High Level Requirements

a) Matches a scaled intensity of outdoor lighting within ±10% lumens of perceived brightness. Matches color of outdoor lighting enough to be indistinguishable to the naked eye, within approximately ±10% in °K (color temperature).
b) A yellow light will turn on when the outdoor light intensity falls below 450 lumens (average lumens necessary for reading) [4].
c) Lights in the room will turn on when IR sensors are crossed and off when nobody is detected in the room. A single pole light switch will be used to override the system by turning the lights on or off.

1.2 Summary

The project was split up into six different blocks; The Sensors, LED bank, LED controller, Master ATmega, Slave ATmega, and power supply. This document will describe the purpose of each block and provide the verification.

2. Design

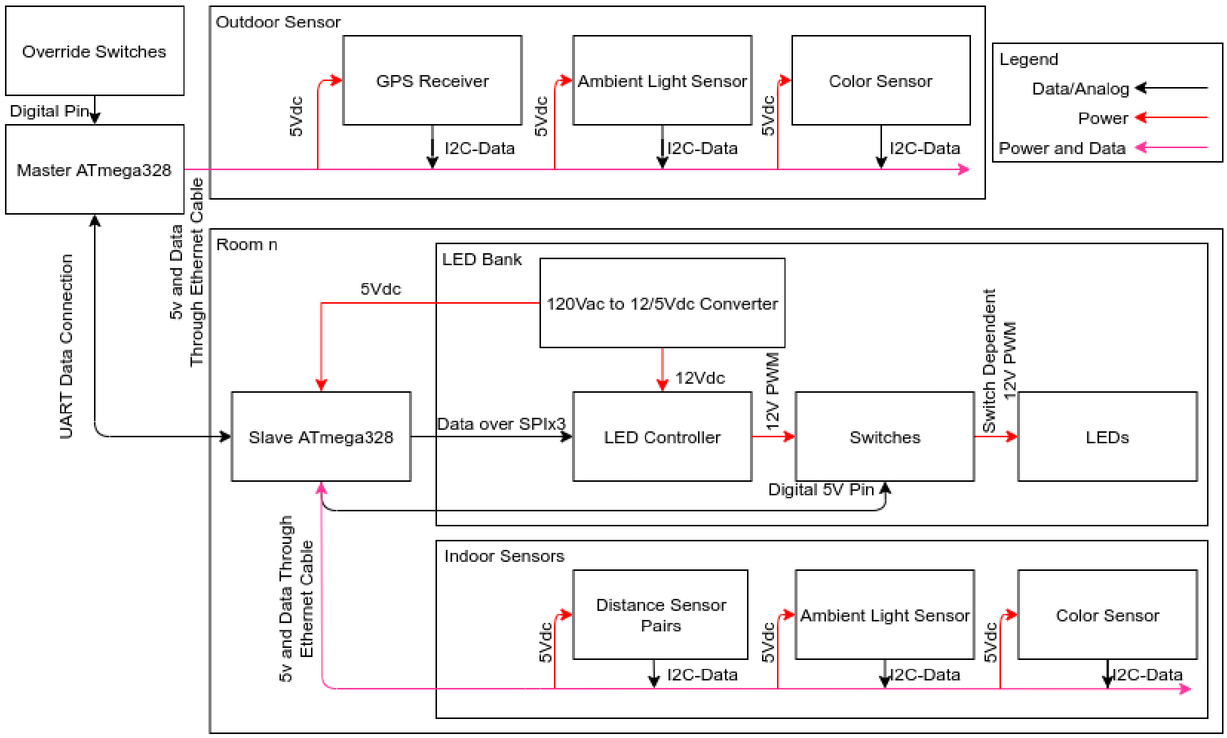

Figure 1: Block Diagram

2.1 Sensors

The sensor network currently contains six sensors in total, and expanding modules will add on two sensors each. The master ATmega has four sensors, ambient light, RGB, GPS, and laser, and the slave ATmega has two sensors, ambient light and RGB. We specifically picked sensors that are precise and have wide ranges to compensate for the drastic changes that outdoor light can go through during the day. This allows for the accurate color and intensity matching that we are able to perform.

2.1.1 Ambient Light Sensor

Uses a photodiode to detect from 0.045 - 188000 lux. We are using this between 0 - 10000 lux, as this portion of the curve is linear and easier to scale. An open source library for the MAX44009 and examples found on Github were referenced to utilize this device [5].

2.1.2 RGB Color Sensor

Outputs RGB values with 3.8 million:1 dynamic range. We use these RGB values to calculate a color temperature. An open source library for the TCS34725 and examples were found on Github and referenced to utilize this device [6].

2.1.3 GPS Module

Receives real-time from satellites that we use to perform time-based effects, such as scaling down blue light past 7 PM. An open source library for the GPS Module as well as examples were found on Github and referenced to utilize this device [7].

2.1.4 Laser Sensor

Displays time-of-flight with a laser source. We are using two of these in parallel mounted to a doorway to act as a counter for people inside a room. An open source library for the VL53L0X as well as examples for operating two on the same I2C bus were found on Github and referenced to utilize this device [8].

2.2 LED Bank

Four 3-watt Chip-on-Board (COB) RGB LEDs are connected in series to output a maximum of 800 lux. Each color has a corresponding resistor that steadies the current to a maximum of 300 mA. This value is slightly below the rated current of 350 mA, ensuring no burnout or fire hazards in long-term use. Our LEDs are placed inside a light fixture to disperse the light evenly throughout an entire room.

2.3 LED controller

The LED control will be a dimmer circuit utilizing PWM for smooth brightening and dimming. When the master ATmega sends data to the slave ATmega, the slave will adjust the duty cycle of the PWM to match the data it receives within 10%, thereby dimming or brightening our LEDs. We are utilizing an IR520 MOSFET to control each color of our 12V LEDs from the Slave ATmega.

Due to delays in parts and unfortunate digital potentiometer burnouts, we opted to use the ATmega PWM pins to generate the signal needed. This was not our first option as these pins have a 490 Hz frequency, resulting in flickering visible on camera. Nonetheless, this allowed us to send PWM signals to our LEDs when the slave ATmega updated.

2.3.1 555 Timer

The 555 timer chip is used to produce a PWM at a certain frequency through discharging a capacitor in conjunction with a resistor and a potentiometer. By varying the potentiometer, we can change the PWM duty cycle and the brightness of our LEDs.

2.3.2 Digital Potentiometer

A 50k ohm digital potentiometer (R2) is used as part of a voltage divider with a 1k pull-up resistor (R1) to control the duty cycle of our 555 timer chip, given by:

$$Duty\ cycle\ =\ R1/(R1+R2)\,. \qquad \text{Eqn. 1}$$

2.4 Master ATmega

The Master ATmega was made up of an ATMega328 PU, the accompanying capacitors and resistors, and an FTDI adapter in order to facilitate programming of the module. This module would talk to the three sensors, the Ambient Light Sensor, GPS Module, and RGB Color Sensor, over the I2C bus and send that information over the RX and TX lines through UART serial communication. Another two digital pins were used to add extra control to the GPS module over a SoftwareSerial Connection.

2.4.1 Override Switch

An override switch was added to the project in order to make the system more user-friendly. A system override switch was implemented in order to set a hard shutoff to the entire system. This was implemented alongside a potentiometer in order to give the user the ability to scale the brightness of the system to their desired liking.

2.5 Slave ATmega

Similar to the Master ATmega, the Slave ATmega is made up of an ATMega328 PU, the accompanying capacitors and resistors, and an FTDI adapter in order to facilitate programming of the module. This module would talk to two sensors, the Ambient Light Sensor and RGB Color Sensor, over the I2C bus and send that information over the RX and TX lines through UART serial communication. SPI connectivity was reserved and implemented to communicate to the Digital Potentiometer in order to control the LED modules assigned to this specific Slave ATmega Module.

2.6 Power Supply

Our power supply uses a 120 VAC to 12 VDC transformer along with a 12 V regulator to be able to power our light with a standard U.S. wall socket. We are then using a 5 V regulator to power our lower powered components.

3. Design Verification

3.1 LED Bank

Lux Matching Data (Lux)

Lux values were ascertained using a separate luxmeter where the values were measured inside and outside an isolating enclosure. The system was allowed to reach equilibrium and the luxmeter placed at Master/Slave sensor height.

Trial Number	Outside Light	Emitted Light	% Error
1	626	588	6.07%
2	42.3	41.3	2.36%
3	540	575	6.48%
4	493	508	3.04%
5	193	209	8.29%
6	190	191	0.52%
7	170	169	0.58%
8	441	432	2.04%
9	578	544	5.88%
10	425	401	5.64%

Table 1: Lux Matching Data

Average % Error: 4.09% which is within the requirement range of ± 10% lumens.

$$\% \text{ Error} = \frac{|\text{ emitted-outside}|}{\text{outside}}$$

Eqn. 2

Color Temperature Matching (Kelvin)

Color temperature was obtained through an application on the phone that we verified was accurate through python. The color temperature utilizes several equations: transforming RGB to chromaticity coordinates XYZ, normalizing XYZ values, and calculating correlated color temperature from the normalized values [9]. The test was similar in setup to the previous brightness test

Trial Number	Outside Light	Emitted Light	% Error
1	3890	3730	4.11%
2	6490	6450	0.61%
3	6440	6490	0.77%
4	4410	4240	3.85%
5	4480	4400	1.79%
6	4490	4350	3.11%
7	4360	4230	2.98%

Table 2: Color Temperature Matching

Average % Difference: 2.46% which meets requirement of being with 10% °K

3.2 Dimmer Circuit

3.2.1 555 Timer

Verify the proper output of the circuit on an oscilloscope. It should be a PWM signal that has a variable duty cycle with a constant frequency of 1.4 Khz from our resistance and capacitance values.

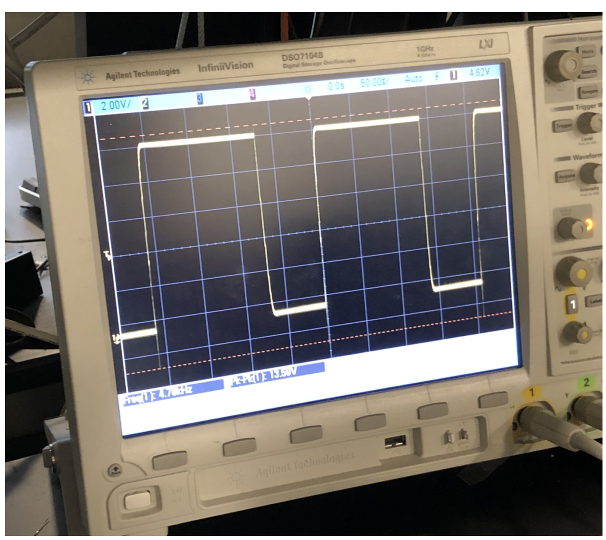

Figure 2: Dimmer Circuit PWM on Oscilloscope

3.2.2 Digital Potentiometer

Using a multimeter and through visual affirmation, we were able to note that by varying the digital potentiometer, the voltage output of the 555 timer and the LED varies.

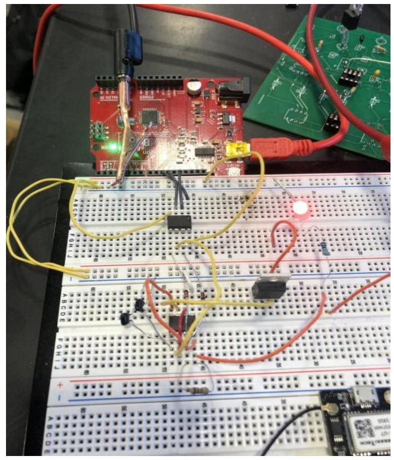

Figure 3: Digital potentiometer with 555 timer circuit

3.3 Master ATmega

Verify that the module can be programmed through the FTDI adapter and can run a simple blink sketch. Next test individually the I2C for sensors, SPI for LED control, and UART for Serial Communication with the Slave ATmega Module.

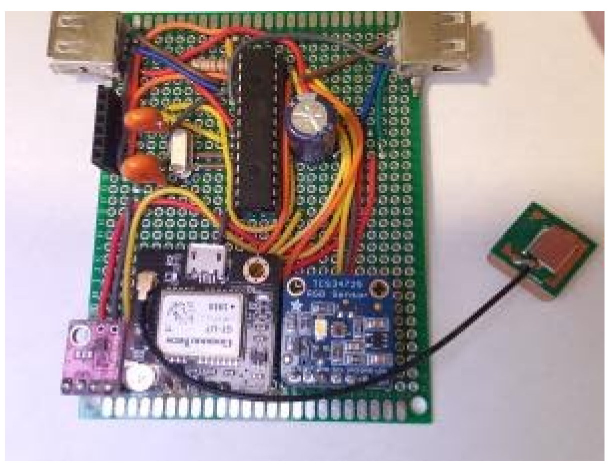

Figure 4: Master ATmega Module with necessary capacitors and resistors as well as the necessary sensors

3.4 Slave ATmega

Verify that the module can be programmed through the FTDI adapter and can run a simple blink sketch. Next individually test the I2C bus for the sensors and UART for serial communication with the Master ATmega Module.

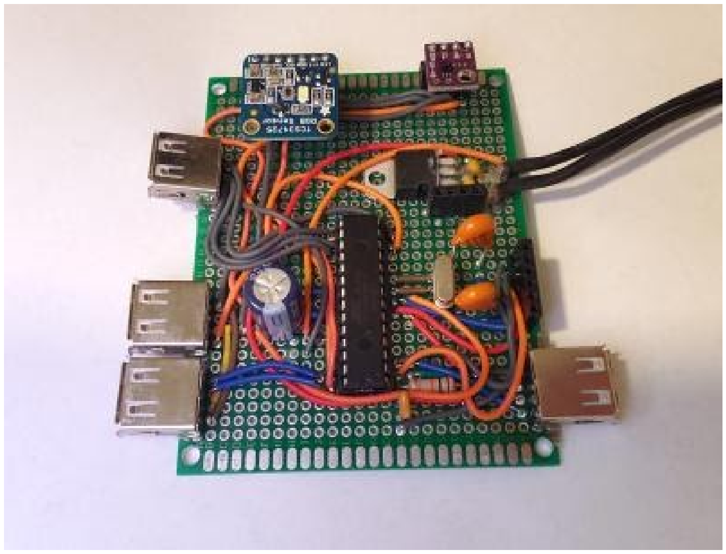

Figure 5: Slave ATmega Module with necessary capacitors and resistors as well as the necessary sensors

3.5 Power Supply

Our proposed power supply schematic is detailed below, however it was extremely difficult to locate a small enough transformer that could also handle the power requirements for our project. In an effort to make everything compact as well as shipping delays, we went with a store-bought 12 V power supply that fulfills all our requirements.

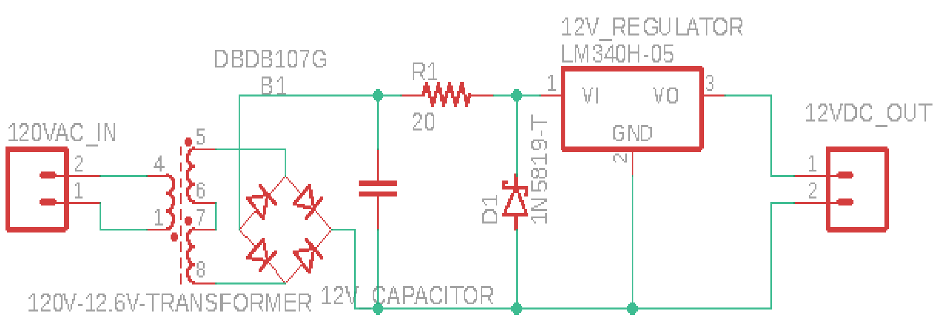

Figure 6: Schematic of the proposed Power Supply Circuit

Figure 7: 120 VAC to 12 VDC Power Converter used in project

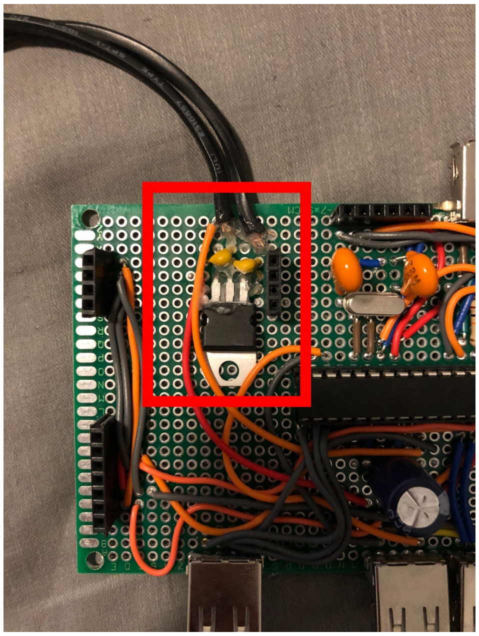

Figure 8: The on-board 5 Volt Regulator and accompanying stability capacitors

4. Costs

4.1 Parts

Part	Cost	QTY	Total Cost
Color Sensor	$9.78	1	$9.78
GPS Module	$10.99	1	$10.99
IR Distance Sensor	$7.98	1	$7.98
Ambient Light Sensor	$11.99	1	$11.99
RGB LEDs	$8.99	1	$8.99
16 Mhz Crystal	$0.48	3	$1.44
22 pf Capacitor	$0.59	3	$3.54
10k Resistor	$0.11	3	$0.33
10uf Capacitor	$0.46	3	$1.38
ATMEGA Chip	$2.30	3	$6.90
IRF520 Mosfet	$5.99	1	$5.99
0.1 uf Capacitor	$0.60	4	$2.40
Mosfet	$0.93	3	$2.79
Diodes	$0.06	10	$0.59
0.01 uf Capacitor	$0.68	4	$2.72
10 Ohm Resistor	$0.28	2	$0.56
1.3 Ohm Resistor	$0.27	2	$0.54
5 Ohm Resistor	$0.70	2	$1.40
Solder Boards	$10.99	1	$10.99
Light Fixture	$13.99	1	$13.99
USB Connectors	$4.99	1	$4.99
Wall Socket Power Supply	$8.99	1	$8.99

50k Digital Pot*	$1.57	4	$6.28
0.01 uf Capacitor*	$0.68	5	$3.40
MUX IC*	$0.48	3	$1.44
50k Digital Pot*	$1.57	3	$4.71
12 V Power Supply*	$12.99	1	$12.99
0.1 uf Capacitor*	$0.36	3	$1.08
Total Costs:			$149.17

Table 3: Parts and Costs list

*Note: Parts with * were intended to be used in the project but due to issues such as shipping delays and changing designs they were not used.

4.2 Labor

The fixed development cost for labor would be about $48,000. This is based on the average salary of an EE grad from the University of Illinois being $79,714 which averages out to about $40/hour. This fixed cost is for 3 engineers working each 10 hours/week for 16 weeks.

$$3\ Engineers\ *\ 10\ \frac{hours}{week}\ *\ 40\ \frac{\$}{hour}\ *\ 16\ weeks\ *\ 2.5\ =\ \$48,000 \quad \text{Eqn. 3}$$

Total overall costs including labor and parts was $48,149.17.

5. Conclusion

5.1 Accomplishments

The project was able to accomplish the main goal by creating a light fixture that could accurately update the emitted light to match both the color temperature and intensity. Additionally, a manual on/off control was added to the system for the times when the user wants to manually turn off the lighting system. Overall, the system is a cost effective lighting system that will improve the health of an individual who is working from home.

5.2 Ethical Considerations

There are a couple of safety considerations that arise with this project. A major goal of the project is to uphold the “IEEE Code of Ethics” by creating a system that benefits society while ensuring that the safety and well-being of the public is the highest priority [10]. The system will follow the “ACM Code of Ethics” by disclosing all information to the public and ensuring that the consumer is aware of all risks associated with the product [11].

One of the first major ethical issues is related to privacy concerns. The IEEE Code of Ethics is dedicated to protecting the privacy of the public [10]. This system may cause privacy concerns because of the fear an outside source may hack the lighting system. This issue was avoided because the system is completely wired and does not require any connection to bluetooth or wifi. Another major issue is related to safety issues in the event that the LED lights burn out and start a fire. While LEDs are much safer than the older more traditional light bulbs there is always the possibility of danger. Overall, this system will deal with overheating hazards by ensuring that the light system is turned off when not in use and using a proper heatsink. Mental well-being concerns is another issue that arises with this project. Poor or incorrect lighting can cause anxiety, stress, and other mental health issues [12]. To alleviate this issue the system produces the necessary warm colored lights while dimming the lights at appropriate times to ensure that it creates a healthier lifestyle. The last safety/ethical issue deals with light pollution. The impact of individual households adds to the issue of light pollution, and there is an ethical concern by creating a system that will cause excessive light pollution. The system reduces the amount of light pollution by using IR distance sensors to ensure that the lights in a room remain off when it is not in use.

5.3 Future Work

If there was additional time to continue work on this project the next steps would be to to finish the integration of the IR distance sensors to be able to accurately count the number of people in a room. The second thing that would be done would be to get the entire project on pcbs. At its current stage all of the project has been soldered but due to shipping delays not all of the pcbs that were in the original design were included. Lastly, to ensure that the light fixture would like up an entire room, additional LED strips would be added to reach the desired brightness.

References

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Appendix A: Requirement and Verification Table

Table 4 System Requirements and Verifications

Module	**Requirement**	**Verification**	**Verification Status (Y or N)**
Sensors	1. Operate light sensor within the linear regime of its resistance vs. lux curve 2. Be under 1000 lumens indoors 3. Display real CT time 4. Accurately track the number of people inside a room	1. Measure lux values emitted using lux meter and ensure correct operation 2. Measure max brightness of light with lux meter 3. Match time from GPS module with time on cell phone 4. Increment and decrement counter when someone enters or exits room	1. Y 2. Y 3. Y 4. N
LED Bank	1. Light sensor and color sensor work in conjunction to bring LEDs to within ±10% °K and ±10% lumens of scaled brightness. 2. Dispersed light will light up an entire room evenly	1. Utilizer lux meter and color temperature reader to determine percent error of values. 2. Use diffusing light fixture to disperse light	1. Y 2. Y
Dimmer Circuit	1. Dim 12 V LEDS with flickering below human eye perception (300 Hz) 2. Generate accurate PWM signal with varying duty cycles for optimal control	1. Carefully watch dimming lights to see if flickering is noticeable 2. Use an oscilloscope to measure duty cycle	1. Y 2. Y

Master ATMEGA	1. Communicate with indoor sensors and outdoor sensors through 12C and slave ATMEGAs through UART 2. Include master switch to turn off switch	1. Read communication between sensors 2. Flip switch and see if light turns off	1. Y 2. Y
Slave ATMEGA	1. Read data from master ATMEGA at a delay of 10 ms 2. When indoor light differs from outdoor light by 10% in brightness or color, change indoor light accordingly	1. Read communication between master and slave 2. Use lux meter to gauge light differences and determine values before and after light updates	1. Y 2. Y
Power Supply	1. Voltage input is properly rectified from 120 ± 10 V AC to 12 V DC 2. Current output it limited to 300 ± 10% for each LED	1. Use multimeter to probe input and output voltages 2. Use multimeter to probe current through LEDS	1. Y 2. Y