Modular Light Matching Network

ECE 445 Design Document

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1. Introduction

1.1 Problem and Solution Overview

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 will be building a light system that will emulate natural light and conserve energy during a normal work day. Through an ambient light 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 ir 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.

1.2 Visual Aid

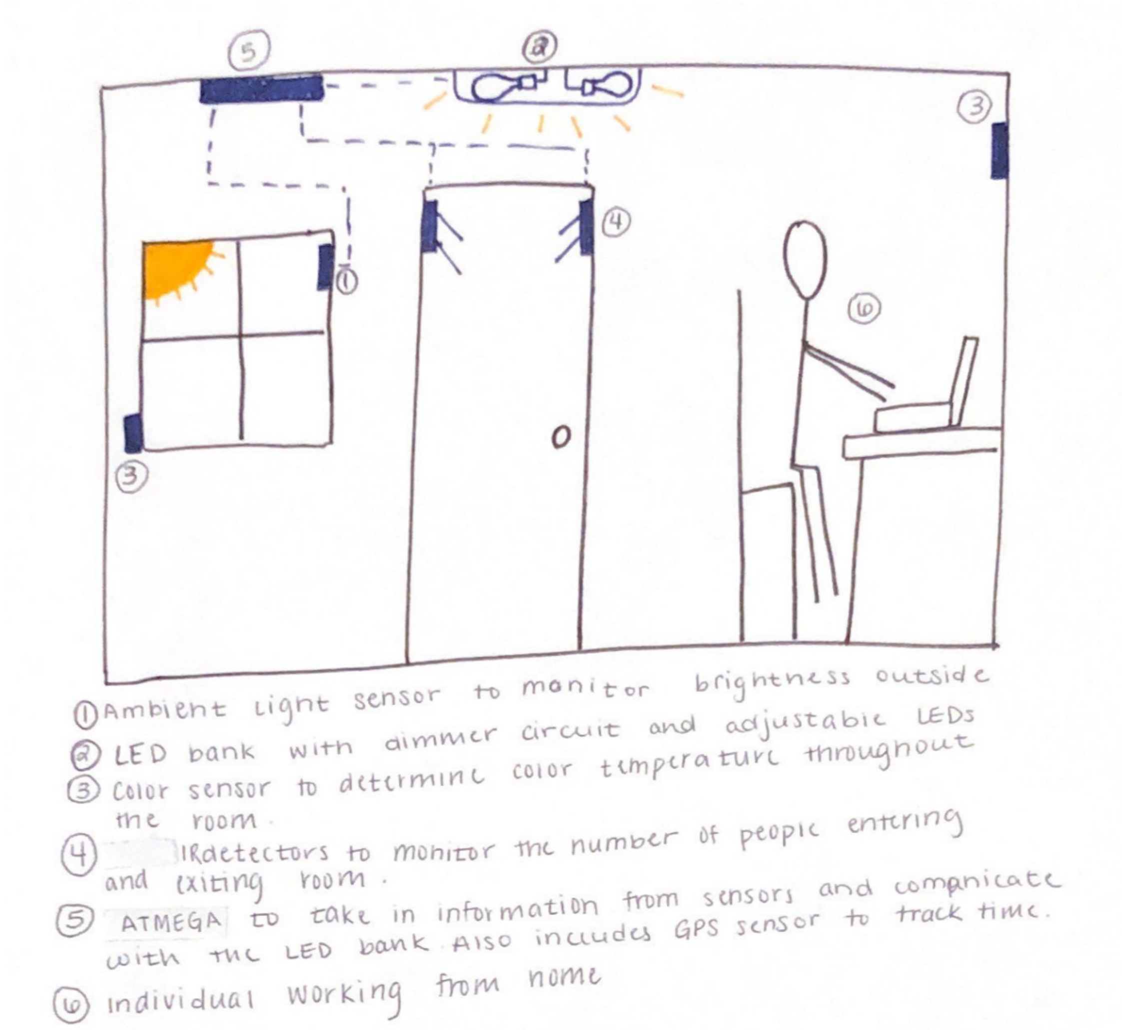


Figure 1: Representation of design with subcomponents

1.3 High-level Requirements

a) Matches a scaled intensity of outdoor lighting within ±10% lux 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 lux (average lux necessary for reading) [4].
c) The light system will turn on and off when a person enters or leaves the room, accounting for the number of people in the room.

2. Design

2.1 Block Diagram

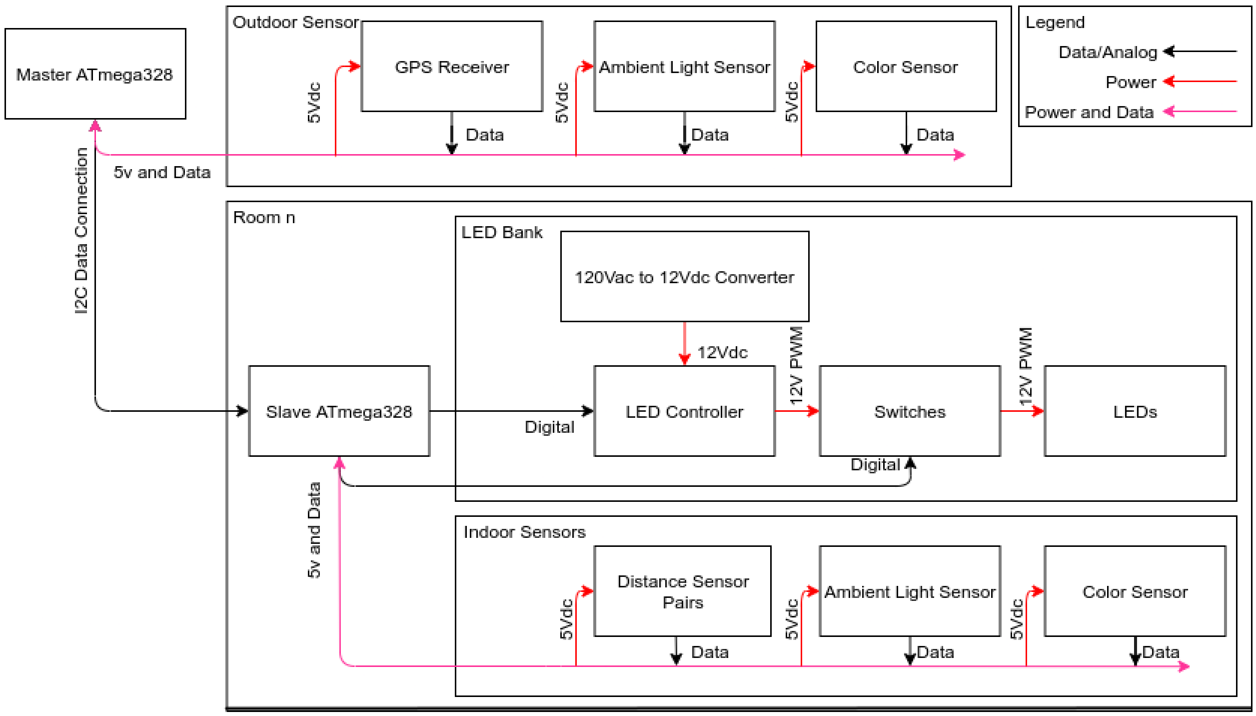
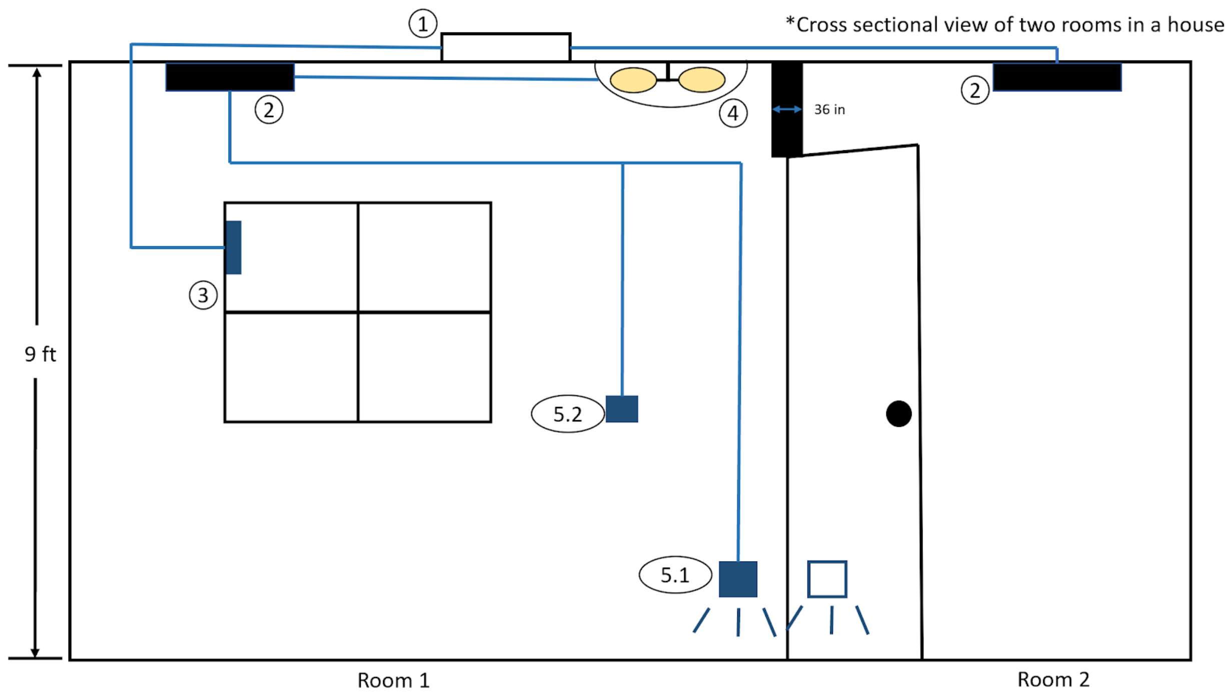


Fig 2: Block Diagram

2.2 Physical Design



1. Master ATMEGA
2. Slave ATMEGA
3. Outdoor Sensor including GPS Receiver, Photoresistor, and Color Sensor
4. LED Bank including LED Controller and PSU, and LEDs
5. Indoor Sensor
   5.1: Laser Sensor Pairs
   5.2: Photoresistor and Color Sensor

Figure 3 : Physical Design

The physical design shows the lighting system including one and a half rooms. Each room has its own slave ATMEGA chip which is contained inside a box and mounted to either the wall or ceiling. The slave ATMEGA chip communicates with the LED bank and indoor sensors. Each slave ATMEGA chip is also connected to the master ATMEGA chip which is connected to a power supply through the house and gathers information from the outdoors sensors including the GPS receiver, light sensor, and color sensor. This information is then communicated to each of the slave ATMEGA chips which turn on the correct lighting if necessary.

2.3 Requirements & Verification

2.3.1 Light sensor network

The light sensor network will contain an ambient light sensor that operates at 5V from the ATMEGA chip. Using a light dependent resistor (LDR), the system will scale down the intensity of outdoors to a suitable intensity indoors.

Requirements	Verification
1. Operate the light sensor within the linear regime of its resistance vs. lux curve. 2. Be under 1000 lux indoors. 3. Maintain temperatures below 75°C.	1. a) Place the sensor in an area that senses ambient lighting of varying brightnesses. Note various lux values measured and the maximum and minimum values. b) Find the optimal position where it is operating within ~10 to 10,000 lux as dictated by figure 9. 2. Scale down maximum brightness outdoors to a maximum of 1000 lux for indoors. 3. Use a temperature gun to ensure LDR does not exceed operating temperature of 75°C. Cover with translucent film if necessary to prevent overheating.

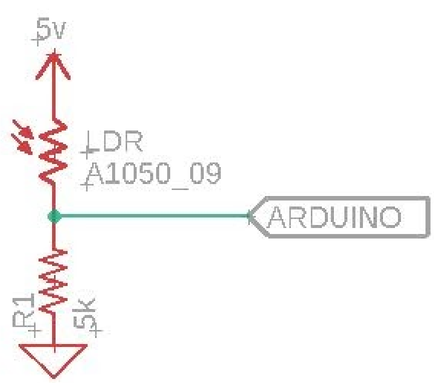


Figure 4: Basic Ambient Light Sensor Schematic

2.3.2 LED Bank

A LED driver that connects to a 120 V outlet and drops it to a constant 12 V DC and minimum current that satisfies our LED ratings. The PWM circuit will be current-controlled and able to dim the light from minimum to maximum brightness depending on resistance values from the ATMEGA chip. Using light and color sensors to measure and match the intensity and color temperature of the outdoor lights to the indoor lights within ±10%.

Requirements	Verification
1. Light sensor and color sensor work in conjunction to bring LEDs to within ±10% °K and ±10% lux of scaled brightness.	1. a) Utilize a light sensor to measure intensity of the indoor light. b) Through the use of MOSFETs, we will turn on or off LEDs until total lux within ±10% lux of scaled outdoor lux. c) Utilize an indoor color sensor to ensure indoor and outdoor color temperatures are within ±10% °K.

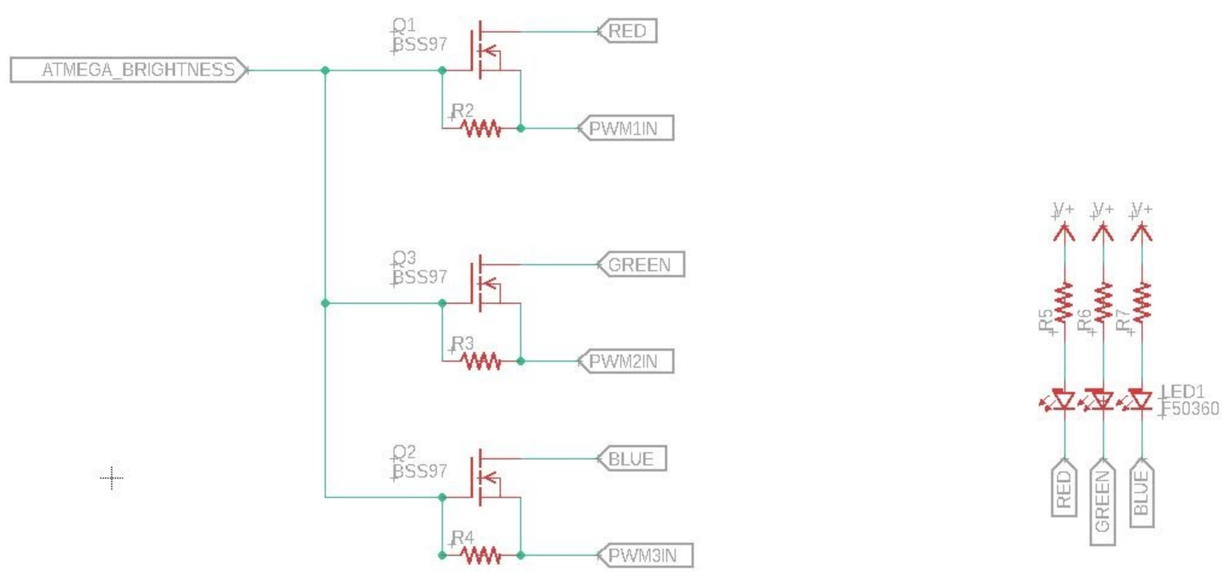


Figure 5: ATMEGA chip to PWM Schematic

2.3.3 Power supply

The power supply will ensure that the current outputted to the rest of the circuit will be limited to 20 mA. This power supply will step down the voltage to a safe level of 12 V DC.

Requirements	Verification
1. Voltage input is properly rectified and stepped down from 120 ±10 V AC to the 12 V DC. 2. Current output is limited to 20 ± 1 mA for each LED .	1. a) Use a 120 V AC to 12 V DC converter to step down voltage. b) Use a zener diode as a voltage reference for constant 12 V DC. c) Test and verify through the use of an oscilloscope that the system stays within its intended values at every step. 2. Use a constant current regulator to ensure ± 1 mA.

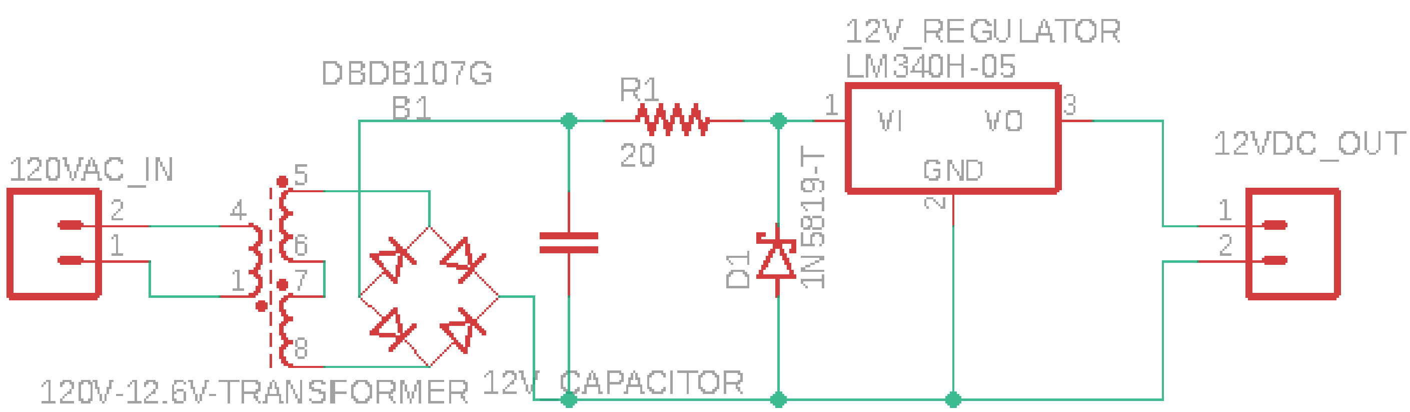


Figure 6: Power Supply Schematic

2.3.4 Dimmer circuit

The system's dimmer circuit will be composed of 12 V LEDs. When given an input from the ATMEGA chip about the light intensity of the outdoor light, the dimmer circuit will dim the LEDs accordingly and ensure that the flickering is not noticeable to the users.

Requirements	Verification
1. Dim 12 V LEDs with flickering below human eye perception.	1. a) Use an oscilloscope to measure the duty cycle and frequency of the timer chip and note frequencies that are uncomfortable to look at. b) Raise frequency to above 200 Hz (ideally 1000 Hz) and change duty cycle to get full range of dimming.

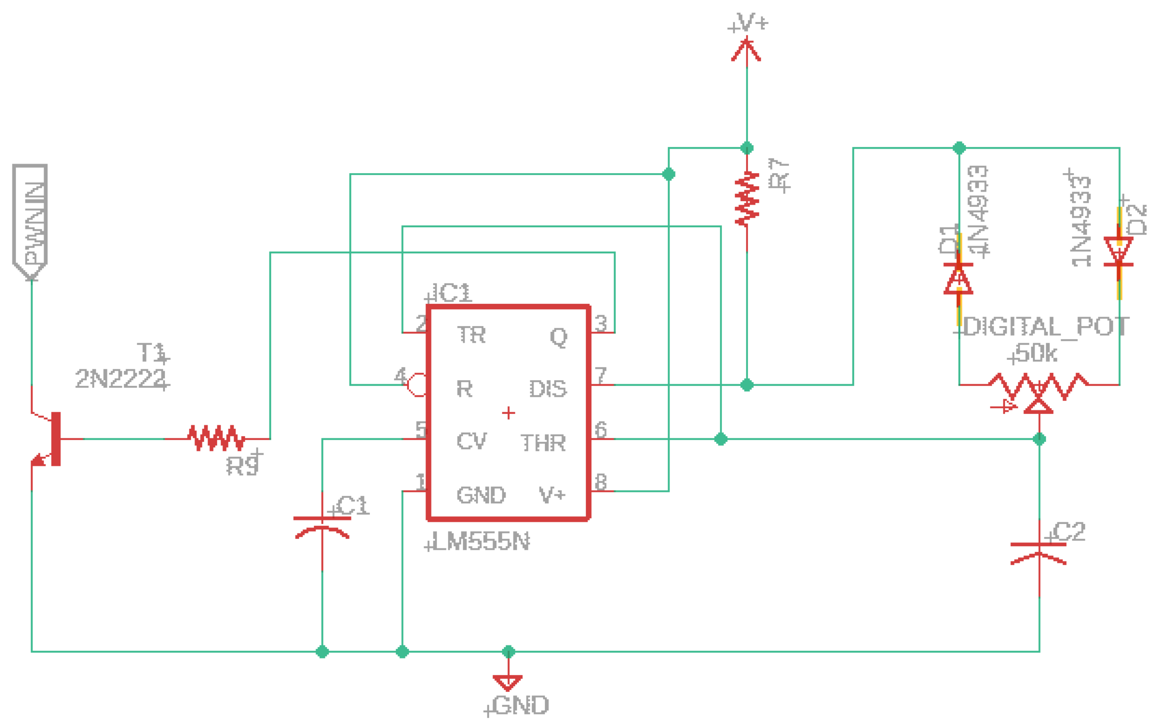


Figure 7: Dimmer Circuit Schematic

2.3.5 ATMEGA

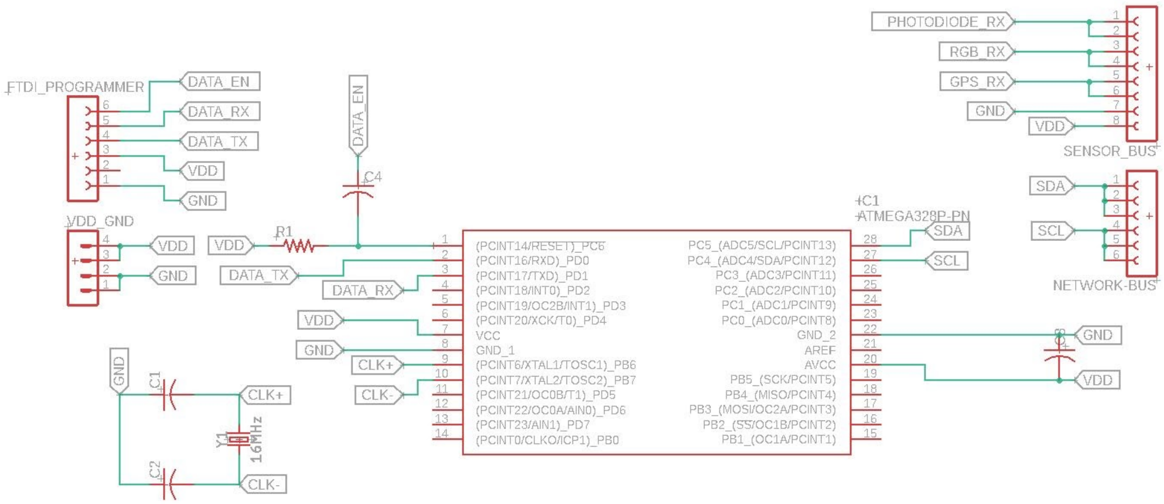


Figure 8: ATmega328 for networking and data analysis schematic

2.4 Plots

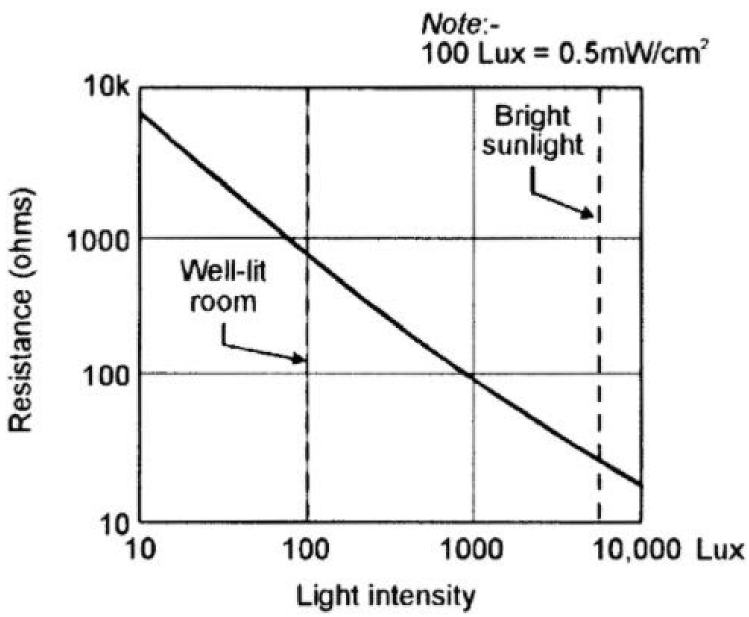


Figure 9: Resistance vs, Illumination Plot [5]

A resistance vs. lux curve is not entirely linear, as it becomes more logarithmic at the extremes. We will limit this by testing the best locations dictated by where sunlight is strongest, and by placing the LDR circuit inside a translucent layer, which will help shave off extremal regions.

2.5 Tolerance Analysis

The most crucial portion of our project is accurately matching color and intensity. Perceived brightness is one issue we must tackle. The brightness our eyes detect is not the same as the brightness measured.

$$Perceived\ Brightness\ Percentage\ =\ \sqrt{Measured\ Brightness\ Percentage} \quad \text{Eqn. 1 [6]}$$

This equation points out that a linear model for outdoor lux vs. indoor lux is not optimal for our perception. A 50% decrease in brightness from 1000 lux to 500 lux will appear to be a 71% decrease to the human eye. This is especially apparent at the lower bounds of the light intensity scale, where a shift in brightness can appear to be a larger step than it actually is. We are tackling this issue by implementing an exponential curve. At low outdoor lux levels, approximately 2000 lux and below, the derivative of our lux curve will be small and essentially flat. As outdoor lux levels increase higher throughout the day, the derivative of the lux curve will increase exponentially. Through our minimum and maximum of 10-10,000 lux outdoors and 1000 lux indoors, we can accurately graph our lux curve with the exponential function: Y = 2^(X/1000) represented below.

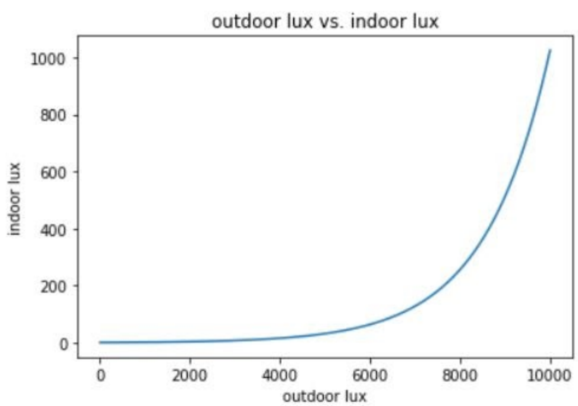


Figure 10

Another issue with perceived brightness is the use of RGB. The luminous flux function below dictates how much each wavelength contributes to luminance.

$$\varphi_v = 683.002\ lm/W\ *\ \int_0^\infty y(\lambda)\varphi_{e,\lambda}(\lambda)d\lambda \quad \text{Eqn. 2}$$

Following the photopic luminosity function (luminance level detected by the eye) given by the graph above, we note that green at a peak of 555 nm produces the highest luminosity, and green at 420 nm produces the lowest. By normalizing the values of the flux for each color, we find the equation below to determine perceived brightness of an RGB LED.

$$Y = 0.2126R + 0.7152G + 0.0722B \quad \text{Eqn. 3}$$

This quite possibly will cause our indoor light sensor to detect a different intensity than the outdoor ambient light sensor. Because the brightness of each LED is directly linked to its RGB values, we will require perceived brightness to determine how many LEDs to turn on or off without causing distortion to the color.

3. Cost and Schedule

3.1 Cost Analysis

Our fixed development cost would be about $19,200. 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.

$$3\ Engineers\ *\ 10\ \frac{hours}{week}\ *\ 40\ \frac{\$}{hour}\ *\ 16\ weeks\ *\ 2.5\ =\ \$48,000 \qquad \text{Eqn. 4}$$

Part	Cost	QTY	Total Cost
Color Sensor	$9.77	1	$9.77
GPS Module	$10.99	1	$10.99
Ethernet Cable Adapter	$8.29	1	$8.29
Cat5 Cable	$7.95	1	$7.95
IR Distance Sensor	$7.99	1	$7.99
LDR	$4.95	1	$4.95
50k digital potentiometer	$2.82	1	$2.82
RGB LED	$8.99	1	$8.99
Ambient Light Sensor	$11.00	1	$11.00
Diode	$2.48	1	$2.48
Voltage Regulator	$1.58	3	$4.74
Zener Diode	$2.70	1	$2.70
ATMEGA chip	$2.09	3	6.27

Total Costs:			$88.94

Our prototype costs for this project's components $88.94. Therefore, the total costs for the project's prototype is $48,088.94.

3.2 Schedule

Week	Josh	Richard	Elizabeth
3/1	Prepare for design review check and work on design document	Prepare for design review check and work on design document	Prepare for design review check and work on design document
3/8	Design review, order necessary components	Design review, work on pcb design	Design review, finalize designs with machine shop
3/15	Solder assignment	Solder assignment	Solder assignment
3/22	Finalize and order pcb design, order any remaining components	Finalize and order pcb design	Finalize and order pcb design
3/29	Begin power supply/ATMEGA I2C testing/assembly	Begin dimmer circuit assembly	Begin sensors testing/assembly
4/5	Assembly and debugging	Assembly and debugging	Assembly and debugging
4/12	Finalize assembly and complete testing	Finalize assembly and complete testing	Finalize assembly and complete testing
4/19	Mock demo, prepare for demonstration, begin final paper	Mock demo, prepare for demonstration, begin final paper	Mock demo, prepare for demonstration, begin final paper
4/26	Demonstration, continue working on presentation and final paper	Demonstration, continue working on presentation and final paper	Demonstration, continue working on presentation and final paper
5/3	Presentation, final paper, lab checkout,	Presentation, final paper, lab checkout,	Presentation, final paper, lab checkout,

	finalize lab notebook, and teamwork evaluation	finalize lab notebook, and teamwork evaluation	finalize lab notebook, and teamwork evaluation

4. Safety & Ethics

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 [7]. 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 [8].

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 [7]. This system may cause privacy concerns because of the fear an outside source may hack the lighting system. If an individual's home lighting system was compromised then the hacker would be able to turn on and off the lights at any point causing fear for the user's safety and privacy. This project goal is to ensure that situations like this will not occur and an outside source would not be able to access the entire lighting system. To protect against this issue the system will not require connection to a wifi which will decrease the risk of the system being hacked.

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. This project deals with the major fire issues that are a concern with incandescent lighting because LEDs do not get as hot or produce heat [9]. 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. Additionally, the system will only use LEDs that have been rated with high safety ratings and standards. The project group has also completed the lab safety courses to ensure that all trials and tests are completed in the safest manner possible.

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 [10]. There is a concern that this system would increase these issues caused by bad lighting. This project is aiming to correct an individual's everyday light exposure and, through research on the topic, the system will be able to improve the overall health of the user. Warm colored and dim lights have been proven to not only improve an individual's circadian rhythm but also increase production of both melatonin and glutamate [11]. This system will produce 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. This is a huge environmental issue that can also affect an individual's health. 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. While this project does add to the issue, it reduces the amount of pollution that a typical lighting system would emit. This is because our system will sense when additional lighting is necessary and dim or shut off the lights when they are not required. The distance detection that is included in the system will ensure that the lights in a room remain off when it is not in use.

With all of the safety and ethical concerns taken into account, the system will reduce any negative effects that could arise. It will follow both "IEEE Code of Ethics" and "ACM Code of Ethics" to create a safe environment for the user at all times.

5. Citations

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