UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Auto Adjusting Desk Lamp

Electrical & Computer Engineering

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Premise

- Problem Introduction
- Our Solution

Problem Introduction

People spend long hours working under poor or inconsistent lighting.

- Lighting that is too dim or bright/ warm or cool
- Lighting that is poorly distributed
- Lighting that fluctuates over time in color or brightness

Impact:

- Eye strain
- Headache and Fatigue
- Reduced Productivity

https://www.flexispot.com/spine-care-center/poor-lighting-a-safety-hazard

Our Solution

Build a lamp that autonomously adjusts brightness & color based on environmental lighting

- Unlike traditional lamps, our solution addresses how lighting can be dynamic due to changes in time, weather, or local obstructions.

Success Criteria:

- Maintain desk lighting within **±10%** of the target lux (≈450 lux).
- Smoothly adapt brightness & CCT (Correlated Color Temperature) with **<2% change per second**.
- Reduce power consumption by **≥20%** under daylight.
- Deliver stable, comfortable, flicker-free lighting.

Our Solution Cont'd

Brief Demonstration Videos

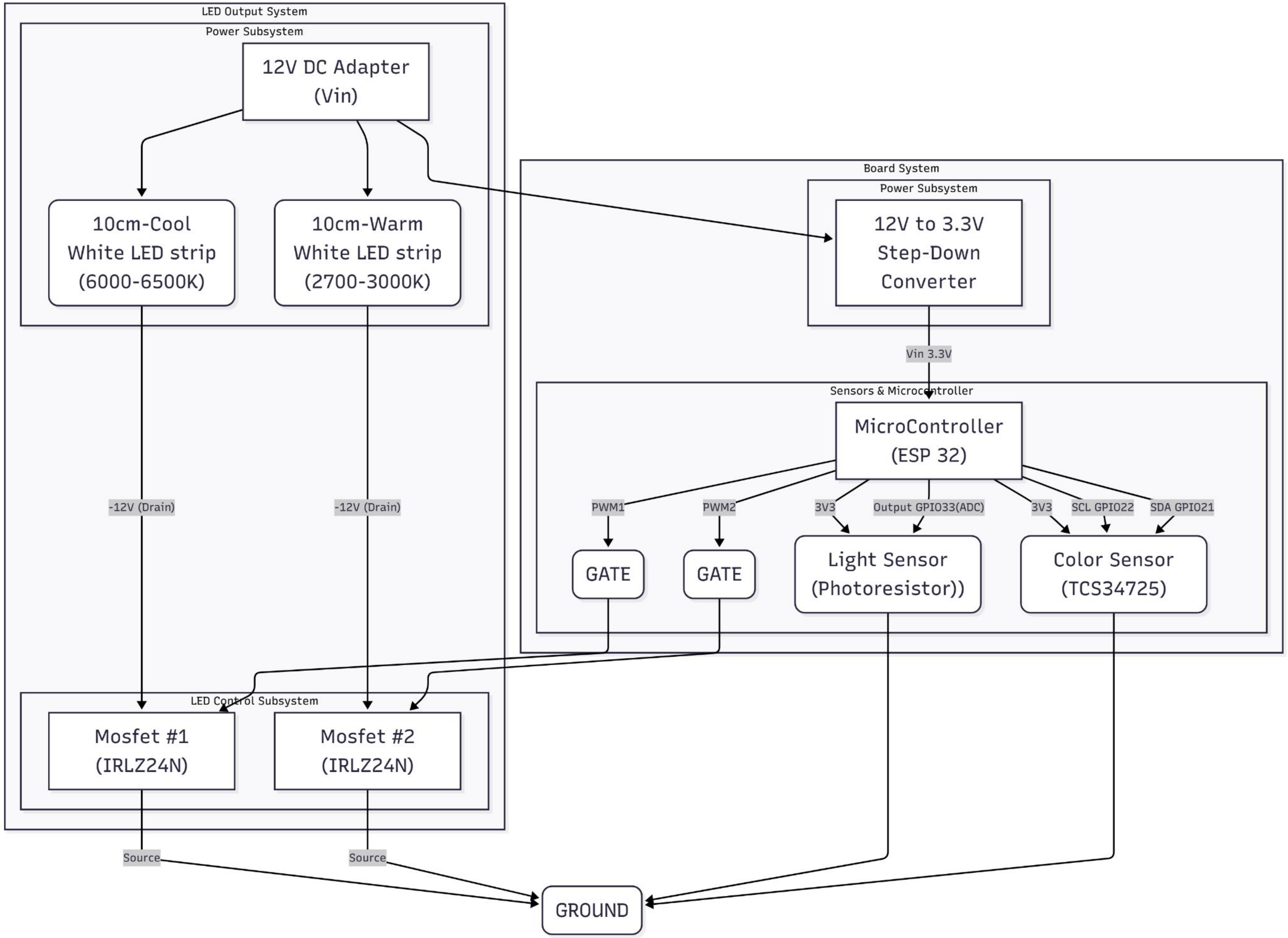
<- From Bright to Dark Surroundings

From Dark to Bright Surroundings ->

Design Overview

- Block Diagram
- Subsystems Overview

Block Diagram

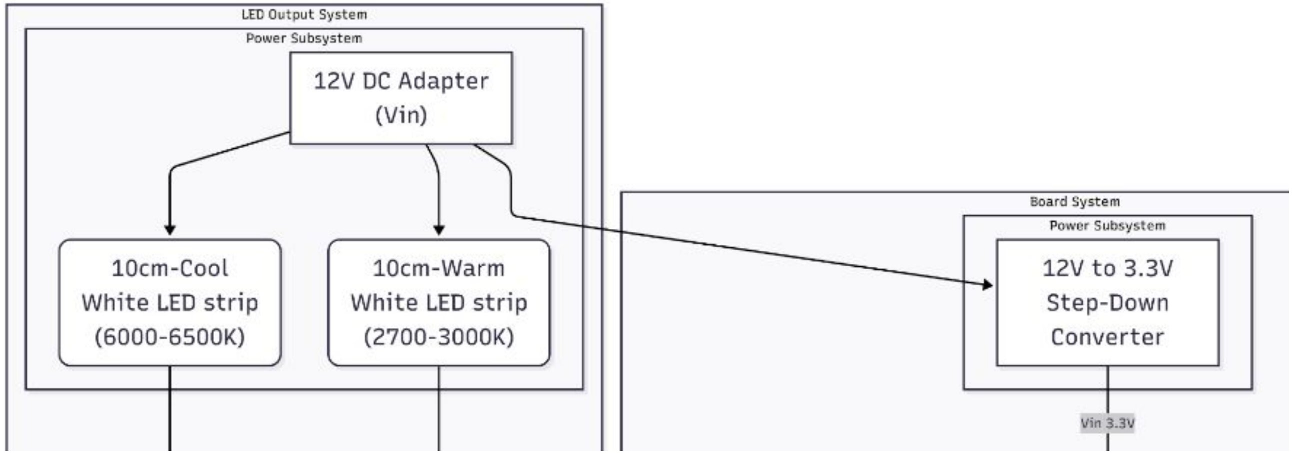


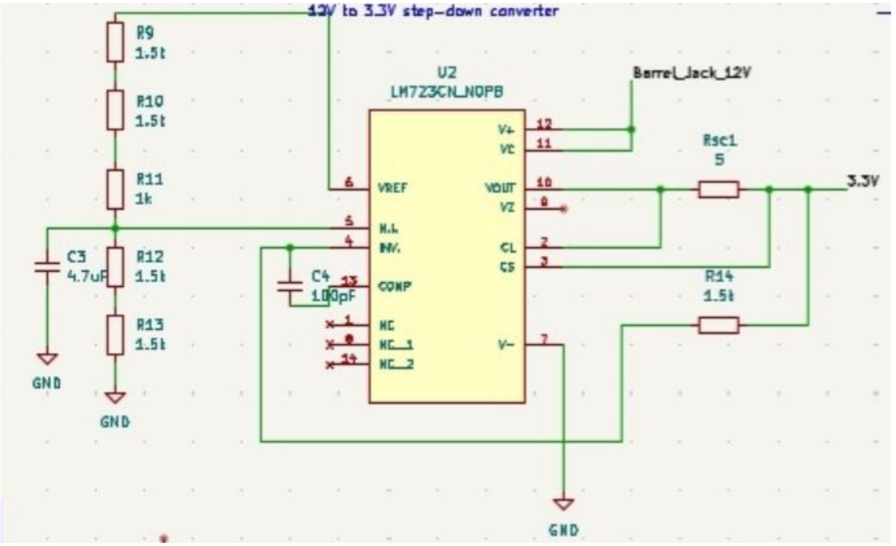
Subsystems Overview- Power

3.3 ±0.3V at ≥500 mA must be supplied to the ESP32-S3 and sensors, and 12V must be supplied to the LED output subsystem.

- We used the LM723CN voltage regulator to divert ~3.1V from our 12V power supply to power our ESP32 and sensors.

Voltage (V)	3.1
Current (A)	1.1





Subsystems Overview- Sensors

Brief Definitions of Terms:

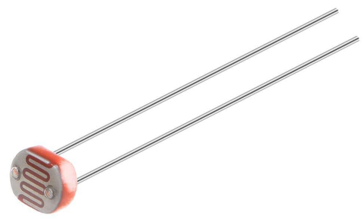
- “Lux” & “CCT” will be used interchangeably with “brightness”. It can also refer to a unit describing brightness level when there is data being shown.

- “Color”, “Temp”, & “Temperature” will refer to color temperature. It can be either warm (red) or cool (blue) and will have the unit K.

Subsystems Overview- Sensors Cont’d

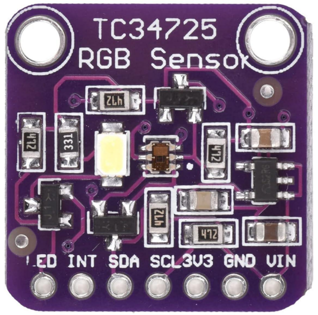
Our design uses 2 sensors to measure environment lighting:

Photoresistor Voltage Divider - Lux Sensor*



- Delivers a voltage between 0-3.3V to ESP32’s ADC with adequate precision and lux range
- Used for adjusting overall brightness

TCS34725 - Color Sensor



- Delivers RGB values to ESP32 via I2C protocol
- 2700–6500K measurement range
- Used to balance warm/cool channels

*Originally OPT101 but due to its limited lux range it became saturated in relatively dim environments and thus unusable for our application

Subsystems Overview- LED Output

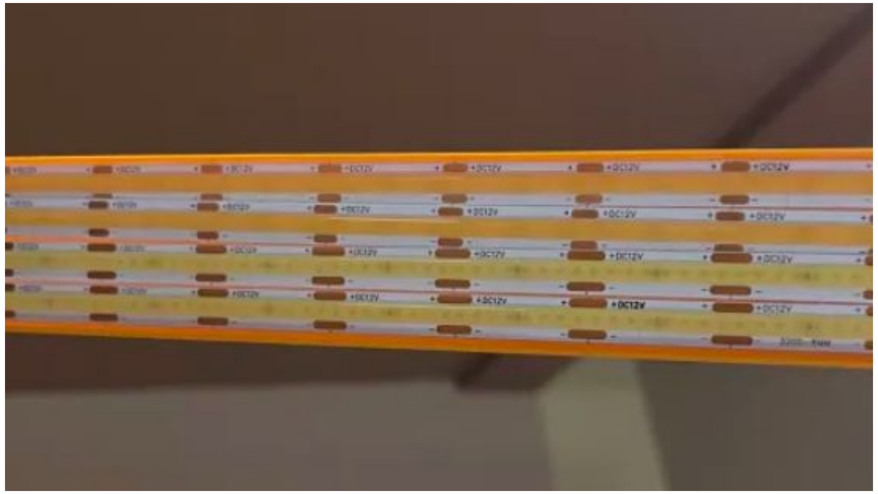
Our design uses a combination of warm and cool LED strips to achieve color mixing:

- Cool white 6000–6500K COB
- Warm white 2700–3000K COB

The LEDs are powered via external power adapter and driven by IRLZ24 MOSFETs.

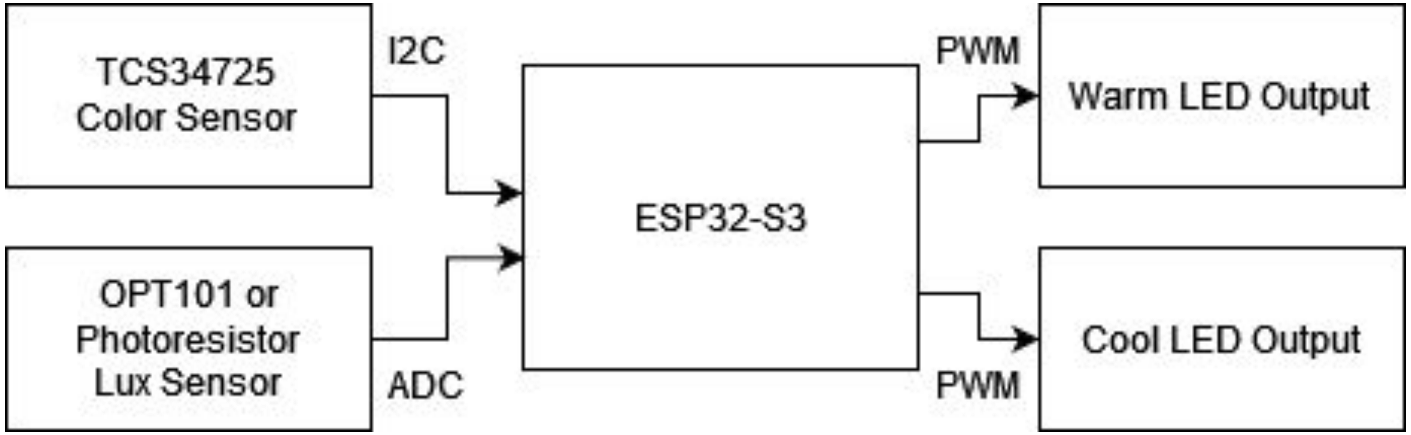
- Each set of colored LEDs (warm or cool) are driven independently by separate ESP32 PWM signals through the IRLZ24's gate

LED output achieved <u>1173 lux</u> @ 30cm



Subsystems Overview- Microcontroller

Our design uses an ESP32-S3 microcontroller to process sensor data and output 2 PWM signals to our 2 sets of LED strips:



Our final iteration has more IO for the user to adjust parameters in the auto adjusting algorithm:

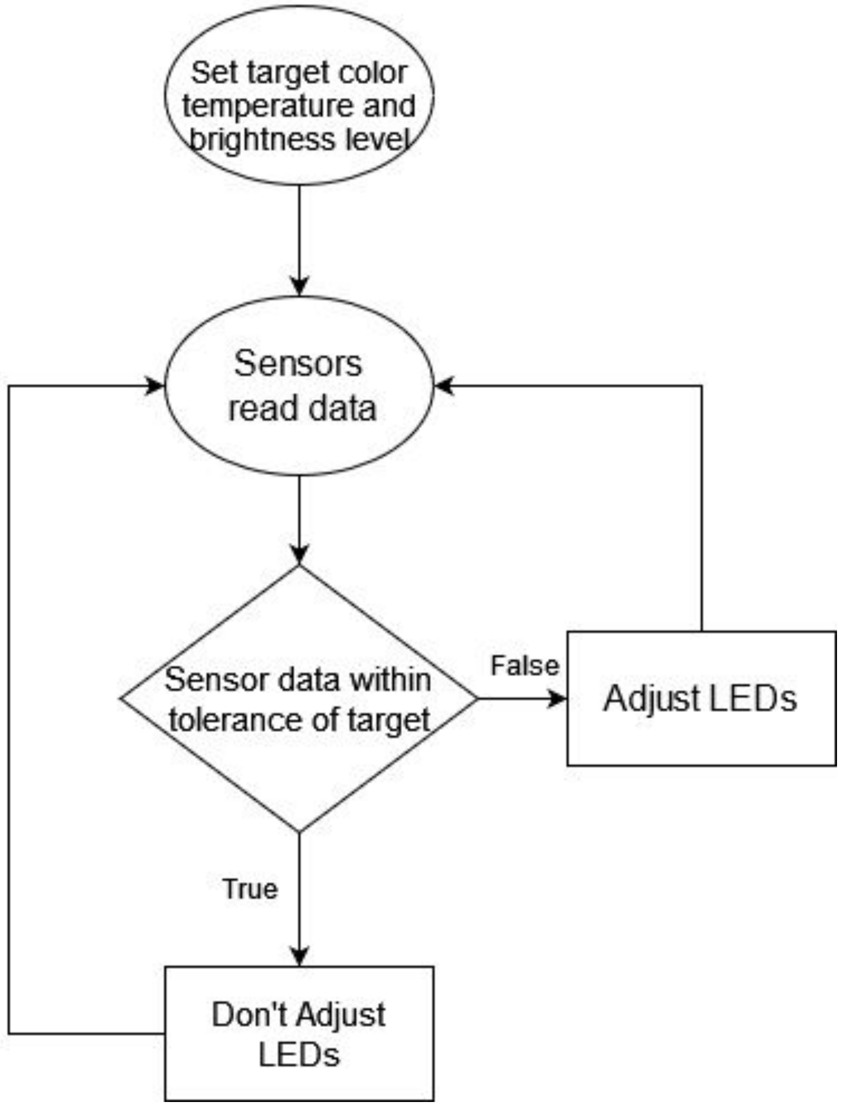
- Target lux and temperature
- Sensor and adjustment tolerance sizes (sensor sensitivity and rate of adjustment)

Subsystems Overview- Microcontroller Cont'd

High-Level Overview of Auto Adjustment Algorithm:

1. Initialize preset target lux and temp or user set lux and temp
2. Poll sensors and check if readings are within tolerance of target lux and temp
3. If readings are not within tolerance, adjust PWM- otherwise do nothing
4. Repeat step 2

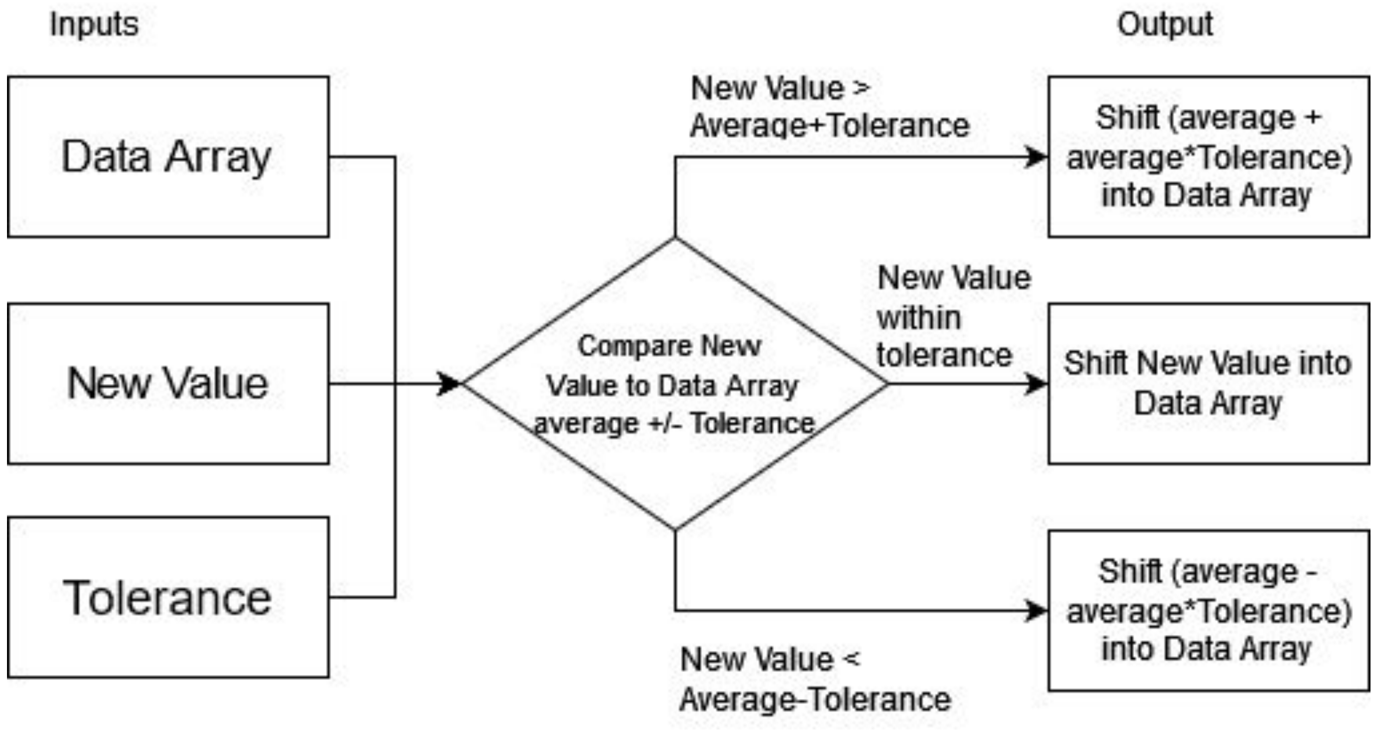
Ultimately the sensors determine if the lamp has reached a target lux and temperature.



Subsystems Overview- Microcontroller Cont’d

High-Level Overview of Data Filtering Algorithm:

- The data filtering algorithm is central to our design since it ensures smooth LED output adjustment.
- It is applied to both sensor readings and LED PWM output.
- We use the average of the data array for our outputs

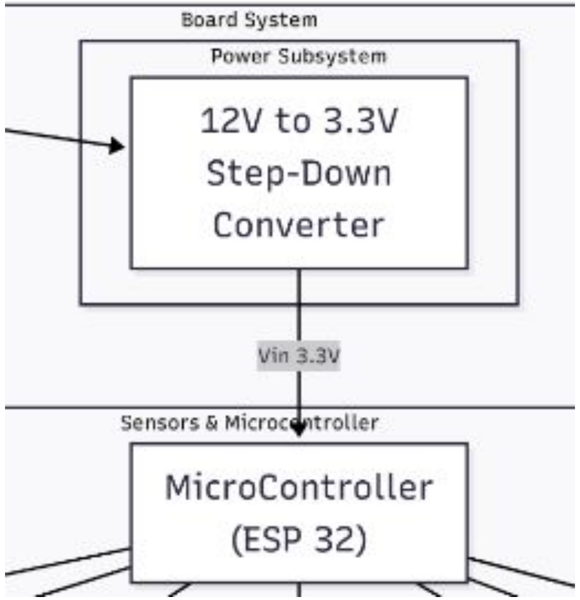


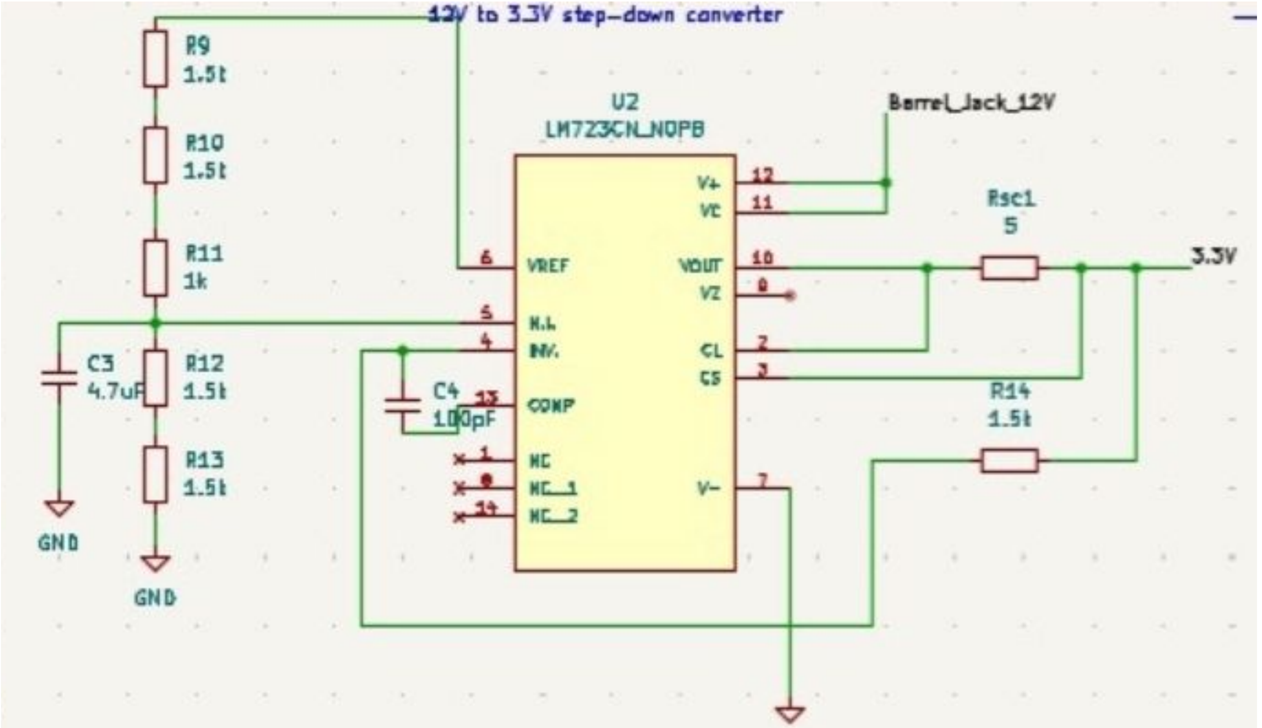
Hardware Implementation

- PCB Schematic
- Physical Design

PCB Schematic

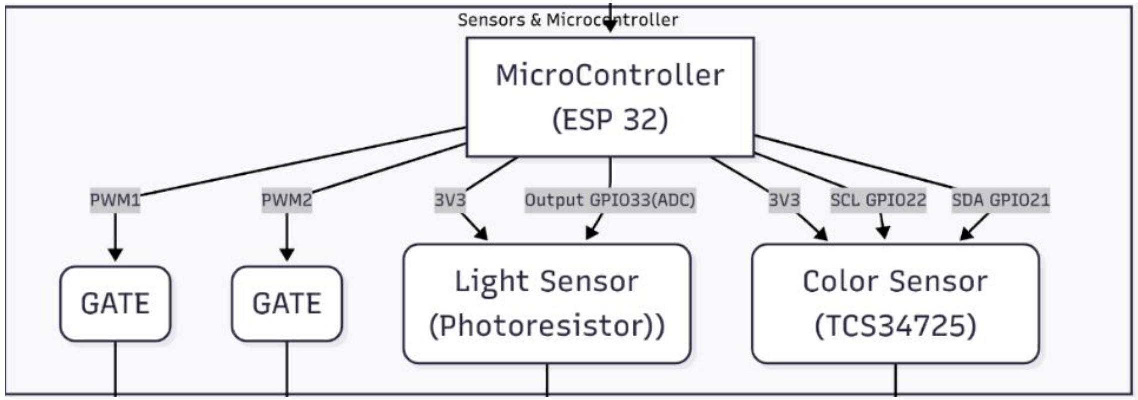
12V-3.3V Voltage Step-down

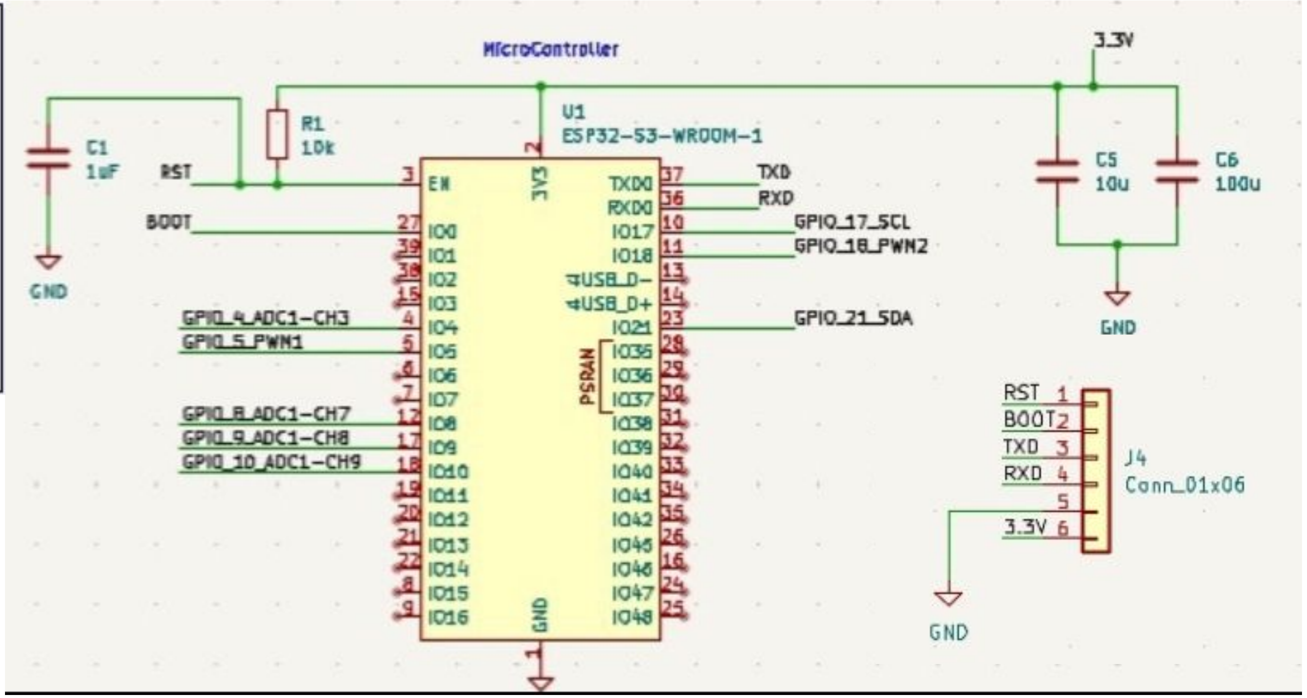




PCB Schematic

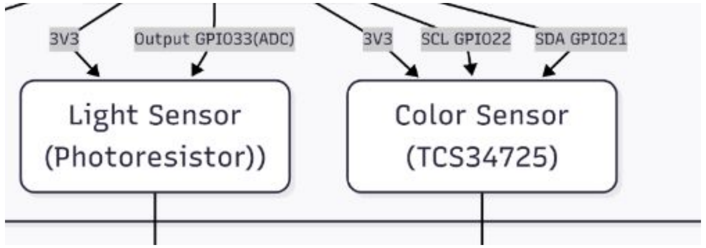
Microcontroller (ESP32-S3)



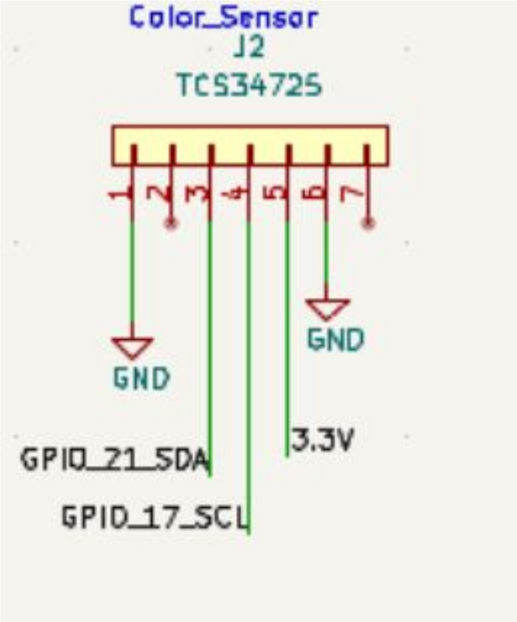


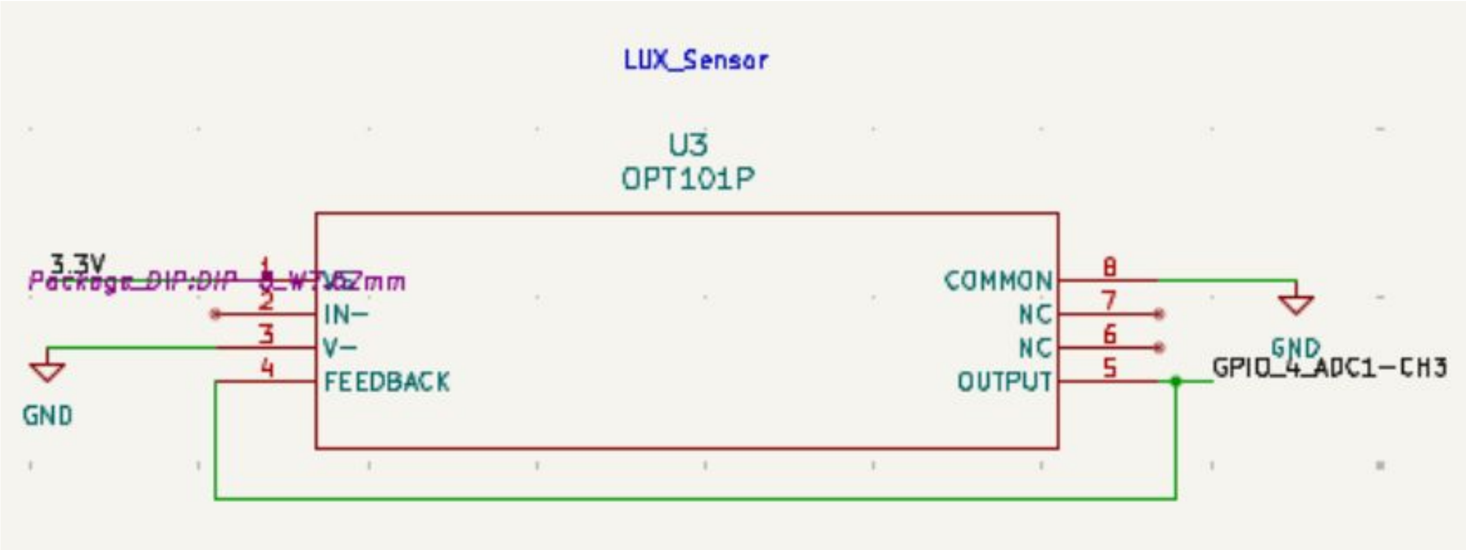
PCB Schematic

Sensors



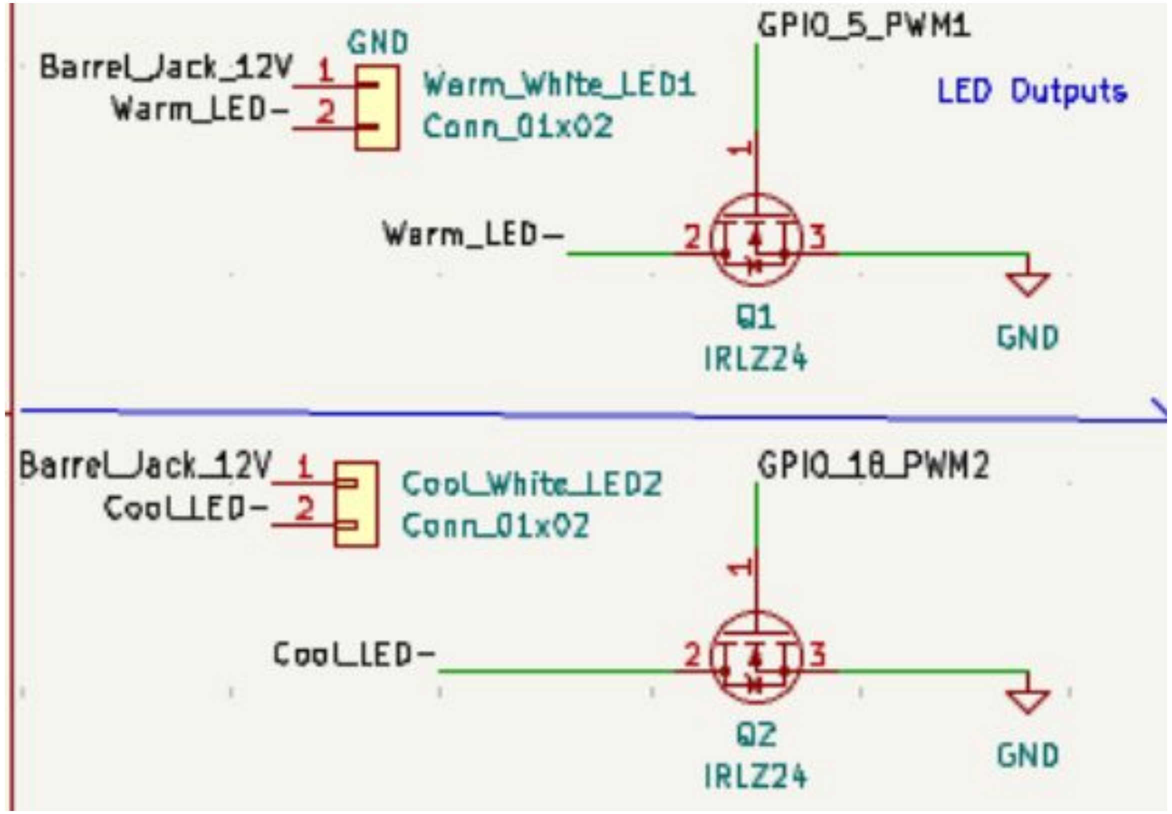
Note:
We kept the OPT101 through-holes on our PCB design because we could repurpose them for our photoresistor-voltage-divider lux sensor.
The option to use either sensor was open to us during assembly.





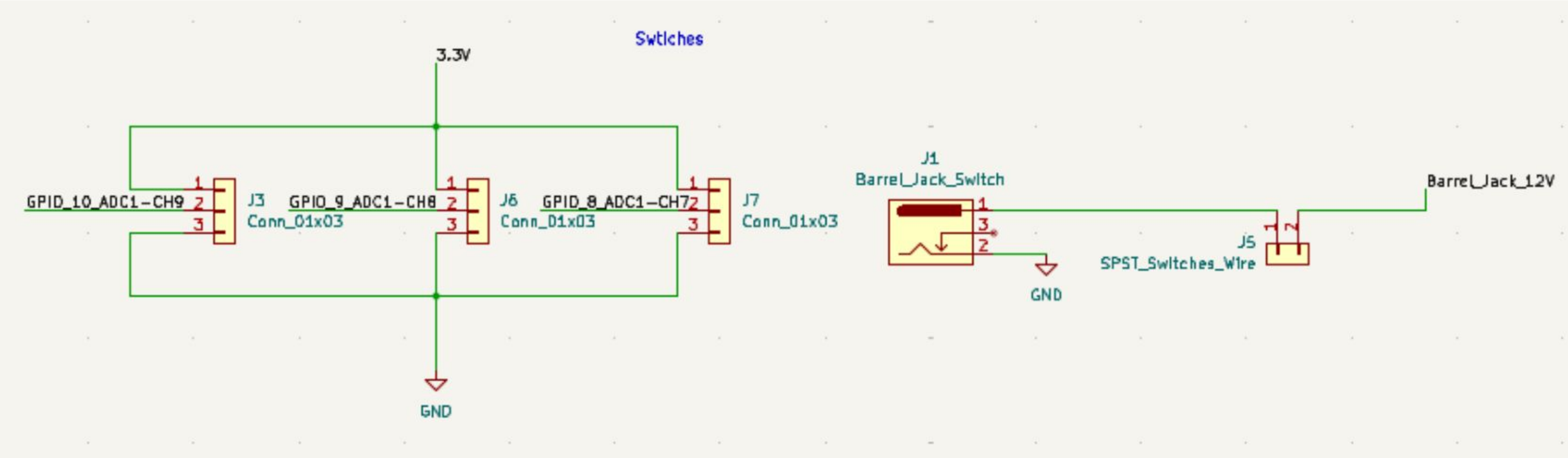
PCB Schematic

LEDs and MOSFET drivers



PCB Schematic

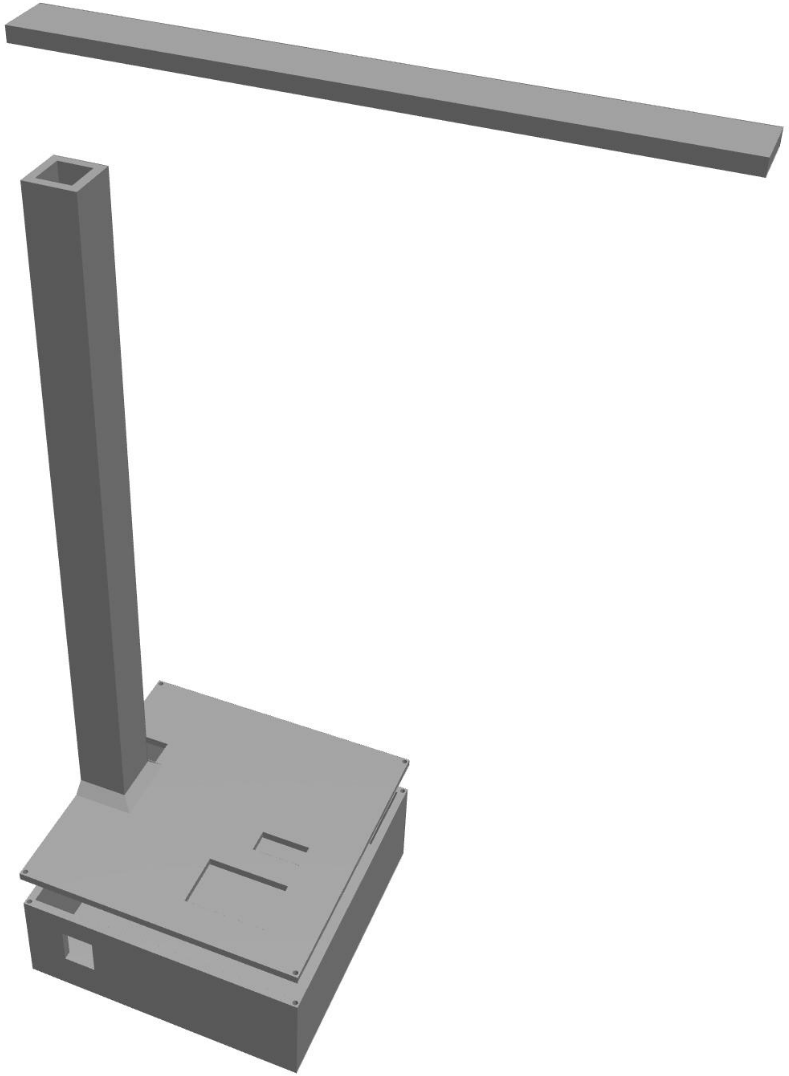
User IO



- The right sub-schematic shows through holes connected to the ESP32's GPIO pins for user controls
- The left sub-schematic is for the on/off switch

Physical Design

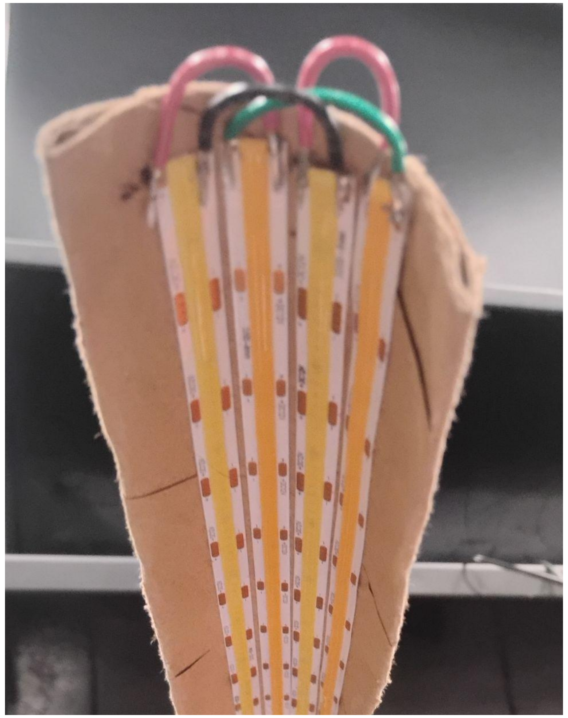
3rd Round PCB Design

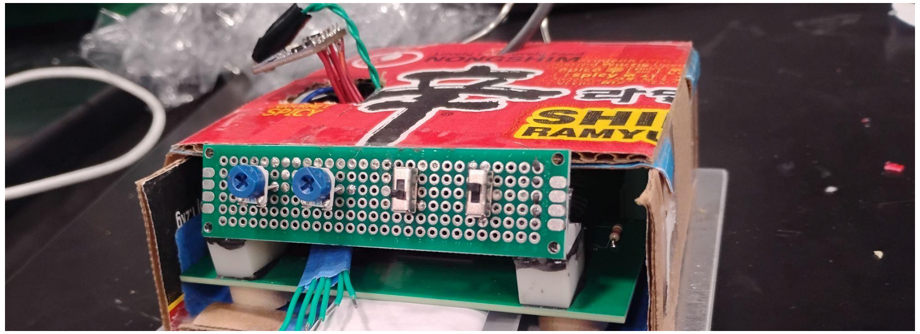


Physical Design

4th Round PCB Design

- Added User Input
    - Target Lux and Temp dials
    - Power and Mode switches
- Curved lamp head and alternating LED strips for better color mixing
- Sensors soldered to wires for adjustability





Verification

- Lux and Color Levels
- Adjustment Smoothness
- Gamma Correction
- Power Saving

Lux and Color Levels

The lamp must keep the desk surface within ±10% of the target brightness level, with about 450 lux even when the surrounding light changes.

Environment	Measured Lux	Target	Error
Enough light	411	450	–8.7%
Dark	478	450	+6.2%

-Enough light (300lux)

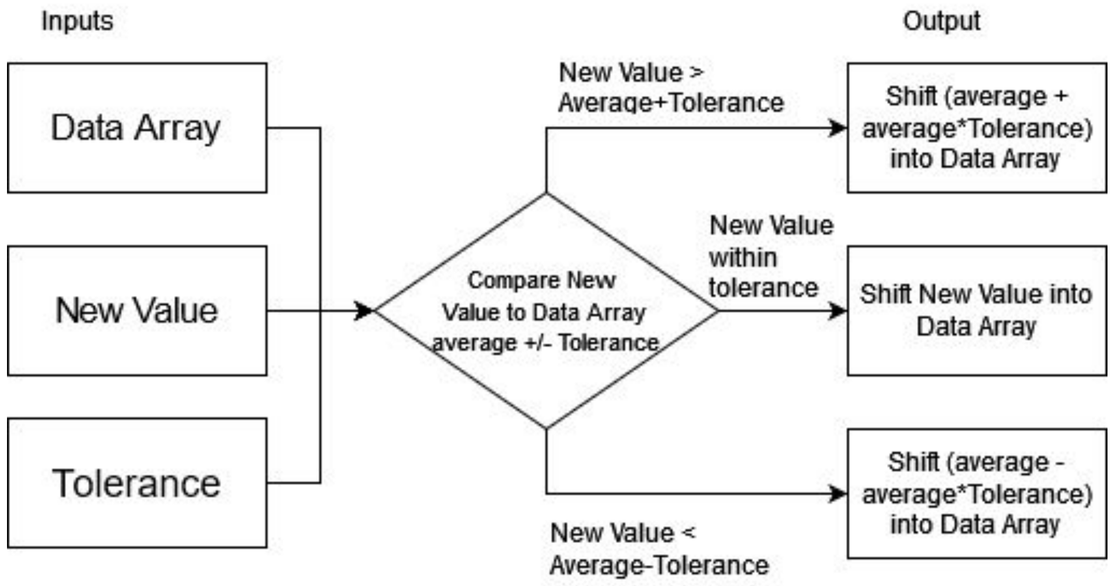
-Dark (10lux)

(Building and Environment, vol. 186)

Adjustment Smoothness

- The lamp change must change brightness no more than 2% per second to maintain stable visual perception without oscillation

- This is achieved through passing the PWM output through a data filtering algorithm that sets a hard limit on the allowable rate of change (see Subsystems Overview- Microcontroller)

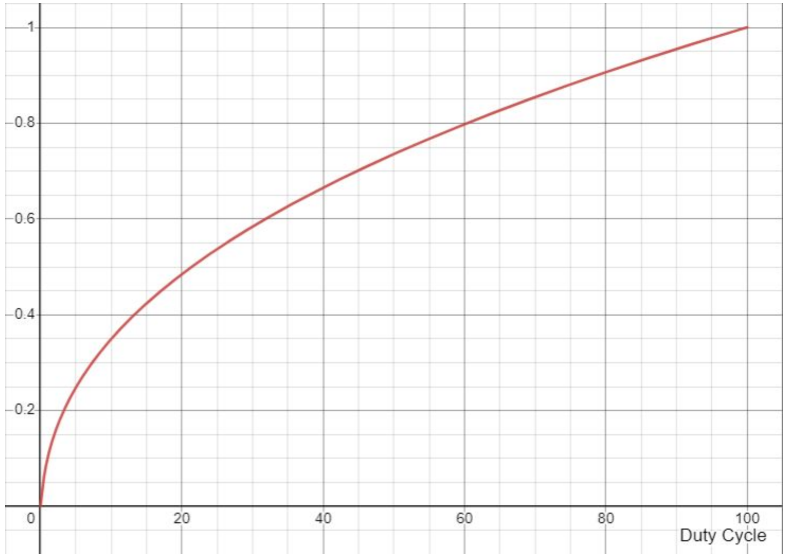


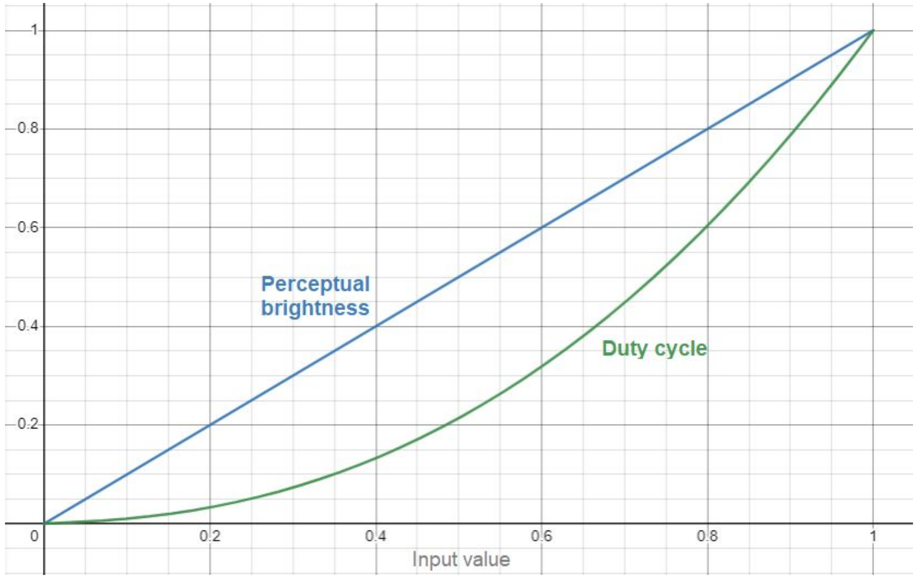
Gamma Correction

- Human vision is non-linear and scales logarithmically in response to increasing brightness (more sensitive in darkness)

- Gamma Correction refers to the correction of this scaling by having our LED output increase exponentially to achieve a linear perception of change in brightness

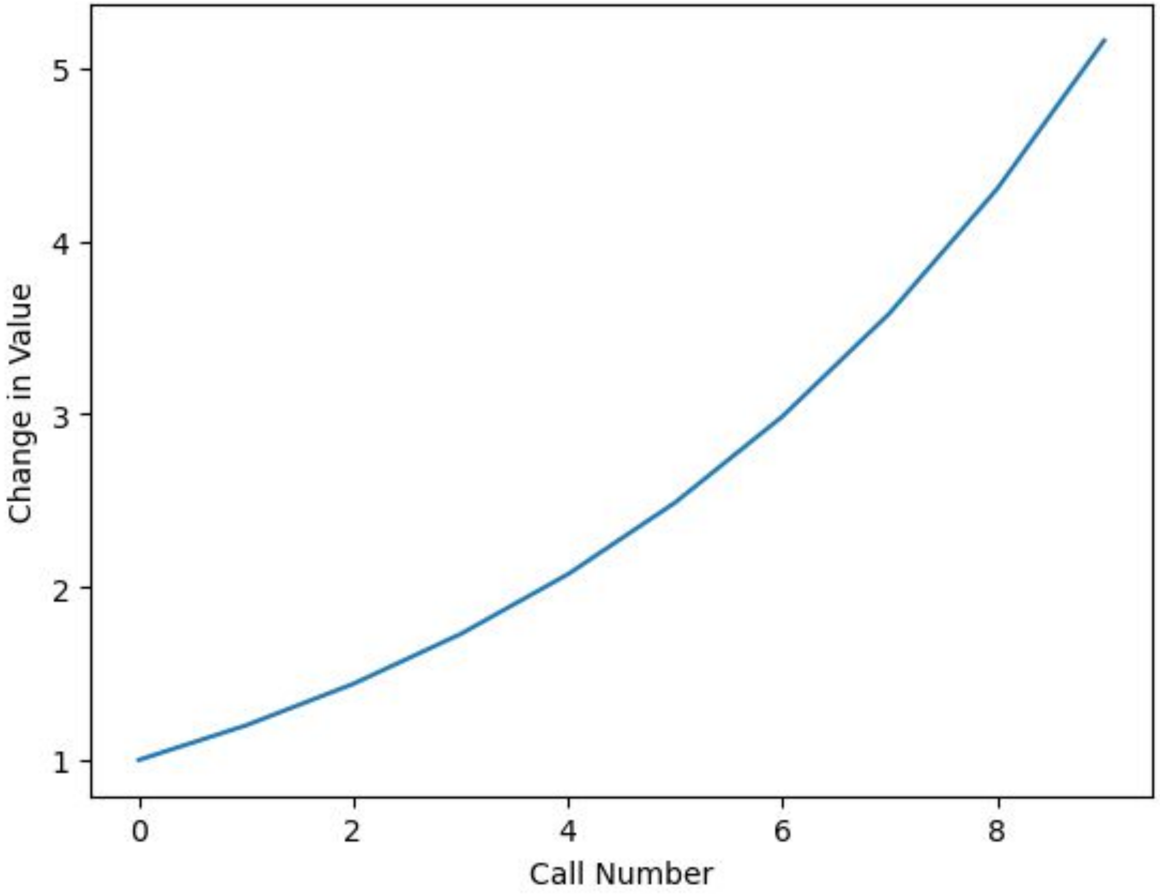
- See Citation https://codeinsecurity.wordpress.com/2023/07/17/the-problem-with-driving-leds-with-pwm/





Gamma Correction Cont'd

- Our data filtering algorithm has Gamma Correction built in mathematically
- As the data in a data array increases, the average of the data array increases non-linearly every call



Power Saving

- The lamp must lower its power use by at least 20% compared to full brightness when there is enough daylight in the room.

Environment	Current/A	Voltage/V	Power/W
Dark (10lux)	1.585	10.433	16.536
Enough Daylight (300lux)	1.237	8.657	10.709

The system achieved a 35.2% reduction in power.

Thank you!

The Grainger College of Engineering

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