ECE 445 Senior Design Laboratory

Project Proposal

Auto-Adjusted Smart Desk Lamp for Healthy Lighting

Team 15

TEAM MEMBERS:
Howard Li [zl114]
Jihyun Seo [jihyun4]
Kevin Chen [kdchen2]

TA
Zhuoer Zhang

Table of Contents

1. Introduction

1.1 Problem

Prolonged desk work under poor or inconsistent lighting can cause eye strain, headaches, and fatigue. Most desk lamps today are static; they require manual adjustment and do not adapt to changes in daylight or different tasks. This often leaves users with lighting that is either too dim or too bright for their task.

Research shows that digital eye strain is a growing issue, especially for people spending hours on screens. Poor lighting around the desk only makes this problem worse, leading to discomfort and reduced productivity[1]. A desk lamp that can automatically adjust brightness and color temperature would help create a healthier and more comfortable environment for studying, gaming, or working.

1.2 Solution

We plan to build a smart desk lamp that adjusts itself based on the lighting around the desk. The lamp will use two sensors: one to measure overall brightness and one to measure color temperature. These readings will go into a microcontroller (ESP32), which processes the data and decides how the lamp should respond.

The light itself will come from two LED sources, one warm white (2700–3000K) and one cool white (6000–6500K). By mixing these two channels with PWM control, we can cover a wide range of color temperatures, from warm evening light to cooler daylight. A pair of LED drivers will supply a stable current to the LEDs.

The ESP32 will run the control logic. It will filter out noise from the sensors, calculate the target brightness and color temperature, and then adjust the LEDs gradually. Gamma correction will make sure the brightness changes look smooth to the eye, and a rate limiter will prevent sudden jumps.

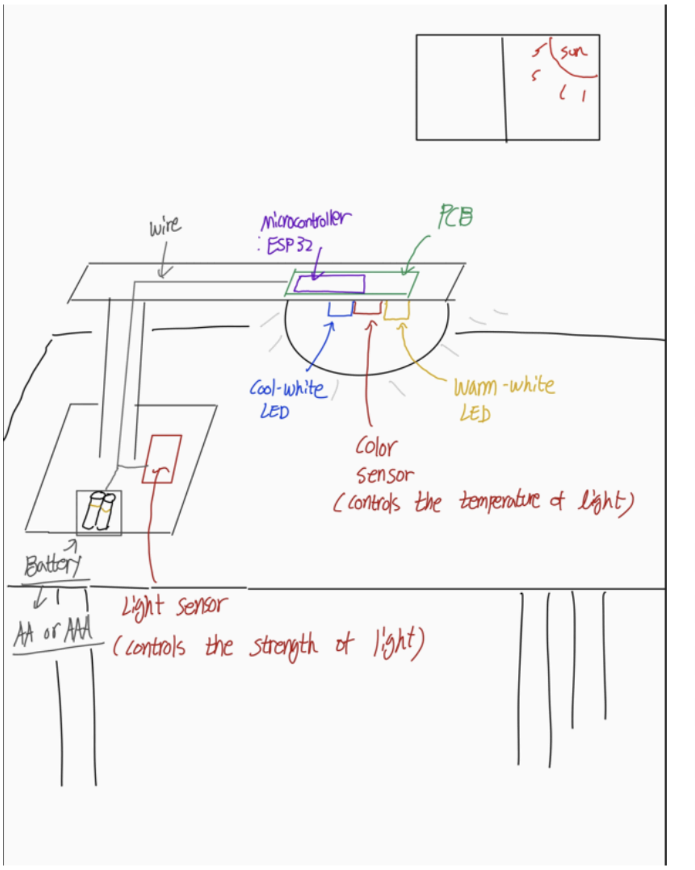
For the user, we plan to include a simple button to switch between modes like Study, Relax, or Gaming. Each mode will set a different brightness and color target, but the lamp will still adapt to the room lighting in real time. An optional knob can allow manual override if someone wants full control.

This design keeps the system straightforward: sensors read the environment, the microcontroller decides the output, and the LEDs adjust to maintain healthy and comfortable lighting while saving energy when daylight is available.

1.3 Visual Aid

The smart desk lamp will sit on a normal study desk and face the work area where a person reads, studies, or uses a computer. A light sensor near the lamp will measure the brightness on the desk, and a color sensor will check the tone of the surrounding light. The lamp will then adjust its own output to keep the desk at the right brightness and color temperature.

When there is strong daylight from a window, the lamp will dim automatically to save energy. At night or in darker conditions, it will brighten and shift to a warmer tone for comfort. A simple button on the lamp lets the user switch between modes like Study, Relax, or Gaming. An optional knob gives full manual control if needed.



1.4 High-level requirements list

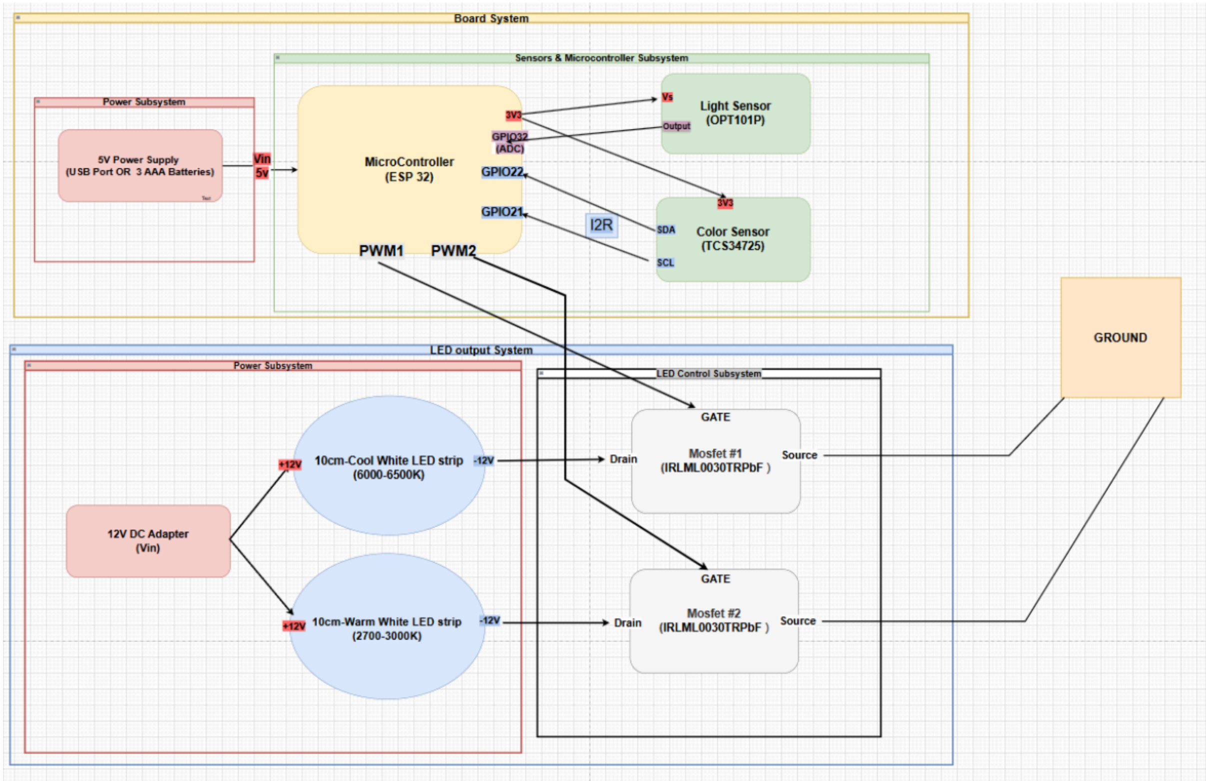
-The lamp must keep the desk surface within ±10% of the target brightness level, with about 500 lux in Study Mode and 300 lux in Relax Mode, even when the surrounding light changes.

-The lamp must adjust brightness and color temperature gradually, with changes limited to no more than 2% per second, so the user does not notice sudden jumps or flicker.

-The lamp must lower its power use by at least 30% compared to full brightness when there is enough daylight in the room.

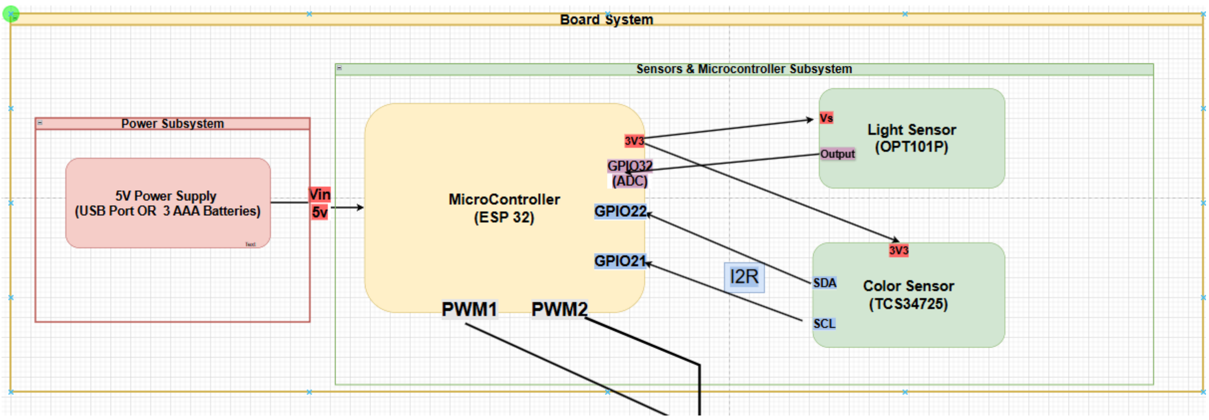
2. Design

2.1 Block Diagram



2.2 Subsystem Overview

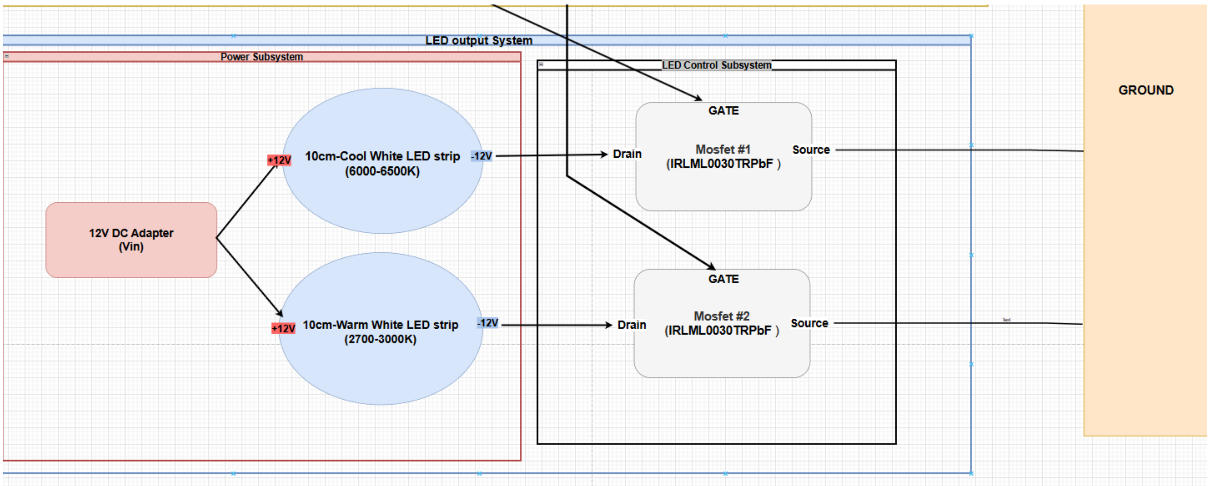
1. Board System



The first major subsystem is the board system, which includes the low-power electronics. A 5V supply, either from a USB port or three AAA batteries, provides input to the ESP32 microcontroller. The ESP32 is the control unit of the lamp and runs all the logic. Two sensors are connected to it: the TCS34725 color sensor through the I²C bus (GPIO22 as SCL and

GPIO21 as SDA), and the OPT101P light sensor, which outputs an analog signal to GPIO32 (ADC). Both sensors are powered from the ESP32's 3.3V output. This setup lets the ESP32 read both brightness and color information from the desk environment and compute how the lamp should respond.

2. LED Output Control System



The second major subsystem is the LED output system, which is powered separately by a 12V DC adapter. This 12V supply drives two LED strips: a cool white strip (6000–6500K) and a warm white strip (2700–3000K). Each LED strip is connected through a MOSFET (IRLML0030TRPbF). The drains of the MOSFETs connect to the LED strips, the sources are tied to ground, and the gates are driven by PWM signals (PWM1 and PWM2) from the ESP32. By adjusting the PWM duty cycles, the ESP32 can control both brightness and color temperature smoothly, blending the two strips to reach the desired lighting conditions.

Together, these two subsystems make the smart desk lamp. The board system handles sensing and decision-making, while the LED output system produces the actual light. With real-time feedback from the sensors, the ESP32 can adjust the lamp's output to maintain comfortable brightness and color temperature, giving the user a stable and adaptive lighting experience.

2.3 Subsystem Requirements

1. Power Subsystem (5V USB or 3×AAA batteries): Must supply 5V ±0.1V at ≥500 mA to power the ESP32 and sensors. If the voltage drops below this range, the microcontroller or sensors could fail.
2. Light Sensor (OPT101P): Must measure ambient brightness from 0–65,000 lux with ±5% accuracy. This data is needed to keep desk lighting within ±10% of the target lux level.
3. Color Sensor (TCS-34725): Must detect correlated color temperature (CCT) in the range of 2700K–6500K with ±10% accuracy. This allows the system to adjust the LED mix correctly.
4. Power Subsystem (12V DC Adapter): Must supply 12V ±0.2V at ≥1A to the two LED drivers. If the voltage drops, the LEDs will not reach full brightness.

5. LEDs (Strips of Warm white and white): Must output enough light to reach at least 1000 lux at 30 cm from the desk surface. By mixing the two, the lamp must cover the full color temperature range from 2700K–6500K.

2.4 Tolerance Analysis

The lamp must dim smoothly with no visible steps or flicker. We control light level by changing the PWM duty cycle that goes into the LED drivers. If we drop duty from 75% to 50%, a user should clearly see it get dimmer—but the transition should be gradual and step-free. Our main concern is whether the ESP32 can change duty in small, precise increments and whether the LED drivers will track those changes cleanly.

feasibility:
Choose PWM frequency = 1 kHz (period = 1 ms) to stay far above visible flicker; the datasheet confirms we can still keep 16-bit duty precision at this period. That's 65,536 duty steps. Each step is ~0.0015% of full scale (1/65536), which is much finer than our design goal (we cap visible change to ≤ 2%/s in firmware). With such fine resolution, we can implement gentle ramps (e.g., change duty by a few dozen counts every 10–20 ms) so the user won't see discrete jumps. The LEDC hardware can also do automatic step ramps, which lowers firmware burden and makes timing consistent.

Non-idealities and how we handle them:

1. Perceived brightness is nonlinear. The eye roughly follows a gamma response, and LED + optics are not perfectly linear with current. We will apply gamma correction in the control loop so "equal steps" look equal to the user (we already do this in the control plan).
2. Driver tracking and rise/fall time. Constant-current LED drivers typically accept logic-level PWM and average the current over a cycle. We'll validate that the driver's PWM input threshold works with 3.3 V logic and that it tracks cleanly at ~1 kHz (no pulse swallowing). If needed, we'll adjust frequency (e.g., 1–2 kHz) to match the driver's recommended range.
3. Sensor noise & step visibility. We use an exponential moving average on lux readings and a rate limiter in software so even if ambient light shifts quickly, the lamp changes at a capped slope (≤2%/s). This prevents "hunting" or rapid oscillations.

Test plan (demonstrable):

1. Bench step test: Command duty steps (e.g., 1%, 2%, 5%) and record LED current vs. time. Expect a smooth current without overshoot.
2. Ramp test: Sweep duty 50%→75% over 5–10 s and measure desk lux with the sensor. Expect a monotonic curve with no plateaus or jumps.

3. Flicker check: Use a phone high-fps camera or light sensor to confirm no visible flicker at 1 kHz under different duty settings.

4. Closed-loop test: Change ambient light (cover/uncover lamp area) and verify the output follows the target with gradual transitions and ±10% lux accuracy.

3. Ethics and Safety

3.1 Ethical Analysis

We want this lamp to help people, not create new problems. We'll follow the IEEE and ACM codes as practical guardrails and keep our choices simple and transparent.

1. Safety first, honest claims. IEEE I-1 and I-5 ask us to protect public safety and be honest about limits, to seek/accept criticism, and credit others [2]. We will publish measured lux/CCT ranges, flicker limits, and power data from repeatable tests. If we find errors, we'll correct them in our docs and code commits before the demo.

2. Avoid harm. ACM 1.2 and 1.1 say to minimize negative consequences and support well-being [3]. We'll cap maximum output and blue-heavy settings (upper CCT limit ≈6500 K), ship warm defaults at night, and keep flicker outside risky bands (see "Standards" below).

3. Be fair and respectful. IEEE II-7/8/9 and ACM 1.4 require respect and non-discrimination [2][3]. Team roles, code reviews, and decisions are shared; feedback is invited in stand-ups so everyone is heard.

4. Competence and review. IEEE I-6 and ACM 2.6/2.4 call for working within competence and using peer review [2][3]. Power and thermal design will be led by the teammate with the most experience; all safety-critical PRs require a second reviewer before merge.

5. Privacy by design. IEEE I-1 (privacy) and ACM 1.6/1.7 emphasize respecting privacy [2][3]. Our lamp does not log or transmit personal data. If we later add BLE for settings, it will be local-only and opt-in; no cloud.

3.2 Safety Considerations

1. Flicker: follow IEEE Std 1789-2015 recommendations; use high-frequency PWM (≥1 kHz) or DC dimming and limit modulation depth at low frequencies to avoid headache/eye-strain risks [4].

2. Light exposure: check against IEC 62471 (photobiological safety of lamps/LEDs). Our power level and diffusers keep us in exempt/low-risk categories; we will verify during testing [5].

3. Lab Safety: We will follow the University of Illinois lab safety guide[6]: Never work alone, at least two people present; Complete the online safety training and submit the certificate before lab work; Extra training if any high voltage is involved; Follow battery and current-through-body guidelines exactly (we are not sending current through a person).

4. Thermal: heatsink the LED board, add NTC-based derating, and shut down on over-temp.

5. Batteries (if we go portable later). We will default to bench supplies for development. If a battery is introduced for demos, we will follow the ECE 445 battery safety rules: avoid batteries unless needed, cover terminals, use protection circuits, charge only in approved bags, and get TA approval before any test. Emergency steps (swelling/heat/noise → isolate, notify TA) will be posted at the bench.

4. References and Datasheets:

4.1 References

[1]K. Kaur et al., “Digital Eye Strain- A Comprehensive Review,” Ophthalmology and Therapy, vol. 11, no. 5, pp. 1655–1680, Jul. 2022, doi: https://doi.org/10.1007/s40123-022-00540-9.

[2]IEEE, “IEEE Code of Ethics | IEEE,” Ieee.org. https://www.ieee.org/about/corporate/governance/p7-8 (accessed Sep. 18, 2025).

[3]Association for Computing Machinery, “ACM Code of Ethics and Professional Conduct,” Association for Computing Machinery, Jun. 22, 2018. https://www.acm.org/code-of-ethics (accessed Sep. 18, 2025).

[4]“IEEE Standards Association,” IEEE Standards Association. https://standards.ieee.org/ieee/1789/4479/ (accessed Sep. 19, 2025).

[5]“IEC 62471-7:2023,” Webstore.iec.ch, 2023. https://webstore.iec.ch/en/publication/68810 (accessed Sep. 18, 2025).

[6]University of Illinois Urbana-Champaign, “Laboratory Safety Guide.” Accessed: Sep. 18, 2025. [Online]. Available: https://drs.illinois.edu/site-documents/LaboratorySafetyGuide.pdf

4.2 Datasheets

OPT101P
Information:
https://www.digikey.com/en/products/detail/texas-instruments/OPT101P/251177?gclsrc=aw.ds&gad_source=1&gad_campaignid=120565755&gbraid=0AAAAADrbLIiWQ1ouMUvblb-SaV

DuzeTuJ&gclid=Cj0KCQjw_rPGBhCbARIsABjq9ccN2LmBRx2S3Xc2wu6SPwWX1pKaTdl6Dy6j1Usr1ENnvJ4gfj3UqjgaAgfGEALw_wcB
Datasheet:
https://www.ti.com/lit/ds/symlink/opt101.pdf?HQS=dis-dk-null-digikeymode-dsf-pf-null-wwe&ts=1758304012910&ref_url=https%253A%252F%252Fwww.ti.com%252Fgeneral%252Fdocs%252Fsuppproductinfo.tsp%253FdistId%253D10%2526gotoUrl%253Dhttps%253A%252F%252Fwww.ti.com%252Flit%252Fgpn%252Fopt101

TCS-34725
Information:
https://www.amazon.com/Teyleten-Robot-TCS-34725-TCS34725-Recognition/dp/B087Z3K6P5/ref=sr_1_1_sspa?dib=eyJ2IjoiMSJ9.XPYcZF8Ig8Nnz-kBMROzM9CXqq8_9xSdNBImpSFcXNiArBzxLe4SkRmNtmWSfeTsLHJYDfXTeYGg2PkzhCn9ZEv8UnZTCU8noaNOALHAMFBW7QSUB2_Av6dUMwM5SZBm26Ez6EsZ7CsKBAdKjDT-ZjWbatOeAGxDSIryIVIKJXtmONQLFa4SVnLqoHbBt2Dg56NpXGToUkfcEjYOvoGLUc2_s7XXq_wtqAXR7ctMo1c.DKjITpdsINJ1AtBmpRp08JFZuJWpg5GSMJowTVQA2Vw&dib_tag=se&keywords=tcs34725&qid=1758305817&sr=8-1-spons&sp_csd=d2lkZ2V0TmFtZT1zcF9hdGY&psc=1
Datasheet:
https://cdn-shop.adafruit.com/datasheets/TCS34725.pdf

COB LED Strip Light - 12V LED COB Strip 16.4ft/5m 320LED/M Warm White 3000K - CRI90+ 8W/M
Information:
https://www.amazon.com/gp/product/B0FDKTL2F5/ref=ox_sc_act_title_1?smid=A1KTRSYCZ04XQJ&th=1

COB LED Strip Lights 12V 8W/M 16.4ft/5m 320LED/M White 6500K CRI90+
Information:
https://www.amazon.com/gp/product/B0FDQW4MR3/ref=ox_sc_act_title_2?smid=A1KTRSYCZ04XQJ&th=1

IRLML0030TRPbF
Information:
https://www.digikey.com/en/products/detail/infineon-technologies/IRLML0030TRPBF/2202215?gclsrc=aw.ds&gad_source=1&gad_campaignid=120565755&gbraid=0AAAAADrbLIiWQ1ouMUvblb-SaVDuzeTuJ&gclid=Cj0KCQjw_rPGBhCbARIsABjq9cfGhPgfBZdbdBuGDy0U__LxhCapLpWMNpIgCoqJL-wTuh0eqNDSMawaAtc4EALw_wcB
Datasheet:
https://www.infineon.com/assets/row/public/documents/24/49/infineon-irlml0030-datasheet-en.pdf?fileId=5546d462533600a401535664773825df

ESP 32
Information:
https://www.youtube.com/watch?v=lMaDJlYp29s
Datasheet:
https://cdn.sparkfun.com/datasheets/IoT/esp32_datasheet_en.pdf