# Paint Color & Gloss Classification Device

ECE 445 • Spring 2026 • Project No. 69

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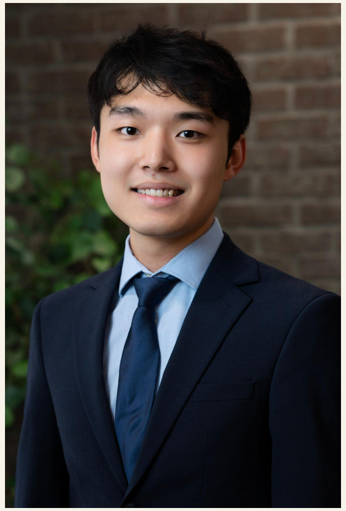
# Who We Are

**Victoria Lee**

Electrical Engineering

Senior Undergraduate



**James Lee**

Computer Engineering

Senior Undergraduate

# The Problem With Touch-Up Paint : Our Goal

## Destructive chip-scanning

The hardware-store method requires peeling a chunk off the wall — impossible for renters and damaging for owners.

## Phone cameras lie

Auto white-balance and ambient light make smartphone color apps unreliable and irreproducible.

*Our goal: a reliable, first-time color + sheen match, without touching a paint chip.*

# What We’re Building : Our Solution

## A handheld, non-destructive device

**Spectral color sensor**

AS7343 14-channel reading in an isolated chamber.

**Angled optical gloss**

Red LED + 3 photodiodes measure diffraction.

**Light-sealed enclosure**

3D-printed housing eliminates ambient light.

### High-Level Requirements

**ΔE < 5**

color accuracy in CIELAB space

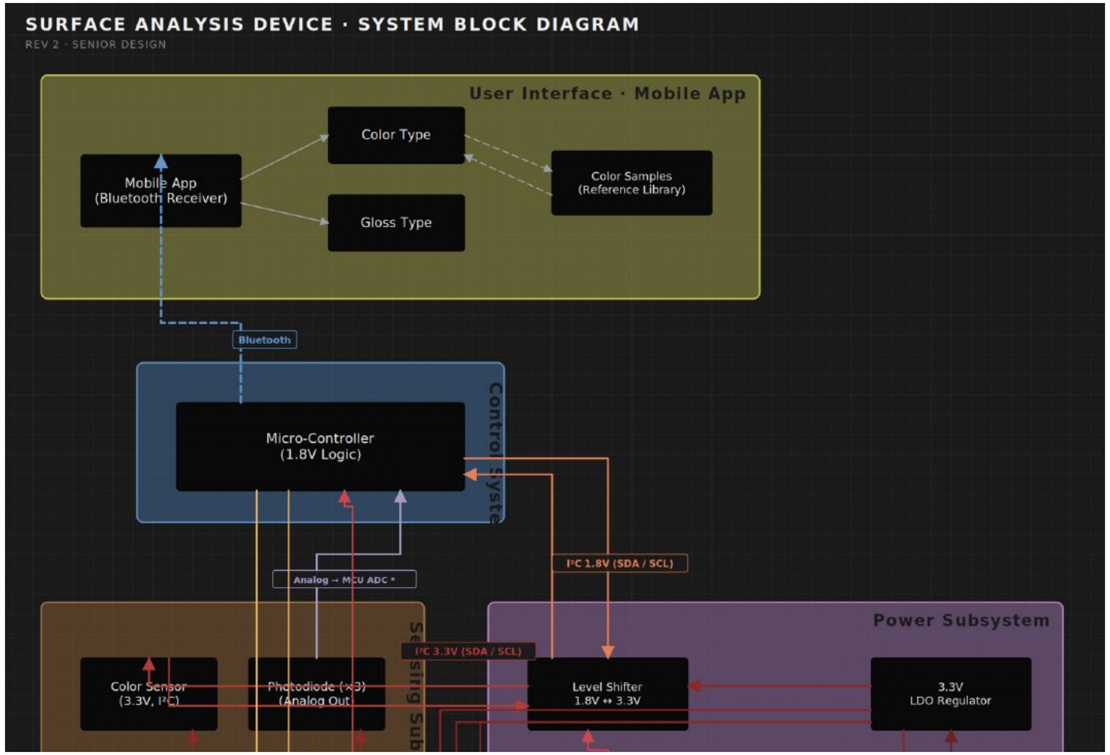
**80% / 10**

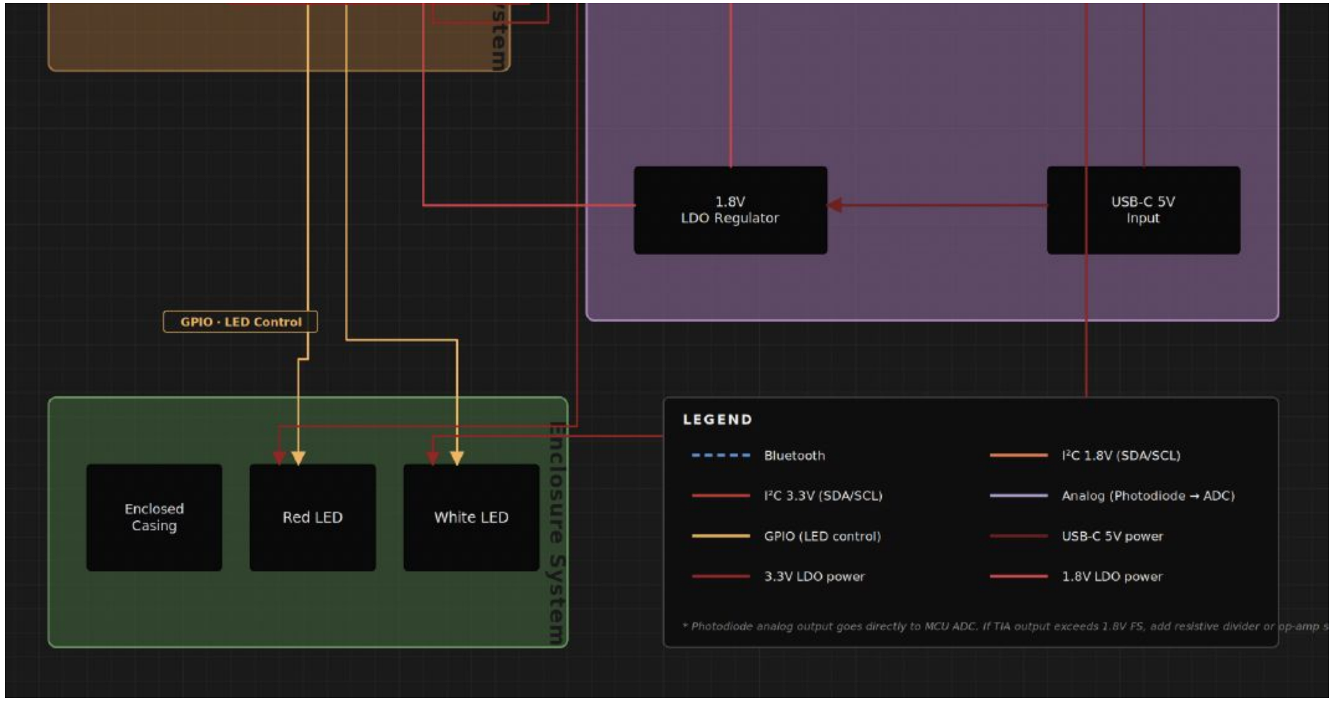
sheen classification accuracy (samples)

**< 10%**

baseline drift from 0 → 500 lux ambient

# Block Diagram



# Design Process

# Sensing: Gloss

## Three-Photodiode Geometry

### Specular peak near 70°

PD3 is positioned to capture the specular reflection, which falls closer to 70° than 60° in our optical setup.

### PD1, PD2 sample diffuse light

Off-axis photodiodes register scattered (diffuse) reflection — the dominant signal from matte surfaces.

### Ratio cancels intensity drift

Using three readings instead of one absolute intensity reduces sensitivity to LED brightness, distance, and ambient light.

**Gloss Index = PD3 / (PD1 + PD2 + PD3)**

## Transimpedance Amplifier (TIA)

### Current-to-Voltage Conversion

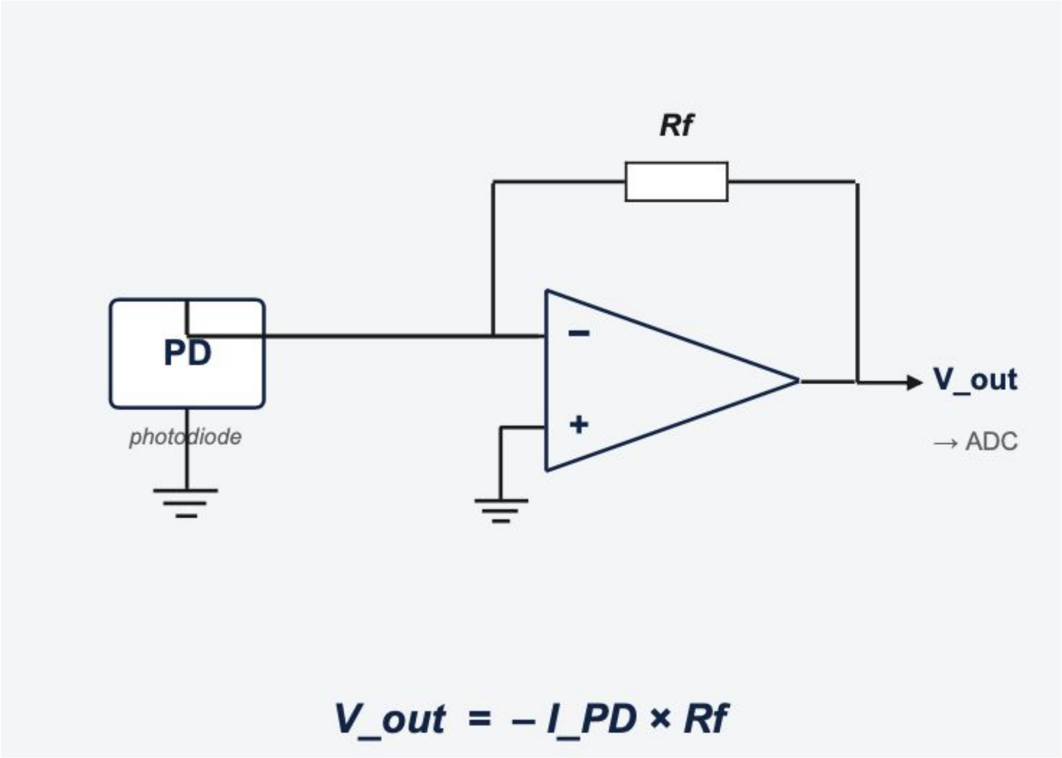
Photodiode output is a small current (μA range). TIA converts it to a voltage the ADC can read.

### Gain Set by Rf

V_out = – I_pd × R_f. Resistor sized for maximum expected photocurrent near full ADC scale.

### Low-Noise, Low-Offset

### TIA Schematic (per photodiode)



# Sensing: Gloss

## Paint Samples — Index Increases with Gloss

*PD3 / (PD1 + PD2 + PD3) · illustrative trend*

### Trend Confirmed

Gloss index rises; sensor distinguishes matte, semi-gloss, and high-gloss.

### Updated Thresholds

**Matte:** < 0.095 | **Semi-gloss:** 0.095 – 0.125 | **High-gloss:** > 0.125

## Calibration Anomaly: Cardboard & Paper

*Both should read matte, but indices came out elevated (~0.124).*

### Sample Data [PD1, PD2, PD3 (spec.) | Index]

```
Cardboard: 32, 39, 10 | 0.124
Paper: 69, 58, 18 | 0.124
```

### Hypotheses

**1. Distance Asymmetry:** PD3 is farther from the sample, causing lower light readings.

**2. Brightness Scaling:** Lighter surfaces reflect more total light, inflating photodiodes and skewing the ratio upward.

**Attempted Fix:** Added a +40 offset to PD3 to compensate for distance loss.

**Result:** No improvement—ratio remains inflated for bright non-paint surfaces.

# Sensing: Gloss

## High-Level Requirement

Classification Accuracy of 80% across 10 trials

**What we changed**

Thresholds were tuned to entire surfaces instead of paint samples

## Verification

| | PD1 | PD2 | PD3 | Gloss Index |
|---|---|---|---|---|
| Matte Paint Sample | 26 | 32 | 3 | 0.049 |
| Glossy Paint Sample | 38 | 42 | 17 | 0.175 |
| Wall | 50 | 64 | 17 | 0.13 |
| Cardboard | 32 | 39 | 10 | 0.123 |
| Paper | 69 | 58 | 10 | 0.073 |
| Mirror | 50 | 64 | 29 | 0.2 |

## AS7343 14-Channel Sensor

Reads 14 distinct spectral channels across visible and near-IR ranges. Povides superior CIELAB accuracy for precise paint matching.

## Isolated Sensing Chamber

A light-sealed chamber with internal white LED ensures reproducible readings. This consistent illumination makes $\Delta E < 5$ achievable in practical field use.

## CIELAB

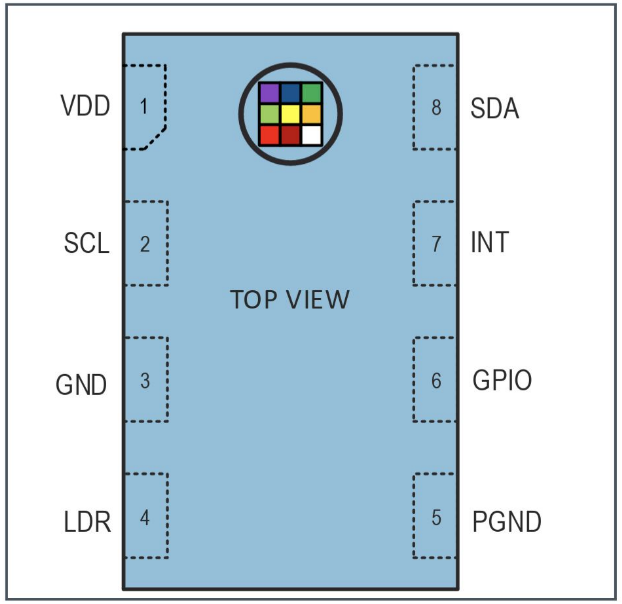
$$\Delta E = \sqrt{(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2}$$

3D color space (L*A*B*) engineered to mathematically map how human eyes perceive color. Allows for perceptrual uniformity and calculator closeness (Delta E)

L* Lightness (0 = Black) (100 = White)

a* = Green (negative) Red (positive)

b* = Blue (negative) Yellow (positive)



# Color Calibration

## Hand-Tested 60+ Colors

- Recorded the raw output from all 14 spectral channels
- LAB reference values
- building a labeled dataset that calibrates our system

## High CRI Light

- Accurately revelas true colors of objects, closely mimicking natural daylight or incandescent bulbs

| **Calibration Method Used** | **Correctly classify by Delta E < 5  for 20 colors** |
| --- | --- |
| Linear Regression into LAB, Distance from LAB to LAB value | 7/20 |
| Distance from Channel Space, Conversion into LAB | 19/20 |
| Distance from Channel Space, Conversion into LAB +Normalization | 19/20 |
| Distance from Channel Space, Conversion into LAB +Normalization + Weighted Channels | 15/20 |

# Control: ESP32 + Bluetooth

## ESP32 Microcontroller

The ESP32 drives the AS7343 over $I^2C$, controls the LED illumination, samples the photodiodes through the ADC, and runs the color matching and sheen classification on-device — no PC or backend in the loop.

## Bluetooth to App

Results stream over Bluetooth to an app that displays the matched paint name, CIELAB value, and sheen classification. The user gets a result in under a second from press to display.

## MOSFETs

Used to control timing of LEDs turning on and off since both LEDs cant be on at the same time.

Red LED <-> Gloss Measurement
White LED <-> Color Measurement

# PCB: Layout & Integration Choices

## Power redundancy headers

1×1 headers on GND / 5 V / 3.3 V let us bypass the USB-C front end with a benchtop supply if it injects noise.

## Edge-biased subsystem placement

Photodiodes + red LED on one edge, color sensor + white LED on another  leaves room for physical dividers.

## Length-matched data lines

Parallel traces kept close in length to minimize propagation skew on the $I^2C$ bus between ESP32 and sensor.

## Accessible test points

Connectors moved to outer edges so a multimeter or logic probe do not interfere.

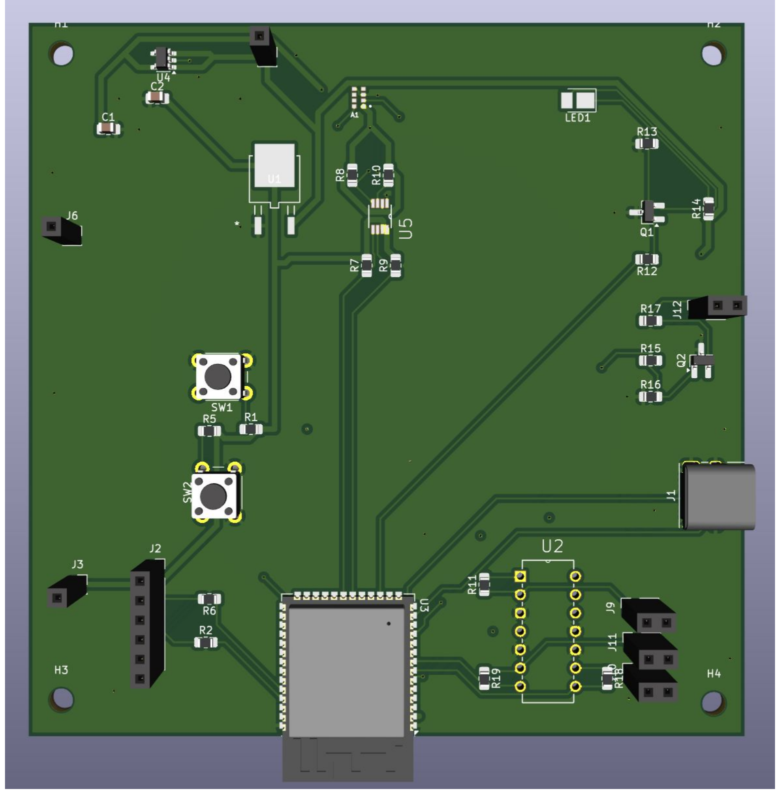


*Figure 1 — PCB layout*

# Power Subsystem

## Regulators

**AZ1117CD-3.3:** Fixed 3.3 V LDO, 800 mA, 1.3 V dropout. Steps USB-C 5 V down to the main 3.3 V rail for the MCU and digital logic.

**LP5907MFX-1.8:** Ultra-low-noise 1.8 V LDO (250 mA). Cascaded after the 3.3 V rail to feed the color sensor specifically.

***Why low-noise here:** Ripple on the sensor supply directly corrupts color readings. The LP5907's high PSRR keeps switching noise off the analog rail.*

## Level Shifter

**Voltage Mismatch:** MCU runs at 3.3 V, color sensor runs at 1.8 V. Direct logic connection risks damage or signal failure.

**Bidirectional Translation:** Translates $I^2C$ (SDA/SCL) between 3.3 V and 1.8 V sides in both directions on the same line.

**Open-drain Compatible:** Preserves necessary $I^2C$ pull-up behavior — each side has its own pull-up to its own rail.

# Requirements & Verification

| Subsystem | Requirement | Verification |
|---|---|---|
| **Power (3.3 V / 1.8 V)** | Output ±5% under load; ripple ≤ 50 mV pk-pk | DMM under DC load; oscilloscope on test points |
| **$I^2C$ level shifter** | 3.3 V ↔ 1.8 V ±10% on both sides | Scope each side of shifter while ESP32 transmits |
| **Enclosure isolation** | Baseline reading drift < 10% (0 → 500 lux) | Flush against wall in dark room; serial monitor |
| **Enclosure geometry** | Red LED & mid photodiode at 60° ± 2° | Protractor on base plane; iterate 3D-printed insert |
| **Control / algorithm** | ΔE < 5 • sheen ≥ 90% accuracy • cycle < 1 s | Compare to reference; timestamp start/stop |

# Power DMM and Oscilloscope 1.8V

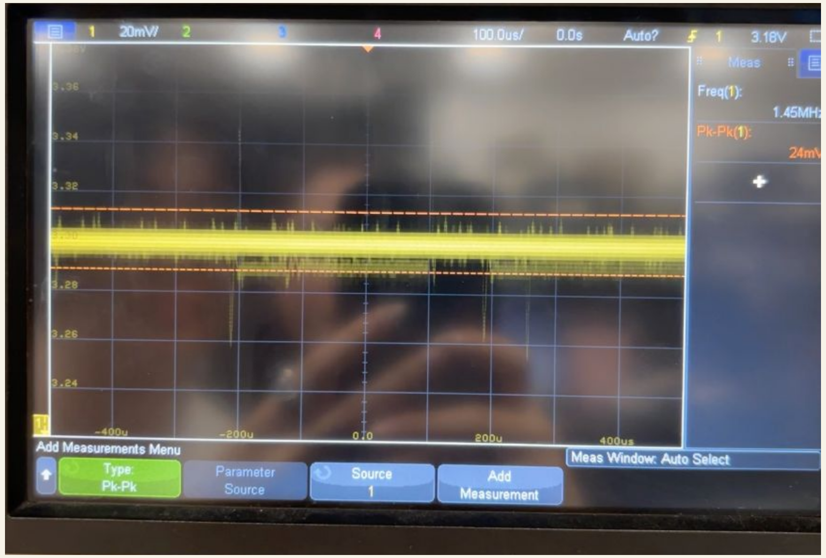
## Digital Multimeter


## Oscilloscope

# Power DMM and Oscilloscope 3.3V

## Digital Multimeter


## Oscilloscope



# Enclosure Isolation

## Measured Light Leakage (PD1, PD2, PD3)

| Test Condition | Sensor Reading (12-bits) | Max Variance (%) |
|---|---|---|
| PCB Faced Up (Bright Room) | 4095 , 4095, 4095 | 100% |
| PCB Faced Down (Bright Room) | 11,45,39 | 1.1% |
| PCB Faced Down (Dark Room) | 0,0,4 | 0.1% |

## Variance Calculation

*Variance (%) = (Leakage / Fullscale) x 100*

Using leakage value of 45:

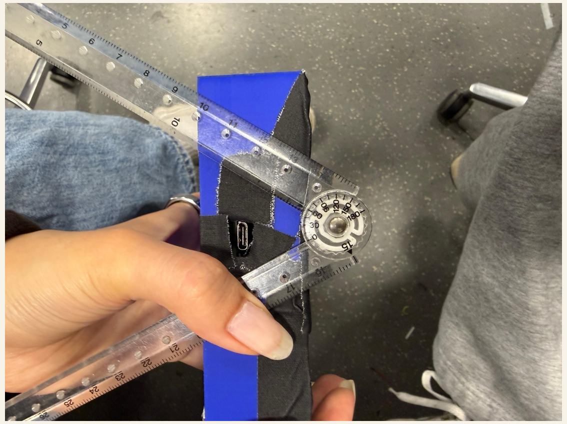
**( 45 / 4095 ) x 100 ≈ 1.1%**

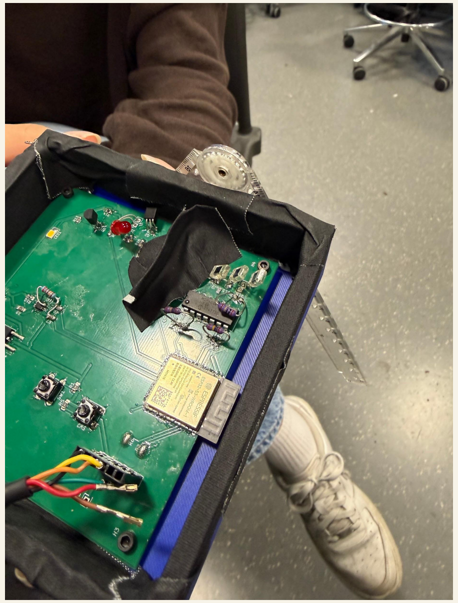
**Constant:**

Fullscale Value = 2^12 - 1 = 4095

# Enclosure Geometry

## Geometric Representation





## Calculations

**X** = Distance from photodiode and LED = **48MM**

**Y** = Ideal height

Spectral angle = **60°**

$$\tan(\text{spectral angle}) = (X/2) / Y$$

$$Y = x / (2 * \tan 60°) = 13.86 \text{ mm}$$

# Control / Algorithm

## Color (Delta E < 5)

**Objective: Accuracy & Consistency**

Tested across sample set. Values fell below the 5-unit threshold when compared against reference swatches.

Algorithm produces consistent color readings; calibration against reference is repeatable.

## Sheen >= 80% Accuracy

**Classification Performance**

Classification reaches the accuracy target when evaluated against larger sample sizes.

*Note: Smaller samples introduce more variance in readings.*

## Cycle time (<1s)

**Processing Efficiency**

Both color and sheen cycles complete in far less than a second.

# Success and Challenges

## Successes

**The project worked as intended:**

- Color matching meets the **ΔE < 5** target.
- Sheen classification separates matte, semi-gloss, and high-gloss samples reliably.
- The enclosure effectively isolates from ambient light.
- The web app delivers results in **under a second**.
- Every requirement is verified.

## Challenges

**What We Would Do Differently:**

Use **larger sample swatches** to:

- Make gloss differences more visible to the optical path.
- Provide the spectral sensor with more even surface

Redesign PCB to be more compact

- Makes device more portable

Optimize Placement of Components to Reduce Noise

- Photodiodes are particularly sensitive to noise

# Redesign and Future Work

## What We Learned

- End-to-End PCB Design
  - How to work around errors
- Hardware and Mechanical Integration
- Full Product Lifecycle
- Dynamic Problem Solving and Scoping
- Tenhnical communication and collaboration

## Possible Future Work

- Scale the color database
- Optimize color matching algorithm
- Add texture input

# Thank you!

# Questions?